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Copepoda—Their Status and Ecology in the Red Sea

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Abstract

The subclass Copepoda is an important driving force in linking the lower trophic to higher trophic levels in aquatic ecosystems. Despite their ecological importance in marine waters, very little work has been done along the Red Sea since the early 19th century. Until now, about 276 species from 76 genera, 55 families, and 6 orders of copepods have been recorded in the Red Sea. This chapter discusses the diversity, distribution and ecology of the Red Sea copepods, which show an increasing gradient of species richness and biomass from north to south. Moreover, the standing stock of zooplankton in the southern Red Sea is higher than the central and northern parts. The majority of copepods recorded are during the winter season. The epipelagic zone in the Red Sea is usually dominated by small-sized genera, especially *Acrocalanus, Calocalanus, Clausocalanus, Corycaeus, Ctenocalanus, Macrosetella, Oithona, Oncaea, Paracalanus, Paraoithona* and *Parvocalanus*. With increasing depths, microcopepods belonging to the family Oncaeidae become numerically more important than the calanoid copepods. A special focus has been provided with reference to the effect of UV-B radiation on their biology, which shows that the maximum mortality rates of copepods under ambient solar radiation levels average a five-fold increase over the average mortality in the dark. The chapter also discusses the symbiotic and parasitic relationship of copepods with other organisms, such as corals and coral-reef fishes. A preliminary report shows that symbiotic copepods attain a high diversity from scleractinian coral genera, such as *Pocillopora* sp., *Acropora* sp., *Stylophora* sp., *Favia* sp. and *Fungia* sp. This chapter provides a baseline introduction on copepods and possible research in different aspects of their biology, which may provide a new step in copepod research in the Red Sea.

Introduction

The subclass Copepoda is a group of small-sized, but most numerous, omnipresent and highly diversified aquatic crustaceans, which forms an important connecting link in the ecological food web. Taxonomically they are categorized into nine major orders, Platycopioida, Calanoida, Cyclopoida, Harpacticoida, Gelyelloida, Mormonilloida, Misophrioida, Siphonostomatoida and Monstrilloida (Boxshall and Hasley 2004; Ahyong et al. 2011). They inhabit almost all aquatic habitats from freshwater to hypersaline waters, from subterranean caves to waters collected in bromeliad leaves or leaf litter, from streams, rivers, and lakes to the sediment layers, from the open surficial epipelagic waters to the deepest known ocean trenches and from the cold polar ice-water interface to the hot active hydrothermal vents (Huys and Boxshall 1991; Boxshall and Hasley 2004). Their mode of living is either or a combination of free-living, symbiotic, or internal or external parasites, on almost every animal phyla known in the aquatic environment, except Protozoa (Huys and Boxshall 1991). Except for Gelyelloida, all other copepod orders have been reported from marine waters (Boxshall and Halsey 2004). Cyclopoida and Poecilostomatoida, although having taxonomic ambiguities (Kim and Kim 2000; Boxshall and Halsey 2004; Huys et al. 2012), were considered as different orders (Huys and Boxshall 1991), but after the discovery of the family Fratiidae Ho et al. (1998), Boxshall and Halsey (2004) grouped them into the order Cyclopoida.

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N. M. A. Rasul and I. C. F. Stewart (eds.), *Oceanographic and Biological Aspects of the Red Sea*, Springer Oceanography, https://doi.org/10.1007/978-3-319-99417-8_25

The Red Sea, being oligotrophic in nature, is considered an unfavourable environment for plankton owing to its high salinity, lack of any freshwater inputs and high evaporation rates (Weikert 1987), although having its own endemic diversity (Halim 1984). Many of the planktonic organisms which immigrate from the Indian Ocean via the Gulf of Aden to the northern Red Sea do not thrive well in higher salinities and temperatures that prevail in the deeper waters of the Red Sea, and hence are not able to survive during migration toward the northern Red Sea, while the evolution of endemic species is favoured (Kimor 1973). The majority of the copepods in the Red Sea are recorded from the planktonic Calanoida and Cyclopoida, and to some extent Harpacticoida that form an important link in the aquatic food chain by linking primary producers with secondary consumers (Gorelova 1974; Sullivan 1980; Kimmerer 1984; Sommer and Stibor 2002). Copepods are the most numerous zooplanktonic group, which makes up more than about 75% in the northern Red Sea (Almeida Prado-Por 1983, 1985; Aamer et al. 2006; Cornils et al. 2007a; Dorgham et al. 2012; Khalil and Abd El-Rahman 1997; El-Serehy et al. 2013), accounts for up to 83% in the central Red Sea (Weikert 1982; Böttger 1987; Schneider et al. 1994), and more than 70% in the southern Red Sea (Beckmann 1984; Böttger-Schnack 1995; Al-Aidaroos et al. 2016a) of the total zooplankton composition. Red Sea copepods originate and/or are closely related to the Indo-Pacific origin (Por 1978; Halim 1990; Sen Gupta and Desa 2001; El-Sherbiny and Ueda 2008b; El-Sherbiny 2009; El-Sherbiny and Al-Aidaroos 2014). Presently, about 977 species of planktonic copepods are recorded from the Indian Ocean (Razouls et al. 2005–2017), with about 276 recorded species in the Red Sea (present study). The epipelagic zone in the Red Sea is usually dominated by copepods, and most conspicuously the small-sized genera: *Acrocalanus*, *Calocalanus*, *Clausocalanus*, *Corycaeus*, *Ctenocalanus*, *Macrosetella*, *Oithona*, *Oncaea*, *Paracalanus*, *Paraoithona*, *Parvocalanus* and *Sapphirina* (e.g., Beckmann 1984; Schneider and Lenz 1991; Schneider et al. 1994; Böttger-Schnack 1990b, 1994; Böttger-Schnack et al. 2001; Farstey et al. 2002). Recently, the importance of *Acartia* species has been documented in the coastal waters of the Red Sea (El-Sherbiny and Al-Aidaroos 2014; Al-Aidaroos et al. 2016a).

In general, the abundance of large and small mesozooplankton in the central Red Sea is higher during winter than in autumn (Weikert 1980b, 1988; Böttger 1987). A decrease of 30% in the total biomass and abundance of zooplankton between the central (21°N) and northern Red Sea (24°N) during autumn 1980 was observed by Böttger (1987), whereas Delalo (1966) and Gordeyeva (1970) reported a continuous decrease in zooplankton from the south to the north. Concerning seasonal distribution, Halim (1969) reported that about 92% of copepod species in the Red Sea recorded were during the winter compared to about 62% recorded in the summer-autumn.

In this chapter, we will focus on the diversity and distribution of copepods, and try to highlight the importance of copepods along the coral reefs, as well as the vulnerability of zooplankton to Ultraviolet-B (UV-B) radiation and some preliminary aspects on the symbiotic copepod associates of coral reefs in the Red Sea region.

History

Most studies carried out in the Red Sea were focused mainly on the oceanic waters through several expeditions, for example, the POLA Expeditions 1895–96, 1897–1898, John Murray Expedition 1933–34, Soviet Expedition 1963, Metalliferous Sediments Atlantis-II Deep (MESEDA program), RV Sonne 1977–1978, RV Valdivia 1979 and 1980–1981, RV Meteor-III 1987, RV Tyro 1992–1993, RV Meteor-44/2 cruise 1999 and RV Pelagia 2012. These works paid much attention to zooplankton, including copepods.

The subclass Copepoda has been studied in the Red Sea since the early 20th century (Cleve 1900). Due to its exceptionally isolated condition, many researchers showed their interest in copepod fauna of the Red Sea, for example, studies carried out along the longitudinal axis of the Red Sea (Sewell 1948; Gordeyeva 1970; Böttger-Schnack et al. 1989, 2004; Böttger-Schnack and Schnack 1989; Böttger-Schnack 1990b, 1991, 1992, 1994, 1995; Kürten et al. 2015), Gulf of Aqaba (Fedorina and Kornilova 1970; Schmidt 1973; Almeida Prado-Por 1983, 1984; Echelman and Fishelson 1990; Khalil and Abd El-Rahman 1997; El-Sherif and Aboul Ezz 2000; Al-Najjar 2002, 2005; El-Serehy and Abd El-Rahman 2004; Al-Najjar and Rasheed 2005; Cornils et al. 2005, 2007a, b, c; Aamer et al. 2006; El-Sherbiny et al. 2007; Al-Najjar and El-Sherbiny 2008; Schnack-Schiel et al. 2008; Dorgham et al. 2012; El-Serehy et al. 2013), central Red Sea (Karbe 1980; Weikert 1980a, b, 1981, 1982; Beckmann 1984; Ferrari and Böttger 1986; Böttger 1987; Böttger-Schnack 1988, 1990a; Schneider et al. 1994), southern Red Sea (Delalo 1966; Weikert 1980a, 1982; Beckmann 1984; Schneider et al. 1994; Böttger-Schnack 1995; Couwelaar 1997; Al-Aidaroos et al. 2016a) and neritic waters (Nicholls 1944; Couwelaar 1997; Al-Aidaroos et al. 2016a). Most of these works demonstrated that the majority of the microcopepod fauna of the Red Sea are the oncaeid copepods, which were prominently dealt with by Böttger-Schnack (1990a, b, 1991, 1992) and Böttger-Schnack et al. (2001).

Abundance and Diversity

In the Red Sea, the diversity of oceanic zooplankton is relatively low compared to adjacent seas as well as other subtropical seas (Halim 1969, 1984; Kimor 1973;

Böttger-Schnack 1994). Most Red Sea copepods are known to be inhabitants of the Indo-Pacific region, of which about 33% are not known from the Mediterranean Sea (Halim 1969). Their diversity and abundance decrease northward with increasing distance from the southern entrance (Bab el Mandab), where the primary production is mainly controlled by the inflow of nutrient-rich waters into the Red Sea from the Gulf of Aden (Wafar et al. 2016). The shallow sill at Bab el Mandab prevents the exchange of bathypelagic plankton between the Red Sea and the deep waters of the Gulf of Aden. These deep-waters are warmer and more saline, and with a combined oxygen minimum and phosphate maximum extending from 300–600 m results in the fluctuation of plankton diversity and biomass related to surface circulation governed by the winds (Morcos 1970; Beckmann 1984; Schneider et al. 1994; Böttger-Schnack 1995; Couwelaar 1997; Sofianos and Johns 2003; Morcos and AbdAllah 2012; Wafar et al. 2016). Abundance varies with sampling depth, and mesh size used under different seasons; for example, calanoids dominate in the larger mesh size of about <150 µm (Gordeyeva 1970; Weikert 1982; Beckmann 1984), whereas smaller copepods like *Oncaea* sp. dominate over the whole depth range of the Red Sea, using a smaller mesh size of <100 µm (Böttger 1987; Böttger-Schnack 1988). The abundance of copepods in surface waters ranged between 251 and 9,825 ind. m^{-3} in the Gulf of Aqaba, northern Red Sea (Gordeyeva 1970; Khalil and Abd El-Rahman 1997; Aamer et al. 2006; El-Serehy et al. 2013), while it ranged between 1,058 and 25,787 ind. m^{-3} in the southern Red Sea (Al-Aidaroos et al. 2016a) (Table 25.1). Moreover, the lunar periodicity also seemed to affect the abundance of copepods (Echelman and Fishelson 1990), where Vaissiere and Seguin (1984) observed that the copepods species like *Calanus robustior, Mecynocera clausi, Oithona helgolandica, Farranula rostrata* were positively phototactic; *Nannocalanus minor, Acartia negligens* were positively phototactic under low moonlight intensities and *Oithona nana* showed negative phototaxis.

