

## Free-living copepods of the Arabian Sea: Distributions and research perspectives

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Received 5 December 1997; revised 29 January 1999

The subclass Copepoda consists of 10 orders and exhibit great diversity in morphology as well as the habitats they occupy. Within the orders themselves, there are sometimes overlaps—some are free living or could be parasitic. There are approximately 11500 known species in this subclass. This paper briefly outlines the distribution, abundances and general feeding habitats of free-living copepods from the Arabian Sea. The role of taxonomy in biodiversity studies, estimates of grazing and production rates of copepods, diapause and carbon fluxes through vertical migration and defecation are some problems which need to be addressed from this region.

The members of the subclass Copepoda Milne-Edwards 1840 (Superclass Crustacea Pennant 1777) are one of the most abundant among zooplankton groups. They are the most plentiful multicellular animals on earth, outnumbering insects, which has more species but fewer individuals<sup>1,2</sup>. It consists of 10 orders viz. Calanoida, Harpacticoida, Cyclopoida, Poecilostomatoida, Siphonostomatoida, Monstrilloida, Misophrioida, Mormonilloida, Platycopioidea and Gelyelloida<sup>3-5</sup>. They are diverse, occurring in marine, estuarine and freshwater areas. They also live in interstitial, subterranean and deep-sea hydrothermal vent habitats (Table 1).

The antiquity of modern copepods date back to the Cretaceous and beyond<sup>6</sup>. At present there are approximately 11500 known species of copepods belonging to 198 families and 1600 genera<sup>2</sup>. About one-third of marine copepod species are parasites or associated with invertebrate hosts. They mainly belong to the orders Monstrilloida, Poecilostomatoida and Siphonostomatoida and may have a partial planktonic life. Species belonging to the families Calanoida, Platycopioidea, Gelyelloida, Mormonilloida, Misophrioida, Harpacticoida and Cyclopoida are free-living although the last two contain a few parasitic species as well<sup>5</sup> (similarly Poecilostomatoida has some free-living species as well).

From an economic point of view, copepods are

important in fisheries (as food), maintaining regenerated primary production, carbon flux and mosquito control. This paper will address the distribution of free-living copepods from the Arabian Sea and adjacent areas. Some of the future research problems are also briefly discussed.

### Distribution and abundance

*Poecilostomatoida*—This order although predominantly parasitic, have five families (Corycaeida, Oncaeidae, Paralubbokiidae, Sapphrinidae and Urocopiidae) which are free-living. They are common in the Arabian Sea<sup>7</sup> and may account up to 40% of the total copepods in the upper 2000 m water column. Many new or unrecorded species were overlooked earlier because of the larger mesh size usually employed to collect zooplankton and also due to paucity of deep-water sampling. Bottger-Schnack<sup>7</sup> found nearly 70 species from the family Oncaeidae alone from the Arabian Sea as compared to earlier listings of 4-5 species. Poecilostomatoida are ubiquitous in coastal and offshore waters and the free-living forms appear to be carnivorous.

*Cyclopoida*—Cyclopoids are common in marine and estuarine waters and are often dominant in freshwater habitat. In the Arabian Sea they may sometime form up to 20% of the copepods in surface layers<sup>7,8</sup> and are generally considered as carnivores<sup>9</sup>. The order consists of 7 families and about 500 species<sup>10</sup> of which the families Cyclopididae (mostly freshwater), Cycloipinidae (coastal) and Oithoindae

Table 1—Evolutionary diversity in some orders of Copepoda<sup>5</sup>. Names of some of the orders are abbreviated.

	Calanoida	Harpacticoida	Misosphrioda	Monstriloida	Cyclopoida	Poecilostom	Siphonostom
<i>Habitat</i>							
Marine	P	P	P	P	P	P	P
Freshwater	R	P	A	A	P	R	P
Interstitial	A	P	A	A	P	A	A
Subterranean	R	P	P	A	P	A	A
Pelagic	P	R	P	P	P	A	R
Free-living	P	P	P	A	P	A	A
Parasitic or associated	A	R	A	P	R	P	P
Hyperparasitic	A	A	A	A	A	P	P
Drought-resistant eggs	A	P	A	A	P	A	A
Dee- sea+vent	R	P	P	A	R	P	P
<i>Adaptations to special life cycle</i>							
Pigmy males, parasitic on females	A	A	A	A	A	P	P
Great sexual dimorphism	A	A	A	P	A	P	P
Great range in body size of females	A	A	A	A	R	R	P
Using intermediate host	A	A	A	P	A	R	P
More than 1 type of male	A	A	A	A	P	A	A
Only 1 ovisac	A	P	A	A	P	P	P
Totals	3P 3R	8P 2R	5P	5P	9P 3R	7P 3R	10P 1R

A = Absent in the group, P = Present in the group, R = Rare in the group

(coastal and oceanic) are free living. In the Arabian Sea, the genera *Oithona* and *Paraoithona* are common<sup>7</sup>. The species *O. oculata* seems to be confined to the atolls of the Lakshdweep<sup>8</sup> and is associated with coral reefs elsewhere in the world as well.

*Harpacticoida*—Members of this order occupy diverse niches (interstitial, epibenthic, subterranean, deep-sea vent) and a few are pelagic or parasitic<sup>5</sup>. They also have ranges from marine to freshwater and the most abundant forms are associated with sediments. In the pelagics of the Arabian Sea, their numbers are usually low<sup>11</sup>, but may form up to 6% of copepod populations<sup>12</sup>. Haridas & Rao<sup>13</sup> listed five genera (*Macrosetella*, *Microsetella*, *Miracia*, *Clytemnestra* and *Aegisthus*) to be common in the epipelagic Arabian Sea. In addition, the genera *Longipedia*, *Euterpina*, *Metis* and *Distiocus* also occur in surface layers while *Bathyidia* and *Tisbe* occupy the bathypelagic zone<sup>7</sup>. The inbenthic harpacticoids from this region need further attention.