Until now, around 276 copepod species (76 genera, 55 families and 6 orders) have been recorded in the Red Sea, from the overall 21,000 species belonging to 2,600 genera within 250 families recorded all over the World. Of these, 22 species are endemic to the Red Sea (Table 25.2, modified from Razouls et al. 2005–2017). During the last decade, more attention has been paid to the neritic copepod community, resulting in the discovery of several new species (Ohtsuka et al. 2000; El-Sherbiny and Ueda 2008a, b, 2010; El-Sherbiny 2009, 2011; El-Sherbiny and Al-Aidaroos 2013, 2014, 2015, 2017), as well as new records for the Red Sea (El-Sherbiny 2009; El-Sherbiny and Al-Aidaroos 2013; Al-Aidaroos et al. 2016b).

Biomass

Zooplankton biomass studies are very limited in the Red Sea, which shows a significantly larger wet weight in the southern Red Sea than in the central Red Sea (Gordeyeva 1970; Weikert 1980a; Beckmann 1984; Couwelaar 1997; Schneider and Lenz 1991) and in the northern Red Sea (e.g., Delalo 1966; Ponomareva 1968; Gordeyeva 1970; Echelman and Fishelson 1990; Al-Najjar et al. 2002; Al-Najjar 2005). As such, the zooplankton biomass decreases from the Gulf of Aden toward the northern Red Sea (Delalo 1966). The vertical profiles show two maxima, the one that occurs in the upper 0–100 m layer, and another in the core of the oxygen minimum layer (Halim 1984). A clear seasonal variation is also observed in the total zooplankton, which is higher during autumn and spring, and lower during summer (Klinker et al. 1978), where more than 65–69% of its biomass was dominated by >500 µm and >1000 µm size fraction (Al-Najjar 2005; Al-Najjar and Rasheed 2005). The mean total biomass of the southern Red Sea zooplankton showed a two-fold increase from the SW monsoon (14–17.5 ml m^{-2}) toward the NE monsoon (23.9–40.2 ml m^{-2}) (Couwelaar 1997). A higher biomass, around a 10-fold increase, was evident from the use of a smaller 65 µm mesh size when compared with a 300 µm mesh sized net from the upper 100 m layer (Böttger 1987; Schneider et al. 1994). However, Al-Najjar and Rasheed (2005) observed a significant difference with depth, showing higher biomass in the surface to 50 m, compared with the surface to 25 m depth, which might be related to the disturbance of the sea surface layer by low air pressure causing vertical mixing (Tomosada and Odate 1995) and subsequent nutrient enrichment (Manasrah et al. 2004; Al-Najjar and El-Sherbiny 2008) (Table 25.2).

Distribution

Zooplankton diversity studies using small nets ($\geq$ 100 µm mesh size) have documented the dominance of smaller sized copepods in the oceanic waters of the Red Sea (Böttger 1987; Böttger-Schnack 1988, 1994; Böttger-Schnack et al. 1989; Schneider et al. 1994). In the epipelagic zone (upper 100 m) of the northern Red Sea, the most dominant copepod genera were small calanoids, like *Paracalanus*, *Acrocalanus*, *Clausocalanus*, *Centropages*, *Acartia*, and relatively large calanoid species, such as *Nannocalanus minor*, *Euchaeta concinna*, *Paracandacia truncata,* in addition to the cyclopoid genera, *Oithona*, *Oncaea*, *Corycaeus* and *Lubbockia*. In the greater depths, the calanoids, *Candacia samassae*, *Eucaheta plana*, *Macandrewella chelipes*,

Table 25.1 Distribution, abundance (ind m^{-3}) and biomass studies carried out in the Red Sea. RS = Red Sea proper; NRS = northern Red Sea; CRS = central Red Sea; SRS = southern Red Sea; GoAq = Gulf of Aqaba; GoAden = Gulf of Aden; # = total depth is considered (all the depths range were added together and total abundance and biomass for the total depth is considered here); *** = total zooplankton

Place	Vertical/horizontal	Mesh size (µm)	Depth (m)	No. of species	Abundance# range (average)	Biomass# (mg m^{-3}/ml m^{-2})	References
GoAq, NRS	Horizontal	100	Surface	51	1,326–9,825 (6,710)	–	Aamer et al. (2006)
SRS	Horizontal	150	Surface	100	1,058–25,787 (5,230)	–	Al-Aidaroos et al. (2016a)
GoAq, NRS	Vertical	200	500	31	(76.3)	–	Almeida Prado-Por (1983)
NRS	Horizontal	100	Surface	–	–	18.40 mg. dry wt. m^{-3} (**annual average**)	Al-Najjar and El-Sherbiny (2008)
GoAq, NRS	Vertical	150	100	55	–	–	Al-Najjar (2002)
GoAq, NRS	Horizontal	150	Surface	–	NA	19.9 ± 3.39 mg m^{-3} (**Autumn**) 31.9 ± 4.257 mg m^{-3} (**Spring**) 10.6 ± 2.52 mg m^{-3} (**Summer**)	Al-Najjar (2005)
GoAq, NRS	Vertical	100	25 50	–	–	2.15–6.71 mg m^{-3} 4.08–9.88 mg m^{-3}	Al-Najjar and Rasheed (2005)
GoAden and CRS	Vertical	300	1050		79,000–83,000*** ind. m^{-2}	20–24 gm m^{-2} ***	Beckmann (1984)
CRS	Vertical	100	450	45	30–39 × 10^3(34 × 10^3) ind. m^{-2}	–	Bottger-Schnack (1988)
GoAq, NRS	Vertical	150	1300	–	93–431 × 10^3 (89.3%)	–	Cornils et al. (2005)
GoAq, NRS	Vertical	200	100	18 families 26 genera	58.19–92.39 (79%)	–	Cornils et al. (2007a)
CRS and GoAden, SRS	Vertical	320	1500	–	–	mean 14–17.5 ml m^{-2} (**SW Monsoon**) mean 23.9–40.2 ml m^{-2} (**NE monsoon**)	Couwelaar (1997)
RS	Horizontal	300	100 100–200 200–500	–	–	**Winter** 47.7 mg m^{-3} (**NRS**) 81.1 mg m^{-3} (**central**) 104.8 mg m^{-3} (**SRS**) 9 mg m^{-3} (**NRS**) 14 mg m^{-3} (**central**) 38 mg m^{-3} (**SRS**) 10 mg m^{-3} (**NRS**) 17 mg m^{-3} (**central**) 19 mg m^{-3} (**SRS**)	Delalo (1966)
GoAq, NRS	Vertical	100	100	52	(2,112) 87.9% copepods		Dorgham et al. (2012)
GoAq, NRS	Horizontal	500	Surface	30	155 (**winter**) 103 (**summer**)	12.2 g m^{-3} (**winter**) 8.5 g m^{-2} (**summer**)	Echelman and Fishelson (1990)
GoAq, NRS	Vertical	55	100	74	–	–	El-Serehy and Abd El-Rahman (2004)
NRS	Horizontal and vertical	90	Surface and 100	81	251–1,940	–	El-Serehy et al. (2013)

(continued)

Table 25.1 (continued)

Place	Vertical/horizontal	Mesh size (μm)	Depth (m)	No. of species	Abundance$^{\#}$ range (average)	Biomass$^{\#}$ (mg m^{-3}/ ml m^{-2})	References
GoAq, NRS	Vertical	100	100	66	(1,840) 84.7% copepods	–	El-Sherbiny et al. (2007)
GoAq, NRS	Horizontal	50	Surface	44	–	–	El-Sherif and Aboul Ezz (2000)
NRS and CRS	Vertical	65 300	500	–	2,520	**Summer** 42 mg m^{-3} (north) 142 mg m^{-3} (CRS) 15.5 mg m^{-3} (**NRS**) 59 mg m^{-3} (**CRS**)	Gordeyeva (1970)
GoAq, NRS	Horizontal	55	Surface	27	(1,945)	–	Khalil and Abd El-Rahman (1997)
Gulf of Aqaba		65 200 330	50	–	–	3.1–504.5 ml m^{-3} (**Summer**) *** 6.4–249.1 ml m^{-3} (**winter**) *** 3.5–392.9 ml m^{-3} (**Summer**) *** 3.1–144.8 ml m^{-3} (**winter**) *** 1.6–596.5 ml m^{-3} (Summer) *** 3.5–83 ml m^{-3} (winter)	Klinker et al. (1978)
RS	Vertical	480	100 m	–	–	**Summer** <100 ml m^{-3} (**NRS**) <300 ml m^{-3} (**central**) 300–500 ml m^{-3} (**SRS**)	Ponomareva (1968)
GoAq, NRS	Vertical	200	300	–	5,060	–	Schmidt (1973)
CRS and GoAden, SRS	Vertical	100	500	–	2.8 ± 0.6 x10^{5} ind. m^{-2} (**NRS**) 4.7 ± 0.2 x10^{5} ind. m^{-2} (**SRS**)	917 ± 113 mg m^{-2} (**NRS**) 1,616 ± 348 mg m^{-2} (**SRS**)	Schneider and Lenz (1991)
CRS	Vertical	300	1850	–	29,880 ind m^{-2}	5.28 m^{-2}	Wiekert (1982)

Pleuromamma indica, *Rhincalanus nasutus* are important, beside the cyclopoids *Oithona* and *Oncaea* (Böttger-Schnack 1988, 1990b; El-Serehy and Abd El-Rahman 2004). The Gulf of Aqaba and Red Sea proper have dominant tropical species in the epipelagic zone, but decrease rapidly below 300 m depth (Wiekert 1980b; Almeida Prado-Por 1983; Beckmann 1984; Cornils et al. 2005). The micro-copepods, mainly the Oncaeidae family, were observed to be more abundant than calanoid copepodids (Boxshall and Böttger 1987), and their relative importance increased with depth showing the numerical importance of smaller meso-zooplankton, especially the genus *Oncaea* (Böttger 1987; Böttger-Schnack et al. 1989), including, but not least, *Oithona*, *Corycaeus*, *Paracalanus*, etc. (Abd El-Rahman 1999; Al-Najjar 2002; El-Sherif and Aboul Ezz 2000; El-Serehy and Abd El-Rahman 2004; Aamer et al. 2006; Cornils et al. 2007a; Dorgham et al. 2012; Kürten et al. 2016). At the central Red Sea, the plankton decreased within the upper 150 m, which coincided with decreasing temperature and oxygen concentration, indicating the occurrence of diurnal vertical migrations of midwater species in the Red Sea proper, showing a secondary peak of zooplankton concentration in the mesopelagic zone with higher abundance and biomass during daytime than at night (Beckmann 1984). However, the relative abundance of cyclopoids decreased with depth, where *Oithona* and *Oncaea* were abundant at all sampled depths, whereas *Corycaeus*, *Copilia* and *Sapphirina* were abundant in the epipelagic zone, which might be due to the influence of a larger 300 μm mesh size sampling rather than 55 μm or 100 μm (Böttger 1987).

Table 25.2 Copepoda diversity in the Red Sea (modified from Razouls et al. 2005–2017). N = Northern Red Sea; S = Southern Red Sea; C = Central Red Sea; RS = Red Sea in general; Es = Estuarine; Ne = Neritic; Oc = Oceanic; Ep = Epipelagic; Mp = Mesopelagic; Bp = Bathypelagic; Hb = Hyperbenthic; B = Benthic; D = Demersal; Sp = Semi-parasitic; - = absent/not available; ? = doubtful presence; [#] = endemic to Red Sea; * = unpublished; [a] = El-Sherbiny and Al-Aidaroos (2014; [b] = Al-Aidaroos et al. 2016b; [c] = El-Sherbiny and Al-Aidaroos 2017; [d] = El-Sherbiny 2009)

Species	Body length in mm		Location and distribution
	Female	Male	
Order: Calanoida Sars, 1902			
Acartia (*Acanthacartia*) *fossae* Gurney, 1927	0.90–1.40	0.91–1.30	N, C, S, Ep
Acartia (*Acartia*) *danae* Giesbrecht, 1889	0.90–1.34	0.70–1.10	N, C, S
Acartia (Acartia) *negligens* Dana, 1849	0.91–2.07	0.80–1.50	N, C, S, Ne, Oc, Ep
Acartia (*Acartiura*) *clausi* Giesbrecht, 1889	0.60–1.47	0.68–1.34	N, C, S, Ne, Ep
Acartia (*Acartiura*) *discaudata* (Giesbrecht, 1881)	1.00–1.20	0.90–1.10	N, Oc, Ep, Mp
Acartia (*Acartiura*) *longiremis* (Lilljeborg, 1853)	0.80–1.40	0.66–1.18	Ne, Oc, Ep–Mp
Acartia (*Odontacartia*) *amboinensis* Carl, 1907*	1.33–1.47	1.25–1.33	S, Ne, Oc, Ep
Acartia (*Odontacartia*) *bispinosa* Carl, 1907[a]	1.32–1.53	1.07–1.16	N, Ne, Ep
Acartia (*Odontacartia*) *centrura* Giesbrecht, 1889	1.13–1.30	1.03	N, C, S, Es, Oc, Ep
Acartia (*Odontacartia*) *erythraea* Giesbrecht, 1889	1.10–1.50	1.00–1.40	N, C, S, Es, Oc, Ep
Acartia eremeevi Pavlova and Shmeleva, 2010	0.30–0.76	0.70–0.75	RS, Ne
Acartia mollicula Pavlova and Shmeleva, 2010	0.57–0.70	Stage V: 0.60	RS, Ne
Acrocalanus gibber Giesbrecht, 1888	0.74–1.28	0.85–1.40	N, C, S, Ne, Ep
Acrocalanus gracilis Giesbrecht, 1888	0.81–1.80	0.80–1.32	N, C, S, Ep
Acrocalanus longicornis Giesbrecht, 1888	0.94–1.55	0.80–1.40	N, C, S, Ep–Mp
Acrocalanus monachus Giesbrecht, 1888	0.88–1.10	0.79–0.88	RS, Ep
Aetideus armatus (Boeck, 1872)	1.33–2.25	1.25–2.10	RS, Ep–Bp
Amallothrix falcifer (Farran, 1926)	1.80–2.20	1.98–2.81	N, Oc, Bp
Archescolecithrix auropecten (Giesbrecht, 1892)	1.80–2.75	1.95–2.43	N, Oc, Mp–Bp
Bradyidius armatus Giesbrecht, 1897	1.70–2.70	1.50–2.20	RS, Ep–Mp, Hb
Calanopia elliptica (Dana, 1849)	1.55–2.10	1.40–1.90	N, C, S, Ne, Ep–Mp
Calanopia kideysi Ünal and Shmeleva, 2002	0.96–1.05	–	C
Calanopia media Gurney, 1927	1.68–2.00	1.60–2.00	N, C, S, Ne
Calanopia minor A. Scott, 1902	1.14–1.40	1.06–1.23	N, Ne
Calanopia thompsoni A. Scott, 1909[b]	1.92–1.98	1.79–1.83	N, Ne, Ep
Calanopia tulina El-Sherbiny and Al-Aidaroos, 2017[c,#]	1.94–2.22	1.88–2.08	C, Ne, Ep
Calocalanus contractus Farran, 1926	0.56–0.91	0.48–0.55	RS, Ep–Mp
Calocalanus elegans Shmeleva, 1965	0.50–0.52	0.46–0.48	RS, Ep–Mp
Calocalanus neptunus Shmeleva, 1965	0.84–0.96	0.81–0.84	RS, Ep
Calocalanus pavo (Dana, 1849)	0.65–1.50	0.60–1.18	N, C, S, Ep–Bp
Calocalanus pavoninus Farran, 1936	0.60–0.97	0.50–0.60	RS, Ep
Calocalanus plumulosus (Claus, 1863)	0.87–1.34	0.52–0.90	RS, Oc, Ep
Calocalanus styliremis Giesbrecht, 1888	0.50–0.95	0.45–0.65	RS, Ep
Candacia bispinosa (Claus, 1863)	1.56–2.16	1.36–2.19	RS, Ep–Mp
Candacia bradyi A. Scott, 1902	1.40–2.10	1.08–1.90	N, C, S, Oc
Candacia catula (Giesbrecht, 1889)	1.32–1.70	1.30–1.62	N, Ep
Candacia curta (Dana, 1849)	1.82–2.90	1.50–2.70	N, C, S, Ep–Mp
Candacia ethiopica (Dana, 1849)	1.97–3.03	1.96–2.93	RS, Ep–Mp
Candacia longimana (Claus, 1863)	2.70–3.90	2.40–3.72	S, Ep–Mp

(continued)

Table 25.2 (continued)

Species	Body length in mm		Location and distribution
	Female	Male	
Candacia samassae Pesta, 1941	1.28–2.12	1.54–1.66	N, Mp
Candacia simplex (Giesbrecht, 1889)	1.62–2.32	1.73–2.20	RS, Ep–Mp
Candacia tenuimana (Giesbrecht, 1889)	2.03–2.40	1.90–2.29	N, Mp
Candacia truncata (Dana, 1849)	1.50–2.30	1.30–2.25	N, C, S, Oc
Candacia varicans (Giesbrecht, 1892)	1.98–2.74	1.91–2.42	RS, Ep–Mp
Canthocalanus pauper (Giesbrecht, 1888)	1.10–1.75	1.00–2.04	N, RS, Ep
Centropages aegypticus El-Sherbiny and Ueda, 2008#	1.50–1.67	1.50–1.70	N
Centropages calaninus (Dana, 1849)	1.72–2.18	1.68–2.11	S, Ep
Centropages elongatus Giesbrecht, 1896	1.50–1.91	1.50–2.00	N, RS, Ep
Centropages furcatus (Dana, 1849)	1.38–1.92	1.40–1.92	N, C, S, Ep
Centropages gracilis (Dana, 1849)	1.70–2.16	1.70–2.04	RS, S, Ne, Ep
Centropages kroyeri Giesbrecht, 1892	1.25–1.52	1.20–1.41	RS, Ep
Centropages mohamedi El-Sherbiny and Al-Aidaroos, 2015#	1.31–1.45	1.20	C, Ne
Centropages orsinii (Giesbrecht, 1889)	1.20–1.70	1.11–1.54	RS, S, Ep
Centropages ponticus Karavaev, 1894	0.70–1.04	0.54–1.05	N, RS, Ne
Centropages typicus Kröyer, 1849	0.79–2.00	1.00–1.90	N, Ne, Ep
Centropages uedai El-Sherbiny 2011#	1.19–1.88	1.83	N, Ne, Ep
Centropages violaceus (Claus, 1863)	1.76–2.24	1.77–2.17	RS, Oc, Ep
Clausocalanus arcuicornis (Dana, 1849)	1.08–1.62	0.90–1.25	N, C, S, Ne, Ep
Clausocalanus farrani Sewell, 1929	0.87–1.22	0.65–0.99	N
Clausocalanus furcatus (Brady, 1883)	0.80–1.75	0.70–1.14	N, C, S, Ep
Clausocalanus minor Sewell, 1929	0.94–1.30	0.79–1.04	N, Oc
Clausocalanus parapergens Frost and Fleminger, 1968	0.95–1.65	0.97–1.20	RS, Ep
Clausocalanus paululus Farran, 1926	0.65–0.86	0.47–0.60	RS, Ep
Cosmocalanus darwini (Lubbock, 1860)	1.25–2.58	1.20–2.35	S, Ep, Bp?
Ctenocalanus campaneri Prado-Por, 1984#	1.12	1.12	N, Ep–Mp
Ctenocalanus tageae Prado-Por, 1984#	1.10	1.10	N
Ctenocalanus vanus Giesbrecht, 1888	0.81–1.70	1.08–1.95	N, RS, Ep–Bp
Disco erythraeus Gordejeva, 1974	0.48–0.52	–	RS, Ep–Mp
Disco populosus Gordejeva, 1976	0.45	–	RS, Mp
Disco robustipes Gordejeva, 1974	0.40–0.48	–	RS, Mp
Disco vulgaris Gordejeva, 1974	0.39–0.45	0.30	RS, Mp
Distioculus minor (T. Scott, 1894)	0.79–1.74	0.77–1.45	RS, S, Ep
Euaugaptilus hecticus (Giesbrecht, 1889)	1.60–2.85	1.20–2.43	RS, Ep–Mp
Euchaeta concinna Dana, 1849	2.10–3.75	2.24–3.10	N, RS, Ep
Euchaeta marina (Prestandrea, 1833)	2.25–3.90	2.56–3.81	N, S, Ep–Mp
Euchaeta plana Mori, 1937	2.58–3.50	2.51–3.16	N,S
Euchaeta spinosa Giesbrecht, 1892	5.18–7.21	5.22–6.90	S, Ep–Bp
Haloptilus acutifrons (Giesbrecht, 1892)	2.00–4.66	2.1–3.19	RS, S, Ep–Bp
Haloptilus longicornis (Claus, 1863)	1.40–2.63	1.16–1.37	N, C, S, Ep–Bp
Haloptilus ornatus (Giesbrecht, 1892)	2.88–5.33	2.75–3.05	N, RS, Ep–Mp
Haloptilus plumosus (Claus, 1863)	4.15–4.20	–	RS, S, Ep–Bp
Labidocera acuta (Dana, 1849)	2.30–3.60	2.29–3.31	N, C, S, Ep

(continued)

Table 25.2 (continued)

Species	Body length in mm		Location and distribution
	Female	Male	
Labidocera boxshalli El-Sherbiny and Ueda, 2010[#]	2.38	2.32	N, Ep
Labidocera kroyeri (Brady, 1883)[c]	1.90–2.75	1.05–2.36	S, Ne, Ep
Labidocera minuta Giesbrecht, 1889	1.60–2.26	1.36–2.00	N, RS, Ne, Ep
Labidocera orsinii Giesbrecht, 1889	2.20	–	RS
Labidocera pavo Giesbrecht, 1889	1.70–2.52	1.45–2.31	N, RS, Ne
Lucicutia clausi (Giesbrecht, 1889)	1.60–2.16	1.60–1.92	RS, S, Ep–Mp
Lucicutia flavicornis (Claus, 1863)	1.25–2.50	1.06–1.92	N, C, S, Ep–Bp
Lucicutia gaussae Grice, 1963	1.10–1.60	1.20–1.50	RS, S, Ep–Mp
Lucicutia gemina Farran, 1926	1.35–1.90	1.25–1.72	RS, Ep–Mp
Lucicutia ovalis (Giesbrecht, 1889)	1.31–2.00	1.20–1.85	S, Ep–Bp
Lucicutia paraclausi Park, 1970	1.72–1.84	1.52–1.86	RS, Mp
Macandrewella chelipes (Giesbrecht, 1896)	3.12–3.50	3.00–3.41	N, RS
Macandrewella cochinensis Gopalakrishnan, 1973	2.88–3.15	2.83–3.21	N, Ne
Mecynocera clausi Thompson, 1888	0.90–1.29	0.75–1.12	N, RS, Ep
Megacalanus princeps Wolfenden, 1904	8.70–13.5	7.90–12.0	N, Mp–Bp
Mesocalanus lighti (Bowman, 1955)	2.10–3.08	1.90–2.68	N
Mesocalanus tenuicornis (Dana, 1849)	1.50–3.40	1.50–2.20	N, RS, Ep–Bp
Metridia lucens Boeck, 1864	1.90–4.00	1.50–3.00	N, RS, Ep–Bp
Nannocalanus minor (Claus, 1863)	1.45–2.45	1.17–2.06	N, RS, Ep–Bp
Paracalanus aculeatus Giesbrecht, 1888	0.75–1.45	0.71–1.36	RS, S
Paracalanus denudatus Sewell, 1929	0.56–0.96	0.75	N, C, S, Ep
Paracalanus indicus Wolfenden, 1905	0.66–1.30	0.74–1.40	RS
Paracalanus nanus Sars, 1907	0.50–0.65	0.50–0.60	RS, Ne, Ep–Mp
Paracalanus parvus (Claus, 1863)	0.62–1.30	0.50–1.40	N, C, S, Ne
Paracartia dubia T. Scott, 1894	1.25	1.20	N, RS
Paradisco gracilis Gordejeva, 1975	0.50–0.57	0.48	RS, Mp
Pareucalanus attenuatus (Dana, 1849)	3.00–7.30	2.75–6.04	N, C, S, Ne
Parvocalanus crassirostris (F. Dahl, 1894)	0.42–0.82	0.34–0.62	N, C, S, Es
Phaenna spinifera Claus, 1863	1.50–3.02	1.80–2.50	N, Ep–Mp
Pleuromamma abdominalis (Lubbock, 1856)	2.40–4.50	2.40–4.30	RS, Ep–Bp
Pleuromamma gracilis (Claus, 1863)	1.20–2.55	1.50–2.25	RS, Ep–Mp
Pleuromamma indica Wolfenden, 1905	1.70–2.72	1.65–2.38	N, C, S
Pleuromamma robusta (F. Dahl, 1893)	2.15–4.70	2.10–4.00	RS, S, Mp–Bp
Pleuromamma xiphias (Giesbrecht, 1889)	3.25–5.87	3.50–6.42	S, Ep?, Mp–Bp
Pontella diagonalis C.B. Wilson, 1950[c]	4.00–4.94	3.50–4.15	N, Ne
Pontella fera Dana, 1849	2.00–3.33	2.33–3.10	RS, Ne
Pontella karachiensis Fazal-Ur-Rehman, 1973	3.40–5.03	3.20–4.08	N, Ep
Pontella princeps Dana, 1849[d]	4.98–5.63	4.20–5.56	Ne, Ep
Pontellina plumata (Dana, 1849)	1.03–1.94	1.25–1.92	N, RS, Ep–Mp
Pontellopsis krameri (Giesbrecht, 1896)	1.86–2.98	1.60–2.17	RS, Ne, Ep
Pontellopsis macronyx A. Scott, 1909[c]	1.68–2.10	1.55–1.80	N, Ne
Pontellopsis villosa Brady, 1883	1.95–3.00	2.05–2.58	N, RS, Ne, Oc, Ep
Pontoeciella abyssicola (T. Scott, 1894)	0.70–1.65	0.90–1.25	RS, Mp–Bp