*Calanoida*—Calanoids are arguably the most common and abundant planktonic copepods anywhere in the world oceans and also in estuarine and freshwater habitats. It consists of 11 superfamilies and 38 families<sup>14</sup>. The family Diaptomidae are

exclusively freshwater whereas Acartiidae and Pseudodiaptomidae are generally specialists in estuarine environment. Madhupratap & Haridas<sup>15</sup> lists 198 species of calanoids from the epipelagic realms of the northern Indian Ocean. Some more are epibenthic forms. Most of them are herbivores although a few genera like *Euchaeta* and *Labidocera* are carnivores. The latter genus seems to be specially adapted to a neustonic life. From the western Indian Ocean information on bathypelagic calanoids is confined to a single study<sup>16</sup>. The study identified 310 species with one new genus, 17 new species, 8 previously unknown males and 1 previously unknown female with 78 new records from the Indian Ocean.

*Misosphrioda*—There does not seem to be any information on this order from the Arabian Sea. This group is believed to have originated in deep-sea hyperbenthic habitat and radiated to colonise shallow neritic waters and bathypelagic zone of the ocean<sup>17</sup>. It consists of a single family Misosphriidae.

*Platycopioida*—This order is also represented only by one family (Platycopiidae) and three genera and one of them is found in hyperbenthic environment in shallow neritic waters<sup>17</sup>. The other two inhabit anchialine caves. There is no record of this order from the Arabian Sea.

*Gelyelloida*—This consists of two congeneric species (family Gelyellidae) and is a freshwater inhabitant of subterranean water in Europe<sup>17</sup>.

*Mormonilloida*—The genus *Mormonilla* consists of two species viz. *minor* and *phasma* and both occur in the mesopelagic depths of the Arabian Sea. The adult male of this genus, probably a non-feeding stage, was discovered only recently<sup>18</sup>.

### Research problems

From a taxonomical point, copepods of the epipelagic habitat of the Arabian Sea and adjacent waters seem to be well studied, but the meso and bathypelagic residents are poorly understood. The latter is also applicable to the epi or hyper benthic habitats from where quite a number of new species have been recently described, from elsewhere in the world. From an ecological point of view also epibenthic forms are important since it was recently demonstrated<sup>19</sup> that zooplankton (mainly harpacticoids) densities may exceed 100,000 organisms/m<sup>2</sup> in the sandy bottoms of the lagoons of the Lakshadweep and 80% migrate into the water column at night. The role of taxonomy as a tool in biodiversity studies is also evident when we consider that 37% of species of copepods were described in the last 30 years which is nearly two-third of all those described<sup>2</sup> in the previous 100 years.

Some gnawing problems with our zooplankton research, particularly from the tropics is that we know practically little about their life histories or feeding habits (grazing rates of copepods) and estimates of production rates. Studies on life histories are not only essential for taxonomy but also to understand behavioural aspects and adaptations. For example, a large number of copepods are known to produce resting eggs in the subtropic and temperate waters, which sink to the bottom in shallow estuarine and neritic waters and 'rest' when adverse conditions<sup>20</sup> set in. In the tropics also, salinity changes or drought may need such a life history strategy. The copepodite stages of the calanoid *Calanoides carinatus* are known to rest at mesopelagic depths in the western Arabian Sea (respiration fuelled by stored lipids) and surface during upwelling periods when food and temperature conditions are favourable<sup>21</sup>.

Studies on feeding gives us a clue in the energy transfer between trophic levels. Grazing by zooplankton often control phytoplankton community structure. Phytoplankton blooms in the Arabian Sea

may be maintained by inefficient or sloppy zooplankton feeding<sup>22</sup>. Recent studies<sup>23</sup> indicate that feeding on some diatoms may actually inhibit copepod fecundity or egg production. Estimates of egg production rates are also an indirect tool in calculating secondary production<sup>24</sup>. These rates will give us an insight to exploitable fishery. It is also known that many copepods feed on microzooplankton or even bacteria (microbial loop) and maintain the biomass during lean phytoplankton regimes<sup>25</sup>. The mechanisms of this paradox of the Arabian Sea<sup>25</sup> that mesozooplankton biomass in the mixed layer remains more or less constant despite varying phytoplankton regimes are yet to be quantified.

Other challenges which require attentions pertain to vertical distributions and carbon flux. In the Arabian Sea, the depths between 150 to 1000 m are almost anoxic. How are zooplankton vertical migrations affected by this? These mesopelagic depths, however, sustain a turnover of about 100 million tons/year of myctophid (lantern) fishes<sup>26</sup>. These fishes exclusively feed on zooplankton and we do not know how such a large biomass is sustained. They seem to be specially adapted to the low oxygen concentrations and this may be of evolutionary significance in escaping from predators. Copepods (zooplankton) abundance seem to be decrease sharply below the mixed layer<sup>11</sup>. The overall composition of copepods is more or less same throughout the year in the Arabian Sea and small filter feedings forms and carnivores dominate. We do not know how vertical migrations might affect carbon flux into the ocean interiors since many of these feed at surface layers in the night and migrate down during day time and produce faecal pellets.

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