(continued)

Table 25.2 (continued)

Species	Body length in mm		Location and distribution
	Female	Male	
Pseudocyclops gohari Noodt, 1958#	0.95	1.00	S, Ne
Pseudocyclops latens Gurney, 1927#	0.63	–	N
Pseudocyclops reductus Nicholls, 1944#	0.50–0.60	–	RS
Pseudocyclops steinitzi Por, 1968#	0.66–0.70	0.59–0.62	S
Pseudocyclops umbraticus Giesbrecht, 1893	0.60–0.70	0.54–0.58	N, Hb
Pseudodiaptomus salinus Giesbrecht, 1896	1.1–1.45	1.25–1.34	N, RS, Es, Ne
Pseudodiaptomus serricaudatus (T. Scott, 1894)	1.03–1.52	1.02–1.29	RS, S, Ne
Rhincalanus cornutus (Dana, 1849)	2.81–4.16	2.40–3.68	RS?, Ep, Mp–Bp
Rhincalanus nasutus Giesbrecht, 1888	2.82–6.10	2.70–4.50	N, C, S, Ep–Mp
Rhincalanus rostrifrons (Dana, 1849)	2.79–3.80	2.40–2.95	S
Ridgewayia typica Thompson and Scott, 1903	0.80–0.85	0.73–0.78	N, Hb
Scolecithricella minor (Brady, 1883)	1.02–1.70	1.07–1.46	RS, Ep–Bp
Scolecithricella orientalis Mori, 1937	1.10	–	RS, S, Ep
Scolecithricella tropica Grice, 1962	1.13–1.30	–	RS
Scolecitrichopsis ctenopus (Giesbrecht, 1888)	1.25–1.65	1.30–1.90	N, Ep
Scolecitrichopsis tenuipes (T. Scott, 1894)	1.15–1.48	1.38–1.45	RS, Ne, Ep–Mp
Subeucalanus crassus (Giesbrecht, 1888)	2.10–4.60	2.40–3.50	S, Ep, Mp–Bp
Subeucalanus monachus (Giesbrecht, 1888)	1.81–2.84	1.86–2.60	S, Mp–Bp
Subeucalanus mucronatus (Giesbrecht, 1888)	2.80–3.49	2.50–3.30	S, Ep, Mp
Subeucalanus subcrassus (Giesbrecht, 1888)	1.84–2.92	1.64–2.70	S, Ep, Mp
Subeucalanus subtenuis (Giesbrecht, 1888)	1.80–3.70	2.60–3.08	RS, Ep, Mp
Temora discaudata Giesbrecht, 1889	1.11–2.05	1.50–1.97	N, C, S, Ne, Oc
Temora stylifera Dana, 1849	1.19–2.05	1.01–1.88	N?, C, S, Ep
Temora turbinata (Dana, 1849)	0.90–1.70	0.89–1.71	S, Ne, Ep
Temoropia mayumbaensis T. Scott, 1894	0.56–1.17	0.84–1.06	N, Oc, Ep?, Mp–Bp
Tortanus (*Atortus*) *ampliramus* Ohtsuka, El-Sherbiny and Ueda, 2000#	2.13–2.46	2.00–2.13	N
Tortanus (*Atortus*) *recticauda* (Giesbrecht, 1889)	1.80–2.00	1.60–1.85	S
Tortanus (*Tortanus*) *barbatus* (Brady, 1883)	1.15–2.10	0.90–1.20	S, Ne, Ep
Tortanus (*Tortanus*) *gracilis* (Brady, 1883)	1.52–2.10	1.35–1.80	N, Ne, Ep
Undeuchaeta major Giesbrecht, 1888	3.50–6.50	3.00–5.50	N, Ep, Mp, Bp
Undinula vulgaris (Dana, 1849)	1.80–3.25	2.00–3.23	N, C, S, Ep–Mp
Order: Cyclopoida Burmeister, 1834			
Conaea rapax Giesbrecht, 1891	0.90–1.16	0.78–1.02	RS, Bp
Copilia mirabilis Dana, 1849	2.13–5.80	3.20–6.61	N, C, S
Copilia quadrata Dana, 1849	1.40–4.58	2.80–5.70	RS, EP
Corycaeus (*Agetus*) *flaccus* Giesbrecht, 1891	1.20–1.89	1.15–1.68	RS, Ep–Mp
Corycaeus (*Agetus*) *limbatus* Brady, 1883	1.24–1.64	1.08–1.67	RS, S, Ep–Mp
Corycaeus (*Agetus*) *typicus* (Krøyer, 1849)	1.30–1.80	1.27–1.62	RS, Ep–Mp
Corycaeus (*Corycaeus*) *crassiusculus* Dana, 1849	1.44–2.00	1.26–1.75	RS, S, Ep
Corycaeus (*Corycaeus*) *speciosus* Dana, 1849	1.37–2.55	0.75–2.00	N?, C, S, Ep–Mp, Bp
Corycaeus (*Ditrichocorycaeus*) *affinis* McMurrich, 1916	0.75–1.25	0.62–0.90	RS, S, Ep
Corycaeus (*Ditrichocorycaeus*) *andrewsi* Farran, 1911	0.65–1.07	0.65–1.04	S
Corycaeus (*Ditrichocorycaeus*) *anglicus* Lubbock, 1857	0.63–1.19	0.54–1.02	N, Ep

(continued)

Table 25.2 (continued)

Species	Body length in mm		Location and distribution
	Female	Male	
Corycaeus (*Ditrichocorycaeus*) *asiaticus* F. Dahl, 1894	1.05–1.40	0.96–1.26	N, C, S, Ep
Corycaeus (*Ditrichocorycaeus*) *brehmi* Steuer, 1910	0.70–1.16	0.76–1.04	N
Corycaeus (*Ditrichocorycaeus*) *erythraeus* Cleve, 1904	0.85–1.12	0.83–0.91	N, C, S
Corycaeus (*Ditrichocorycaeus*) *lubbocki* Giesbrecht, 1891	0.75–1.03	–	RS, Ep
Corycaeus (*Onychocorycaeus*) *agilis* Dana, 1849	0.75–1.40	0.68–0.91	RS, S
Corycaeus (*Onychocorycaeus*) *catus* F. Dahl, 1894	0.87–1.18	0.78–0.99	RS
Corycaeus (*Onychocorycaeus*) *giesbrechti* F. Dahl, 1894	0.80–1.30	0.76–1.10	N, RS, Ep
Corycaeus (*Onychocorycaeus*) *latus* Dana, 1849	0.82–1.18	0.80–1.17	RS, Ep
Corycaeus (*Onychocorycaeus*) *ovalis* Claus, 1863	0.92–1.65	0.80–1.40	RS, Ep
Corycaeus (*Onychocorycaeus*) *pacificus* F. Dahl, 1894	1.04–1.22	0.95–1.19	N, C, S, Ep–Mp
Corycaeus (*Onychocorycaeus*) *pumilus* M. Dahl, 1912	0.65–0.81	0.63–0.73	N, RS
Corycaeus (*Urocorycaeus*) *furcifer* Claus, 1863	1.40–2.10	1.20–1.46	RS, S, Ep–Mp
Corycaeus (*Urocorycaeus*) *lautus* Dana, 1849	2.29–3.05	1.45–2.55	N, Ep–Mp
Corycaeus (*Urocorycaeus*) *longistylis* Dana, 1849	2.38–3.04	2.00–2.72	N, C, S, Ep–Mp
Dioithona minuta (T. Scott, 1894)	0.48–0.64	0.42–0.50	RS, Es, Ne, Ep?
Dioithona propinqua Herbst, 1964#	0.69	–	RS
Dioithona rigida (Giesbrecht, 1896)	0.60–1.00	0.50–0.87	RS, S
Epicalymma bulbosa Böttger-Schnack, 2009#	0.30–0.35	0.29–0.29	N, RS
Farranula carinata (Giesbrecht, 1891)	0.72–0.98	0.70–0.91	N, RS, Ep
Farranula curta (Farran, 1911)	0.67–0.87	0.64–0.77	RS
Farranula gibbula (Giesbrecht, 1891)	0.83–1.10	0.80–0.96	N, C, S
Farranula gracilis (Dana, 1849)	0.79–1.10	0.66–1.00	N, Ep–Bp
Farranula rostrata (Claus, 1863)	0.70–0.90	0.61–0.80	RS, Ep
Lubbockia aculeata Giesbrecht, 1891	1.25–2.84	1.41–2.74	RS, Ep–Mp
Lubbockia squillimana Claus, 1863	0.95–2.00	1.47–2.40	N, RS, Mp
Monothula subtilis (Giesbrecht, 1892)	0.44–0.69	0.34–0.44	RS, S, Ep–Mp
Oithona atlantica Farran, 1908	0.60–1.43	0.60–1.00	RS, Ep–Mp
Oithona attenuata Farran, 1913	0.60–1.78	0.50–0.60	RS, S, Ep
Oithona brevicornis Giesbrecht, 1891	0.48–0.79	0.40–0.65	N, C, S, Ne, Ep
Oithona decipiens Farran, 1913	0.55–0.81	–	RS, Ep–Mp
Oithona fallax Farran, 1913	0.62–1.01	0.55–0.77	RS, S, Ep
Oithona nana Giesbrecht, 1892	0.31–0.95	0.30–0.63	N, C, S, Es, Ne, Ep
Oithona pacifica (Nishida, 1985)	0.41–0.47	0.37–0.40	RS, S, Ep–Mp
Oithona plumifera Baird, 1843	0.83–1.54	0.59–1.01	N, C, S, Ep–Mp
Oithona pulla (Farran, 1913)	0.40–0.46	0.40	S
Oithona robusta Giesbrecht, 1891	1.40–1.65	1.20–1.24	RS, S, Ep–Mp
Oithona setigera (Dana, 1849)	1.10–2.04	0.54–1.20	RS, S, Ep–Mp
Oithona similis-Group Claus, 1866	0.43–1.20	0.43–0.82	N, RS, Ep–Bp
Oithona simplex Farran, 1913	0.30–0.46	0.31–0.47	N, C, S, Ep
Oithona tenuis Rosendorn, 1917	0.96–1.37	–	RS, Ep
Oithona vivida Farran, 1913	0.68–0.83	–	RS, Ep
Oncaea atlantica Shmeleva, 1967	0.25–0.26	0.24	N, RS, Ep
Oncaea bispinosa Böttger-Schnack, 2002	0.31–0.34	0.28–0.32	N, C, Ep–Mp

(continued)

Table 25.2 (continued)

Species	Body length in mm		Location and distribution
	Female	Male	
Oncaea clevei Früchtl, 1923	0.62–0.76	0.46–0.61	N, C, S, Ep
Oncaea cristata Böttger-Schnack, 2005#	0.42–0.46	0.38–0.40	N, RS, Mp–Bp
Oncaea media Giesbrecht, 1891	0.46–1.02	0.38–0.93	N, C, S, Ep–Mp
Oncaea mediterranea (Claus, 1863)	0.85–1.60	0.69–1.12	N, Ep–Mp
Oncaea ovalis Shmeleva, 1966	0.41–0.54	0.31–0.54	RS, S, Mp
Oncaea paraclevei Böttger-Schnack, 2001	0.65–0.66	–	N?, C, S
Oncaea platysetosa Boxshall and Böttger, 1987	0.24–0.25	–	N, C, S, Ep
Oncaea scottodicarloi Heron and Bradford-Grieve, 1995	0.50–0.78	0.38–0.60	N, C, S, Ep–Mp
Oncaea tregoubovi Shmeleva, 1968	0.28–0.40	0.29–0.34	N, C, S, Ep
Oncaea venella Farran, 1929	0.75–1.09	0.55–0.91	N, RS
Oncaea venusta Philippi, 1843	0.84–1.70	0.57–1.10	RS, D, Oc, Ep–Mp
Oncaea vodjanitskii Shmeleva and Delalo, 1965	0.23–0.25	0.22–0.25	N, RS, Ep–Mp
Oncaea waldemari Bersano and Boxshall, 1994	0.42–0.58	0.34–0.41	RS, S
Oncaea zernovi Shmeleva, 1966	0.31–0.38	0.28–0.32	RS, S, Ep–Mp
Pachos punctatum (Claus, 1863)	1.83–2.64	1.87–2.20	RS, Ep
Sapphirina angusta Dana, 1849	1.40–5.00	3.00–6.95	S, Ep
Sapphirina bicuspidata Giesbrecht, 1891	1.40–3.00	2.07–3.42	RS, Ep
Sapphirina darwini Haeckel, 1864	1.20–3.20	1.20–3.58	RS
Sapphirina gastrica Giesbrecht, 1891	1.00–2.68	1.85–3.59	RS, S, EP
Sapphirina gemma Dana, 1849	1.20–3.39	1.65–2.87	N, C, S, Ep
Sapphirina intestinata Giesbrecht, 1891	1.20–3.39	1.65–2.87	N, C, S, Ep
Sapphirina lactens Giesbrecht, 1892	1.20–2.10	1.40–2.19	RS, Ep
Sapphirina maculosa Giesbrecht, 1892	1.00–2.59	1.40–2.71	RS, S
Sapphirina metallina Dana, 1849	1.20–2.52	1.40–3.00	RS, S, Ep–Mp
Sapphirina nigromaculata Claus, 1863	1.20–3.79	1.40–4.15	RS, S, Ep
Sapphirina opalina Dana, 1849	1.20–4.05	1.20–4.34	RS
Sapphirina ovatolanceolata Dana, 1849	1.40–3.65	1.70–4.74	RS
Sapphirina scarlata Giesbrecht, 1891	1.20–4.65	1.40–4.85	RS, Ep
Sapphirina sinuicauda Brady, 1883	1.20–2.20	1.40–2.25	RS
Sapphirina stellata Giesbrecht, 1891	1.20–4.50	1.60–3.50	RS, Oc, Ep
Sapphirina vorax Giesbrecht, 1891	1.88–2.15	1.30–1.83	RS, S, Ep
Spinoncaea humesi Böttger-Schnack, 2003	0.31–0.32	0.28–0.30	RS, Ep
Spinoncaea ivlevi (Shmeleva, 1966)	0.30–0.34	0.28–0.35	N, C, S, Ep
Spinoncaea tenuis Böttger-Schnack, 2003	0.28–0.30	0.28–0.30	N, C, S, Ep–Mp
Triconia borealis (Sars, 1918)	0.56–0.80	0.35–0.56	N, Ep–Mp
Triconia conifera (Giesbrecht, 1891)	0.65–1.50	0.60–1.10	RS, Ep–Bp
Triconia dentipes (Giesbrecht, 1891)	0.42–0.57	0.36–0.57	N, C, S, Ep, Mp
Triconia elongata Böttger-Schnack, 1999	0.45–0.54	0.39	N, C, S, EP
Triconia giesbrechti Böttger-Schnack, 1999	0.42–0.49	0.36–0.41	S, Ep
Triconia gonopleura Böttger-Schnack, 1999#	0.58	–	S
Triconia hawii (Böttger-Schnack and Boxshall, 1990)	0.49–0.56	0.48–0.49	N, C, S, Ep, Mp
Triconia minuta Giesbrecht, 1892	0.41–0.76	0.39–0.62	N?, C, S, Ep, Mp–Bp
Triconia parasimilis Böttger-Schnack, 1999	0.71–0.75	0.60	S, Ep–Mp

(continued)

Table 25.2 (continued)

Species	Body length in mm		Location and distribution
	Female	Male	
Triconia recta Böttger-Schnack, 1999	0.60–0.62	0.47–0.52	N, C, S
Triconia rufa (Boxshall and Böttger, 1987)	0.50–0.67	0.5	N, C, S, Ep, Mp
Triconia similis (Sars, 1918)	0.59–0.90	0.49–0.68	RS, Mp
Triconia umerus (Böttger-Schnack and Boxshall, 1990)	0.57–0.71	0.52–0.57	N, C, S, Ep, Mp
Vettoria granulosa (Giesbrecht, 1891)	0.68–0.85	0.58–0.71	C, S, Ep–Mp
Vettoria parva (Farran, 1936)	0.80–0.93	0.8–1.0	RS, Ep–Mp
Order: Harpacticoida Sars, 1903			
Clytemnestra asetosa Huys and Conroy-Dalton, 2000#	0.76–0.83	–	N, RS
Clytemnestra farrani Huys and Conroy-Dalton, 2000	0.93–0.95	0.40–0.95	S
Euterpina acutifrons (Dana, 1848)	0.38–0.86	0.36–0.76	N, C, S, Ne
Macrosetella gracilis (Dana, 1848)	0.88–1.80	0.86–1.63	RS, Oc, Ep
Microsetella norvegica (Boeck, 1864)	0.35–0.76	0.30–0.66	RS, Ep–Bp
Microsetella rosea (Dana, 1848)	0.36–1.30	0.37–0.70	N, C, S, Ep
Order: Monstrilloida Sars, 1903			
Cymbasoma ghardaqana Al-Kholy, 1963#	–	1.19	S, Sp
Cymbasoma gigas (A. Scott, 1909)	8.00–8.20	–	RS, Sp
Cymbasoma gracile Gurney, 1927	0.90–2.00	1.13	RS, Sp
Cymbasoma janetae Mageed, 2010#	1.78	–	N, Sp
Cymbasoma reticulata (Giesbrecht, 1892)	2.10	–	RS, Sp
Monstrilla ghardaqensis Al-Kholy, 1963#	1.35	–	N, Sp
Monstrilla gohari Al-Kholy, 1963#	2.21	–	N, Sp
Monstrilla grandis Giesbrecht, 1891	0.80–4.25	0.61–2.00	RS, Sp
Order: Mormonilloida Boxshall, 1979			
Mormonilla phasma Giesbrecht, 1891	1.15–2.01	0.90–1.42	N, Mp–Bp
Neomormonilla minor (Giesbrecht, 1891)	0.81–1.38	0.75–0.84	RS, Mp–Bp
Order: Siphonostomatoida Burmeister, 1835			
Ratania flava Giesbrecht, 1892	1.00–1.40	1.00–1.20	RS, Mp–Bp

Northern Red Sea

This seasonal pattern of mixing and stratification has an indirect influence on copepods via controlling the nutrients for plankton growth. Having no river discharge and high evaporation rates during summer lead to more saline surface waters in the central and north, making it difficult for the organisms to thrive (Delalo 1966; Fedorina and Kornilova 1970; Beckmann 1984; Weikert 1987; Wafar et al. 2016). Moreover, the winter cooling and vertical mixing along with hydroecological conditions like surface circulation and wind patterns determine the copepod distribution (Halim 1984). The productivity increases from north to south, both in the main basin and in the Gulf of Aqaba, which is also reflected in the reef-bound coastal zone (Levanon-Spanier et al. 1979). Although the northern Red Sea (NRS) and Gulf of Aqaba show similar zooplankton community composition, they exhibit a clear difference in their species density, where in the winter zooplankton is dominated by copepods (Echelman and Fishelson 1990; Cornils et al. 2005), showing up to 75% of total zooplankton in the Gulf of Aqaba, northern Red Sea (Khalil and Abd El-Rahman 1997). There was a clear difference in density stratification between the Gulf of Aqaba and NRS, which showed an abundance of copepods ranging between 76 and 95% (Cornils et al. 2005). Normally during winter, eukaryotic algae, and the cyanobacteria (*Synechococcus* sp. and *Prochlorococcus* sp.), dominate the nutrient-rich winter mixing conditions of the Red Sea, showing higher plankton production (Levanon-Spanier et al. 1979; Lindell and Post 1995; Stambler 2005) than during summer, where the water column is stratified and the surface layers are depleted of nutrients. In winter, the thermocline deepens and deep convective mixing persists for several months, often reaching depths of 600 m or more (Lindell and Post 1995). The dominance of ultra- and pico- plankton having sizes less than 8 µm showed low phytoplankton productivity, which makes the larger copepods like *Rhincalanus nasutus* and *Pleuromamma indica* not to prefer these waters due to insufficient carbon availability through these prey items per gram body weight of these copepods (Lindell and Post 1995; Yahel et al. 1998; Sommer et al. 2002).

The seasonal abundance of epipelagic mesozooplankton in the northern Gulf of Aqaba shows that copepods dominate the zooplankton community with a mean of 79%, where calanoids contribute a mean of 61% and cyclopoids about 37% (Cornils et al. 2007b) during summer and autumn. In the Sharm El Sheikh area, adult copepods dominate with 22.3% of the total zooplankton, which mainly comprised *Oithona nana*, *Corycaues gibbulus* and *Corycaues* sp. during summer and *Clausocalanus* sp. during winter (El-Sherbiny et al. 2007). However, according to Almeida Prado-Por (1983) and Cornils et al. (2007a), the clausocalanids were abundant and represented by *Ctenocalanus vanus* during winter and spring 2002, followed by *Clausocalanus farrani* during spring. In the subsequent year the clausocalanid community was dominated by *C. vanus* during the first six months followed by *Clausocalanus furcatus*, while *C. farrani* remained stable throughout the year. This seasonality correlated with high temperature leads to increased dinoflagellate infection in the females of *C. farrani* (5.6%) compared to that of *C. furcatus* (2.8%). Moreover, the proportion of mature gonads of *C. vanus* were more significant with temperature and Chlorophyll-*a* than for *C. farrani* and *C. furcatus* (Cornils et al. 2007b). Feeding was more dependent on the food density rather than the size, equivalent to their daily body carbon uptake between 0.4 and 51.8% (Cornils et al. 2007c). In the coastal waters around the Sharm El Sheikh, *Acartia* sp. predominated in the inlet waters and was absent from the offshore region (Aamer et al. 2006), suggesting that the *Acartia* adults inhabit sheltered and organically polluted areas (Kasahara et al. 1974) with high suspended organic matter, like the bay or inlets (Conover 1956).

Central Red Sea

In the central Red Sea, the use of a larger mesh size revealed a uniform decrease in the copepod population within the upper 100 m depth, followed by a sharp decrease in the deeper layers (Gordeyeva 1970). The observation by using a 100 µm mesh showed that there was a 3-fold increase in biomass and 30-fold increase in metazoan numerical abundance compared with 300 µm mesh nets (Böttger 1987), with an increase in cyclopoid copepodids over the calanoid copepodids at all depths. However, 2 distinct surface and deep water morphotypes of the harpacticoid *Macrosetella gracilis* were observed in the northern and central Red Sea (Böttger-Schnack 1989), which might be due to the availability of different species, the cyanophyte *Trichodesmium* sp. during their development, or may depend on the smaller neritic or larger oceanic forms similar to *Oithona* sp. (Nishida and Marumo 1982). In the epipelagic zone, cyclopoids showed clear seasonal variations during autumn and winter, while in deeper layers they remained fairly constant during both seasons, with increasing epipelagic species during winter in their numerical abundance (Böttger-Schnack 1990a, b). During the summer of 1987, among the non-calanoid copepods, almost 16 species out of the 75 species observed in the southern Red Sea were completely absent in the central-northern area with a higher abundance of 19 species, and similarly *Oithona nana*, *Oncaea clevei*, *On. venusta f. typical* and *On. f. venella* were observed with a maximum abundance during winter, and *Corycaeus* (*Corycaeus*) *speciosus*, *Farranula carinata*, *F. rostrata*, *On. conifera* and *On. rufa* were observed at their maximum in summer (Böttger-Schnack 1995).

As a rule, the primary productivity and the zooplankton biomass are higher during the NE monsoon (November to April) compared to the hot SW monsoon (May to October) (Halim 1984; Weikert 1980a, b). The geographic count of zooplankton indicated a reduction of the number of species in the Red Sea compared to the Indian Ocean (Sewell 1948), which could be attributed to the physical barrier of the sill at Bab el Mandab which prevents the influx of Indo-Pacific species (Halim 1969; Weikert 1981), as seen from the low number of species which succeeded in reaching the northern Gulfs of Suez and Aqaba. Based on the molecular analysis of the operational taxonomic units, Pearman and Irigoien (2015) observed that the genus *Corycaeus* showed a higher proportion of reads in the epipelagic zone, with *Pleuromamma* being increasingly dominant with increasing depth.

Southern Red Sea

The zooplankton standing stock in the southern Red Sea is larger in size compared to other regions of the Red Sea, which might be primarily related to ecosystem difference between the areas, leading to a change in species composition (Böttger-Schnack 1989; Schneider and Lenz 1991; Schneider et al. 1994). Conspicuously, larger calanoids like *Candacia longimana*, *Euchaeta spinosa*, *Haloptilus plumosus*, *Labidocera kroyeri*, *Lucicutia ovalis*, *Pleuromamma xiphias*, *Subeucalanus mucronatus*, and *Tortanus* (*Atortus*) *recticauda*, and cyclopoids like *Corycaeus* (*Corycaeus*) *crassiusculus*, *Corycaeus* (*Urocorycaeus*) *furcifer*, and *Sapphirina vorax*, are strictly found in the southern Red Sea and are common Indian Ocean species, which were unable to migrate and thrive beyond the southern Red Sea (Meenakshikunjamma 1974; Beckmann 1984; Weikert 1987; Böttger-Schnack 1995). Higher zooplankton biomass and respiration rate within the euphotic zone (Schneider and Lenz 1991) clearly indicate the involvement of hydrographic features (Beckmann 1984). The cyclopoids exhibited two size variants, whereby the larger form was present in the Gulf of Aden, with smaller cogenric forms in the southern central Red Sea (Böttger-Schnack 1989; Schneider et al. 1994). This increase in the larger size composition of copepods toward the southern gradient might be due to the primary productivity, which ranged from 0.2 to 1.6 g C m^{-2} d^{-1} in the Gulf of Aden to 0.05–0.5 g C m^{-2} d^{-1} in the Red Sea proper (Khmeleva 1970; Krey 1973; Lenz et al. 1988; Weikert 1988). The small copepods (*Oncaea* group) showed increasing abundance toward the southern Red Sea (Böttger-Schnack 1995) and were found to play a major role in the degradation of marine snow aggregates (Kiorboe 2000). Through an extensive study of the zooplankton community from the central Red Sea during spring, and Saudi Arabian coast (i.e., Farasan Islands, Al-Quonfidah and Al-Lith areas), Al-Aidaroos et al. (2016a) showed a predominance of adult cyclopoids and calanoid copepodids, referring the high abundance of copepods to the rich phytoplankton community in surface layers, which is enhanced by nutrients supply brought by the SW monsoonal currents from the Gulf of Aden.

Vertical Distribution

In general, the mesozooplankton vertical distribution in the Red Sea is biologically classified into 3 distinct zones distinguished by their physical, chemical and hydrobiological properties as proposed by Vinogradov (1968): (1) *nutrient-poor epipelagic zone* (surface to 100 m), where most species congregate in the epipelagic zone and carry out vertical migration within this habitat zone; (2) *mesopelagic zone* (100–750 m), having the majority of interzonal species, which accumulate in the oxygen minimum layer between 300 and 650 m; and (3) *bathypelagic zone*, which extends from 750 to about 1850 m, having strongly reduced zooplankton abundance with no observed vertical migrations beyond this level. Most Red Sea copepods are found in the upper 100 m layer (e.g., Weikert 1982; Al-Najjar 2002, 2005; Aamer et al. 2006; Cornils et al. 2007a, b; El-Sherbiny et al. 2007; Dorgham et al. 2012).

In the northern Red Sea, only a small number of mesopelagic species dominate in the Gulf of Aqaba region, in which the epipelagic species predominate, because of the high salinities and the high temperatures in the deep waters at the entrance of the Red Sea and the Gulf of Aqaba (Halim 1969; Echelman and Fishelson 1990), which are separated by a shallow sill, the Strait of Tiran. Furthermore, the weak thermal stratification that occurs by cooling of surface waters and high evaporation leads to vertical mixing up to 900 m (Reiss and Hottinger 1984; Genin et al. 1995; Cornils et al. 2005; Stambler 2005; Manasrah et al. 2006). The prevailing hydrographic conditions in the environment affect the distribution of micro-plankton resulting in the supply of nutrient rich waters from the inflow of Red Sea surface waters (Plaehn et al. 2002) with increased primary productivity, thereby leading to higher planktonic copepods in the surface waters (Kimor and Golandsky 1977; Lindell and Post 1995; Badran et al. 2005; Sommer et al.2002). The community assemblage of the interzonal species in the Red Sea proper are separated by a layer of minimum oxygen concentration and oxycline zones having a diverse distribution pattern of migrating species. For example, *Haloptilus longicornis*, which resides within the oxycline zone, migrates slightly upward in the epipelagic zone; *Temoropia mayumbaensis* migrates a little deeper up to the upper oxygen minimum layer zone and *Pleuromamma indica*, which resides in the oxygen minimum layer, migrates somewhat deeper until the mesopelagic zone. *Rhincalanus nasutus*, which resides within the oxygen minimum layer, shows habitat zonal migration and *Lucicutia paraclausi*, a bathypelagic species, migrates within the mid-oxygen minimum layer until the middle of the bathypelagic zone (Weikert 1982).

Diel vertical migration (DVM) does not affect the interzonal species, which remain confined within their limits during daylight hours and even during night time; for example, *R. nasutus* resides in a narrow layer of about 100 m thick from the oxygen minimum layer (Weikert 1980a, b). The discontinuity layer in-between the epi- and mesopelagic zone seems to be unfavorable for zooplankton. In summer, the *oxycline* is developed in the upper 20–75 m coinciding with the thermocline and halocline, whereas the *oxycline* occurs at greater depths (>100 m) in winter (Morcos and AbdAllah 2012). The observation that the bathypelagic zone is virtually unaffected by the DVM of zooplankton (Weikert 1980b; Beckmann 1984) shows that below 1100 m the nutritive particulate organic matters (POM) are not actively transported from the epipelagic and mesopelagic zones, but are produced by the faeces, carcasses, moults and their debris that originate from the mesopelagic zone.

The pattern of zooplankton vertical distribution in the Red Sea is different from most oligotrophic waters of the world, as its biomass and individual numbers decrease with depth to be completely negligible at around 1100 m (Schmidt 1973; Weikert 1982; Böttger 1987; Böttger-Schnack 1990b; Cornils et al. 2007b). The numerical abundance of the copepodids of both calanoids and cyclopoids were observed to be equal in the epipelagic zone, with cyclopoids increasing with depth and persisting down until 1050 m, showing *Oithona* and *Paroithona* to be predominant in the epipelagic zone and *Oncaea* in the mesopelagic zone. After that, harpacticoid copepods outnumber cyclopoids, having constant numbers of *Macrosetella gracilis* from 1050 m until 1650 m (Böttger 1987). Meanwhile, the mesopelagic zone (100–650 m) harbours the calanoids, *Haloptilus longicornis* in the *oxycline* layer, *Rhincalanus nasutus* in the oxygen minimum layer and *Lucicutia paraclausi* in the meso-bathypelagic zone below 750 m (Cornils et al. 2007b).

The triggering of environmental signals in terminating the resting period of *R. nasutus* during dormancy in the Gulf of Aqaba at a depth between 300 and 600 m is still ambiguous (Peterson 1998). *Rhincalanus nasutus* occurs in higher numerical abundance in the Gulf of Aqaba (585 ind m^{-2}) during spring 1999, than in the northern Red Sea (254 ind m^{-2}), indicating the absence of young developmental stages (nauplii, copepodid CI and CII stages). The immature CV stage dominates the adjacent stations in the northern Gulf of Aqaba and in the northern Red Sea, showing their association with the seasonal vertical migration and their initiation of feeding from wintering mid-water layers, which starts during March in the southern Gulf of Aqaba (Schnack-Schiel et al. 2008). This supports the seasonal dormancy of *R. nasutus* in the Gulf of Aqaba, suggesting the timing of vertical migration, feeding and maturation is closely coupled with the development of the spring bloom in the subtropical oligotrophic waters.

The vertical movement of adult copepods is decided by the timing and depth of the vertical mixing of the water column in the northern Gulf of Aqaba during the stratification of the water column and development of the spring bloom initiating the reproduction of the species (Farstey 2001). This shows that the larger phytoplankton species were selectively fed by all developmental stages of copepods (Mullin and Brooks 1967; Sommer et al. 2002), suggesting *R. nasutus* cannot thrive well in the oligotrophic waters of the Red Sea and Gulf of Aqaba, wherein pico- and nanoplankton predominate (Lindell and Post 1995; Yahel et al. 1998; Ye et al. 2013), except for blooms in spring (Kimor and Golansky 1977). No significant effect of phytoplankton composition on the egg production rate of *R. nasutus* in the Benguela upwelling was observed by Irigoien et al. (2005), suggesting the importance of omnivory during unproductive periods (Kürten et al. 2016). While the *Pleuromamma indica* in the Red Sea proper congregates in the epipelagic zone at night and in the mesopelagic zone during the day, juveniles concentrate in the upper part of the oxygen minimum layer during the day as both sexes preferred greater depths. Some adults and copepodids which showed no DVM, rested in deeper layers at night, the females of which were observed to be smaller in size (Beckmann 1984; Al-Najjar and El-Sherbiny 2008) and some calanoid copepodids like *Mecynocera clausi* and *Ctenocalanus vanus* showed significant intraspecific variations in their lipid contents within a depth difference of 12–15 m (Zarubin et al. 2014).

The density of zooplankton is displayed as two peaks in the central Red Sea, one within the upper epipelagic zone, above the thermocline, and the other peak in the oxygen minimum layer, from 300 to 600 m depth, which are characterized by distinct interzonal calanoid species, having strong affinities for specific habitat zones that exist vertically throughout the year and are less pronounced to the south (Beckmann 1984; Böttger-Schnack 1990a). Temperature plays an important role in the prevailing seasonality in the Gulf of Aqaba (Goldman and Heron 1983; Reiss and Hottinger 1984), resulting in a homogeneous distribution throughout the deep vertical mixed layer in late winter, wherein the copepod community shows no differences within the mixed layer, but during other seasons the majority of the zooplankton is concentrated within the upper 100 m (Cornils et al. 2005). Temperature increases the growth and feeding rates of zooplankton species within the range of their thermal tolerance (Omori and Ikeda 1984). When the fluctuations are stronger than in any other subtropical seas, the zooplankton abundance may be related not only to water temperature but also indirectly to their food items (Arnemo 1965), that is, during summer, the water column is stratified and the surface layers are depleted of nutrients (Reiss and Hottinger 1984). This seasonal pattern of mixing and stratification has an indirect influence on copepods via controlling the nutrient and light regime for phytoplankton.

Copepods are often considered to migrate vertically to feed, and their intensity of diel vertical migration (DVM) changes with food density, for example, no migration during food scarcity, to maximum migration at intermediate food levels, and reduced migration again at high food densities (Fiksen and Giske 1995). This DVM is also considered to be a predator avoidance strategy (Lampert 1989), but observations of vertical migration in waters without fish (Williamson et al. 2001) indicate that there are other adaptive benefits of this behaviour. A pronounced vertical gradient under predation pressure in the ocean leads planktonic animals to select their vertical gradient habitats to minimize mortality risk or energy gain incorporating light- and size- dependent vulnerability to visual predators (De Robertis 2002). A constant photokinetic stimulus of low light intensities is needed for copepod migration, that is, within the optimum zone, copepods move slowly, whereas above and below this light intensity the copepod movement increases (Cushing 1955). Thus, negative geotactic movements are induced by fading light intensities, whereas strong illumination or increased light causes positive geotactic movements inducing downward migration.

In general, Copepoda show no significant diurnal migration, except for the upper water layers around noon

(Schmidt 1973; Almeida Prado-Por 1990; El-Serehy et al. 2013). The concentration gradient within the epipelagic zone for the smaller cyclopoids is less pronounced and their vertical distribution revealed their dominance in the deeper layers (Böttger 1987). Higher species diversity of cyclopoids was observed in the lower epipelagic zone, that is, from 40 to 100 m, which is below the strong seasonal thermocline, whereas lower species diversity was observed in the upper part of the upper mesopelagic zone (100–250 m) characterized by a strong dissolved oxygen gradient, showing distinct distributional patterns among sexes and developmental stages (Böttger-Schnack 1990a). *Paroithona* sp. dominated in the epipelagic zone of the central Red Sea during winter 1981, while *Oithona simplex* dominated in the central and northern Red Sea during autumn 1980. In the upper 250 m depth, cyclopoids experienced clear seasonal changes in abundance, species diversity, and vertical distribution with greater species numbers in winter than in autumn (Böttger-Schnack 1990b). In the upper mesopelagic (*oxycline* zone: 100–250 m depth), *Paroithona* sp. dominated at all stations and seasons, against the dominance of *Oncaea tregoubovi* and *On. ovalis*, forming together more than 52% of total cyclopoids in the oxygen minimum layer (250–450 m depth).

In autumn, cyclopoids displayed similar diversity in both the northern and central Red Sea, except for three species (*On. media f. major*, *Sapphirina auronitens-sinuicauda*, and *S. opalina*), which were restricted to winter in the central Red Sea. However, the mean abundance of most cyclopoid species in the upper 450 m of the northern Red Sea is one third lower than those in the central Red Sea area (Böttger-Schnack 1990b). The upper mesopelagic zone (100–250 m) is characterized by strong oxygen gradients having numerous *Paroithona* sp. and *On. zernovi*, whereas in the lower part of the upper mesopelagic zone (250–450 m), the relative abundances of very small *Oncaea* species (<0.4 mm long) strongly increased. Two species, *Paroithona* sp. and *Corycaeus* (*Agetus*) *limbatus*, were significantly higher in abundance in the northern area, showing their regional adaption to the environmental conditions in the northern Red Sea (Böttger-Schnack et al. 1989), whereas *Oithona simplex* decreased significantly in abundance during autumn, showing that they are not adaptable. The deep living population of *On. mediterranea* and *Lubbockia squillimana* showed a downward shift by about 100 m in the northern area (Böttger-Schnack et al. 1989; Khalil and Abd El-Rahman 1997). However, the vertical distance of diurnally migrating species in the Red Sea was found to be quite small, in the range of 50–100 m or less, and an even smaller habitat zone or short distance migration of 30–50 m among cyclopoid species reveals that their community structure remains fairly constant during the day and night in the three major ecological zones in the Red Sea (Tsalkina 1977; Sameoto 1986). However, the DVM of oncaeids indicates considerable differences between the Red Sea basin and Gulf communities, which can be related to different hydrographic conditions (Böttger-Schnack et al. 2001).

The northern migration of the epipelagic mesozooplankton species around the Sharm El Sheikh area, northern Red Sea, from the southern Red Sea implies marked seasonal variations in their vertical distribution (El-Sherbiny et al. 2007; Dorgham et al. 2012). In general, the environmental parameters, such as temperature, dissolved oxygen and salinity, along with light intensity can influence the profile of zooplankton vertical distribution (Ringelberg 1995). Thus, in the tropical waters where the depth is shallow, both the thermal stratification and force of upwelling may not be strong enough to limit the DVM of copepods. A combination of multiple biotic and abiotic factors, such as food abundance and prey distribution, predation pressure, hydrographical heterogeneities, turbidity, sunlight and UV may synergistically influence the DVM of copepods, leading to the occurrence of different species and stages of the same species preferring differential depth zones and performing various patterns of diurnal distributions.

Near-Reef Copepods

On the coral reef ecosystem, the role of copepods is less significant (but more complex) as compared to the open ocean (Yahel et al. 2005; Pearman et al. 2014), where they play a major role in the food chain as they are considered to be a food source for planktivorous corals and coral-associated fauna. Conversely, many copepod species feed on the suspended mucus released by corals and other benthic dwelling fauna (Richman et al. 1975), rich in organic debris, bacteria and other microplankton. The near-reef zooplankton are not well studied all over the world, which might be due to the unsuitability of the applied sampling techniques (e.g., Sale et al. 1978; Echelman and Fishelson 1990). Very few studies have assessed the zooplankton diversity in both offshore and near-reef regions. The copepod diversity appeared to be higher in near-reef than offshore collections in the Gulf of Aqaba (Echelman and Fishelson 1990), and their productivity is also higher in reef-bound coastal zone areas of the whole Red Sea compared with that of offshore areas (Levanon-Spanier et al. 1979). The near-bottom zooplankton depletion in coral reefs may be due to intense predation by piscivorous fish, which restrict these zooplankton, especially copepods, from deviating from an ideal free distribution (Motro et al. 2005). Coral reef zooplanktivores of the Gulf of Aqaba preferred almost 26 species of copepods, while there were observed to be around 48 copepod species from the coral reef stations of Hibika and Abu Galum (El-Serehy and Abd El-Rahman 2004).

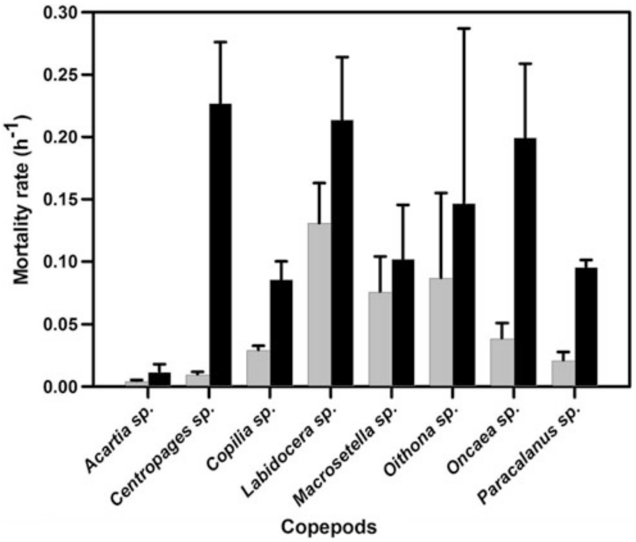

Fig. 25.1 Mean mortality rates of zooplankton taxa incubated under the entire solar radiation spectrum (grey bars), receiving UV-B doses comparable to those at 3.7 m depth in situ, and when UV-B was reduced but PAR was allowed (black bars). Mortality rates calculated based on survival from an initial set of 20 animals per replicate in each of three replicated containers for each treatment (modified from Al-Aidaroos et al. 2014)

Near reef copepods in the northern Gulf of Aqaba accounted for about 65% of the zooplankton (Holzman et al. 2005), but are completely absent in the deepest layer (1.5 m over the bottom) within a depth of 8–14 m in reef regions (Yahel et al. 2005; Holzman et al. 2005). Such a vertical gradient in near reef zooplankton distribution may be attributed to high consumption of zooplankton by corals, other benthos and planktivorous fishes and bottom avoidance by more strongly swimming zooplankton (Holzman et al. 2005), as coral reef zooplankton are capable of swimming effectively against upwelling and downwelling currents (Genin et al. 2005). The dominance of dead copepods with little or no internal tissues near the coral reef of Aqaba constitutes about 22 and 65.5% of total copepod counts in the offshore and near-reef areas, where it was reported by Genin et al. (1995) that there were post-settling fish larvae and crinoids egested copepod exoskeletons in good condition, showing a clear correlation with live zooplankton abundance, suggesting heavy predation. Moreover, an exposed reef south of Ras Abu Shagara, at Shaab Baraja, Sudan, was also observed to have higher zooplankton biomass and species diversity during the night than in the daytime (Karbe 1980). The zooplankton community associated with the coral reefs on the Saudi Arabian coast of the southern Red Sea was more evenly distributed than the phytoplankton community, where the developmental stages and adults of smaller copepods like *Acrocalanus gibber*, *Paracalanus parvus*, *P. crassirostris*, *Oithona nana* and *Oncaea media* dominated at night. In the central Red Sea, the coral reef zooplankton was composed mainly of the larger copepods such as *Centropages elongatus*, *Oi. setigera* and *Lucicutia flavicornis* compared to Indian Ocean species (Kürten et al. 2015).

Impact of Ultraviolet Radiation on Copepods

The Red Sea zooplankton being highly vulnerable to ultraviolet radiation, the copepod species, for example, *Acartia* sp., *Centropages* sp., *Copilia* sp., *Labidocera* sp., *Macrosetella* sp., *Oithona* sp., *Oncaea* sp. and *Paracalanus* sp. exhibited a steep increase in mortality with ambient levels of solar radiation (Figs. 25.1 and 25.2) (Al-Aidaroos et al. 2014). They determined that the maximum mortality rates of these copepods under ambient solar radiation levels averaged a five-fold increase over the average mortality in the dark, which is equivalent to a UV-B dose at 19.2 ± 2.7 m depth in the open coastal Red Sea waters (Al-Aidaroos et al. 2014, 2015). Penetration of this harmful UV-B radiation in highly transparent waters of the Red Sea in the upper epipelagic zone (∼20 m depth) may lead to severe food scarcity by limiting the energy transfer (Al-Aidaroos et al. 2015), creating a direct stress on marine zooplankton communities in tropical oligotrophic waters by affecting the efficiency of food transfer up the food web. For example, copepods, like *Acartia* sp. and *Oncaea* sp., are capable of producing mycosporin-like amino acids in response to the synergistic effect of UV-B and temperature (Al-Aidaroos et al., unpublished data), while a distinct decline in the neustonic copepod abundance was observed by Mojib et al. (2017) in the central Red Sea during July as compared to April and October, which may be due to the mortality of neustonic copepods via the stress produced by the UV-B radiation.

Symbiotic and Parasitic Copepods

Red Sea coral reefs hosts a rich faunal diversity along the 2000 km of the coastline (Lieske and Myers 2004), although very little is known about the symbiotic copepods. Until now, around 340 copepod species have been identified from other parts of the world (Dojiri 1988; Kim and Yamashiro 2007). These parasitic copepods represent the enormous diversity of coral-feeding invertebrates (Stella et al. 2011), with about 199 parasitic species recorded among the 243 species of the known copepod associates (either as facultative or obligate) with live corals. It was observed that the causative agent for tubular outgrowth or galls in *Stylophora* sp. is due to the copepod *Spanimolgus* sp. (Ivanenko et al. 2014). Along Obhur Creek, central Red Sea, Saudi Arabia, symbiotic copepods attained a high diversity and abundance from scleractinian coral genera, for example, *Pocillopora* sp., followed by *Acropora* sp., *Stylophora* sp., *Favia* sp. and

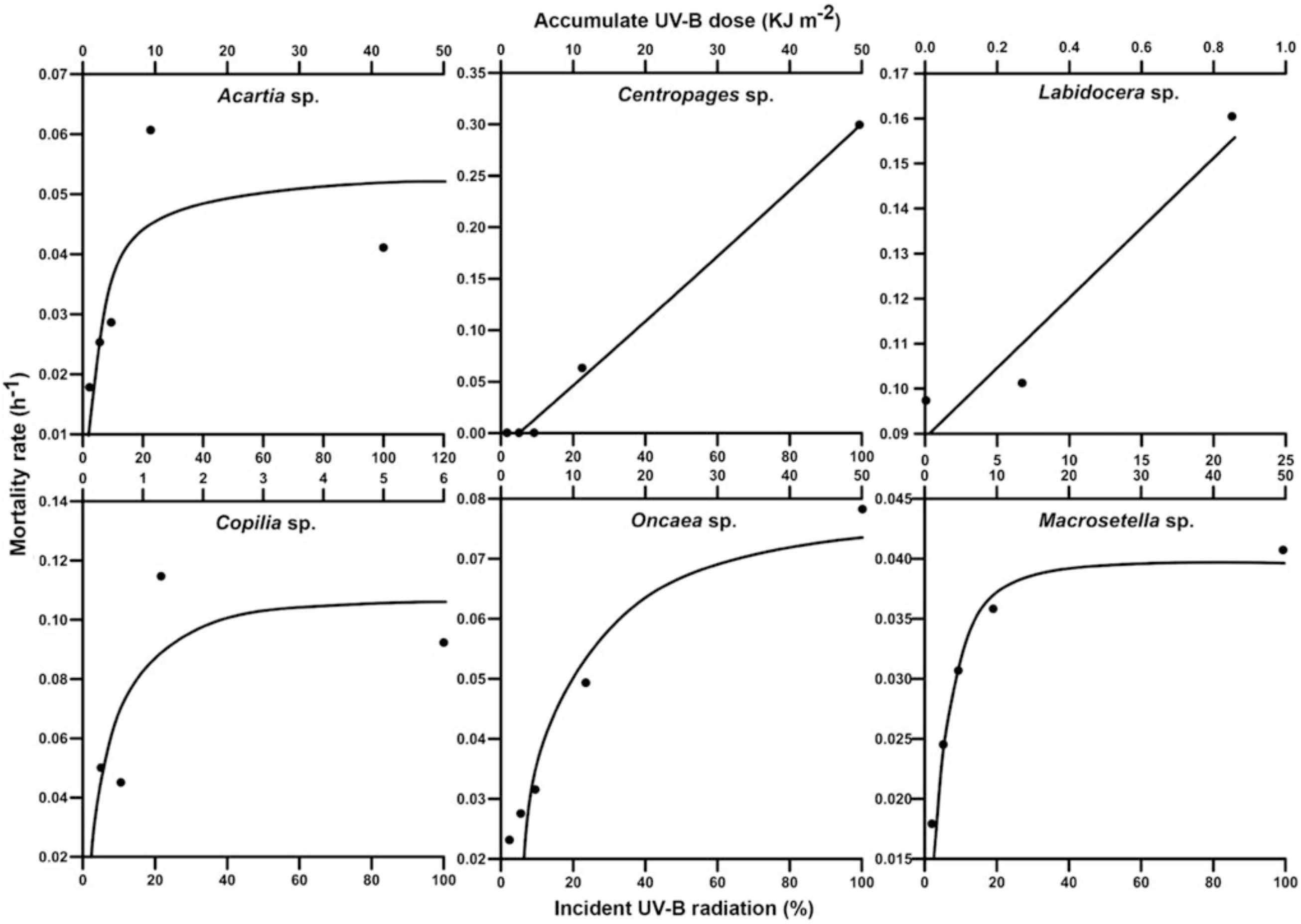

Fig. 25.2 Dose-response curves describing the relationship between the mortality of zooplankton taxa and ambient UV-B levels (as % of UV-B incident below the surface or accumulated UV-B radiation along the experiments). The solid lines show the fitted linear regression of the Michaelis-Menten equation. Catastrophic mortality at 100% UV-B radiation incident below the surface for *Labidocera* precluded resolving m_{max} (modified from Al-Aidaroos et al. 2014)

Fungia sp. (unpublished data) (Fig. 25.3). Parasitic copepods on the Red Sea fishes have also drawn little attention. Two new species of copepods were reported from immigrant rabbitfish (El-Rashidy and Boxshall 2011) and one from immigrant dragonet fish (El-Rashidy and Boxshall 2012). Parasitic Bomolochid copepods from Egyptian Red Sea fishes were reported by El-Rashidy and Boxshall (2016). The Red Sea being rich in coral and its associated faunal diversity (fishes and invertebrates), the associated or symbiotic copepod fauna needs to be identified and studied for their diversity, biology and ecology.

Future Studies

Although copepods are highly diversified and widely distributed in the Red Sea, their ecology and biology has been poorly studied (Dorgham et al. 2012; Pearman et al. 2014; Al-Aidaroos et al. 2016a). The knowledge about symbiotic or parasitic copepods in or on coral reefs, seagrasses and other aquatic organisms is completely lacking within the purview of the Red Sea waters. The process of spatial and vertical distribution, migration, colonization and invasions from Gulf of Aden and Gulf of Suez, and the change in environmental parameters have brought about variations in the actual Red Sea copepod biodiversity, which has been always changing (both physically and biologically). As in most other marine ecosystems, the Red Sea also suffers from human-mediated disturbances, and climate change, which may severely affect the natural balance of planktonic communities. Therefore, further research on different aspects of copepods such as pelagic and benthic interactions, vertical migration, deep-sea, meiobenthic and symbiotic copepods, the effect of pollution on copepods, time-series seasonal and vertical studies, etc., is necessary to elucidate the distribution, biology and ecology of this most dominant and abundant planktonic group. Novel, traditional

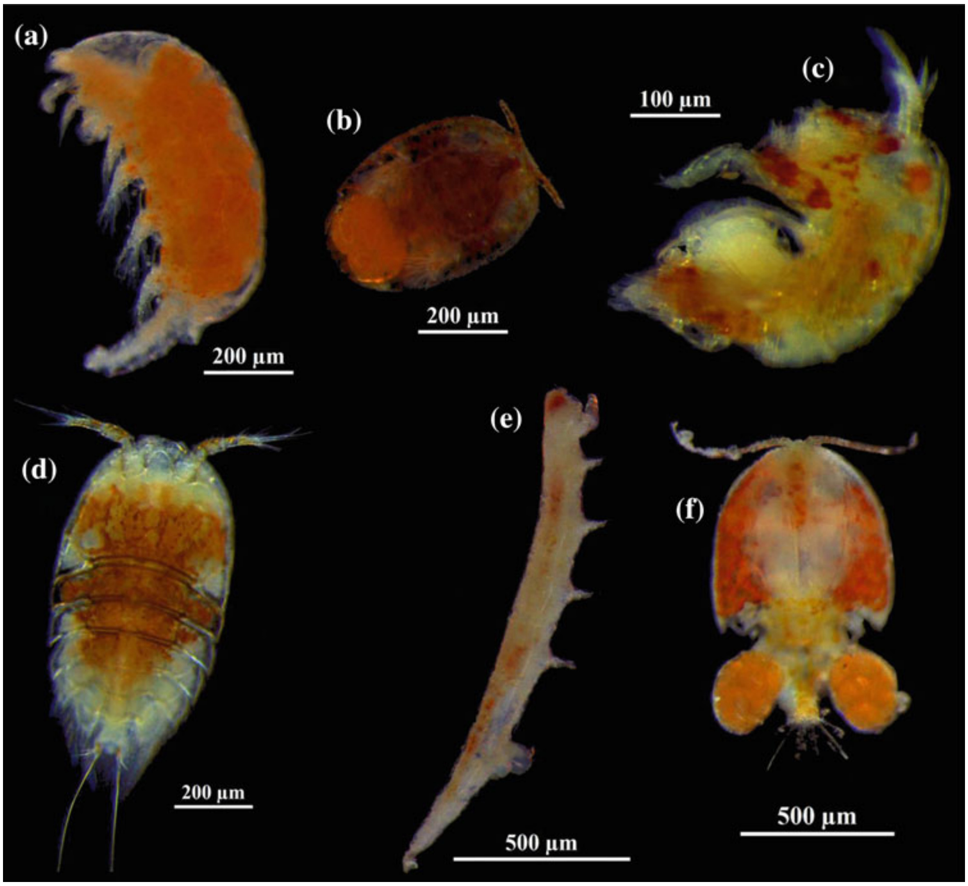

Fig. 25.3 Symbiotic copepod families on Red Sea corals. **a** Notodelphidae, **b** and **d** Peltidiidae, **c** Tegastidae, **e** Xarifiidae, **f** Cletodidae

and molecular approaches should be carried out to elucidate the actual diversity and ecology of copepods to enable large-scale management protocols for sustaining the Red Sea ecosystem.

Aquaculture along the coastal belt of the Red Sea is a major industrial sector which provides a variety of seafood for domestic and international consumers. Since culture of marine organisms needs a constant and prominent supply of larval foods or live foods, copepods are being used in hatcheries in other parts of the world, which provide an excellent larval food for all aquaculture species as they have six naupliar and six copepodid developmental stages, with varying size that suits many cultured marine organisms and their larvae. Since monospecific harvest of planktonic copepods from the wild is laborious and economically not viable, their indoor or outdoor culture is being carried out in many parts of the world, where the orders Calanoida, Cyclopoida and Harpacticoida play an unequivocal role in the production of aquaculture species. Considering the time and its laborious nature involved, very few marine copepod species are presently being cultured and maintained as stock cultures in different laboratories of the world, such as the calanoids (*Acartia grani*, *A. sinjensis*, *A. southwelli*, *A. tonsa*, *Centropages typicus*, *Eurytemora affinis*, *Pseudodiaptomus annandalei*, *Temora longicornis* and *T. stylifera*), the cyclopoids (*Apocyclops royi* and *Oithona davisae*) and harpacticoids (*Ameira parvula, Amonardia normani, Amphiscoides atopus, Euterpina acutifrons* and *Tachidius disciples*) (Drillet and Gael 2007–2009). Thus, by adopting different standardized techniques, indigenous Red Sea copepods can be cultured on a mass scale to sustain the larval rearing of marine organisms in the aquaculture industry, thereby promoting employment in the region.

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