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Biodiversity and diel variation of the benthohyponeuston: A case study of the Northeast Black Sea

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ABSTRACT

The neustal is a specific habitat of oceans, which significantly differs in abiotic parameters from the waters below. One of the most significant components of the coastal neustonic fauna is the benthohyponeuston migrating diurnally between benthic and neustonic realms. Data on this fauna are fragmentary and contradictory, partly due to lack of the criteria to distinguish benthohyponeuston from other benthopelagic animals diurnally migrating to the bulk water from the seafloor. We propose a criterion to quantify the degree of aggregation/avoidance of the neustal zone, reveal four distinct ecological groups and describe patterns of their overnight dynamics. Benthohyponeuston appears in open water at sunset, its biomass most rapidly increases one hour after sunset. Cumaceans, mysids and polychaetes make significant contribution during first three hours after sunset. Decapods are important around midnight and 3 h later. Amphipods are significant overnight. By analogy with the benthopelagic species, we define the benthohyponeuston as benthic animals, which are associated with the neustal zone at least at one stage of their life cycle. This association is necessary for reproduction, dispersal or feeding — that represent three basic pathways connecting neustonic and benthic/benthopelagic coastal communities below. The data on benthohyponeuston and patterns of its overnight dynamics will help in a better understanding of vertical migrations in the coastal zone and in estimating diurnal fluxes of organic matter.

1. Introduction

The neustal is the uppermost layer of the water column, a specific ocean habitat, located in the boundary between the hydrosphere and the atmosphere. This layer significantly differs in abiotic parameters from the waters below (Zaitsev and Liss, 1997; Liss et al., 2005). The upper 10-cm thick layer absorbs nearly half the total amount of solar radiation (Rutkovskaya, 1965), receiving the main bulk of the short-wave light energy (Blough, 1997). In the surface layer, diel temperature fluctuations are higher than in the water column below. The surface of seas and oceans is a collector of numerous particulate and dissolved materials originating from marine organisms, river runoff and atmospheric input. The neustal is also a zone of high concentration of numerous pollutants, such as benz[a]pyrenes, (Izrael and Tsyban, 1989), oil aggregates (Mamaev, 1984), plastic debris (Moret-Ferguson et al., 2010; Collignon et al., 2012). These concentrations are especially high in the inland European seas such as the Black Sea.

Naumann (1917) was first to propose a term 'neuston' for the surface skin layer of a pond. Later, Zaitsev (1971) extended this term to the sea but the definition of the neustal zone is somewhat dependent on the gear which researchers use. Zaitsev (1961, 1963; 1971 and Zakutsky (1965a; 1965b; 1965c) defined the neustal as a layer 5-cm thick. Later authors (Macquart-Moulin, 1968, 1972; Holdway and Maddock, 1983; Tully and Ceidigh, 1987) defined the neustal as a layer 10 cm thick and used a gear of respective height. We join the later authors in

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order to make results more easily comparable and the neustonic database more consistent.

Analysis of this specific habitat revealed significant differences in composition between neustonic and deeper water communities (Hattori et al., 1983; Holdway and Maddock, 1983). Numerous comprehensive studies showed that the neustal zone contains an endemic fauna including insects (Herring, 1961; Cheng, 1985), mollusks (Laursen, 1953), copepods (Voronina, 1962; Matsuo and Marumo, 1982; Sherman, 1963, 1964; Geinrikh, 1969; Jeong et al., 2009), decapod larvae (Zeng and Naylor, 1996; Queiroga and Blanton, 2004), fish eggs, larvae, and juveniles (Doyle, 1992; Leal et al., 2010). Further studies focused on the whole zooplankton assemblage and the factors influencing composition, biogeography and dynamics of these assemblages (Hempel and Weikert, 1972; Weikert, 1982; Holdway and Maddock, 1983).

All these studies showed enrichment of the neustonic fauna in the open tropical ocean and its sparse representation in the Mediterranean Sea, and inland seas of the East Atlantic (Holdway and Maddock, 1983). Detailed overnight observations in the Mediterranean showed that neustonic animal diversity was lower during daylight hours (Campalbert 1969, 1971; Champalbert and Macquart-Moulin, 1970), whilst at night a rich fauna from subsurface waters and the seabed ascended to the surface (Macquart-Moulin, 1968, 1972, 1973; 1984, 1985; Macquart-Moulin and Maycas, 1995). A similar fauna was also recorded in the Black, Azov, and Caspian Seas (Zaitsev, 1961, 1963; 1971; Zakutsky, 1965a; 1965b, 1965c). The fauna migrating diely between benthic and neustonic realms was called 'benthohyponeuston'. Further we will follow this term taking into account that benthohyponeuston is a part of wider ecological group migrating between benthic and pelagic realms and called benthopelagic (Marshall and Merrett, 1977; Vereshchaka, 1995, 2000). Benthohyponeuston includes those benthopelagic animals, which concentrate near the surface, not in the bulk water below. Benthohyponeustonic animals occur above shallow areas (continental shelves and seamounts) where their diel migrations is comparable to depth (this does not preclude occurrence above greater depths due to horizontal advection).

In contrast to the other benthopelagic animals, the presence of the true benthohyponeuston in the surface layer should be a necessary event at their life cycles (mating, dispersal, growth, feeding). In order to detect a benthohyponeustonic species, we must accurately investigate life cycles with use of experimental methods or analyze distribution in the neustal zone and in the bulk water (water column below) and prove that the species aggregates in the neustal zone. This is a more tentative method but provides much faster output, provided we understand what is the adaptive significance of the species aggregation in the neustal zone.

The main problem of existing data is the absence of quantitative criteria, describing the degree of species aggregation in the neustal zone. The second problem is a low temporal resolution in sampling the neustonic layer (2–4 times overnight). Addition problems for the Black, Azov, and Caspian Seas neustonic data are the absence of data on the water column below. It remains unclear, whether those species numerous in the neustal zone (1) are aggregated here near the surface and rare in the bulk water thus representing the true benthohyponeuston or (2) they are vagrants of even much more abundant benthopelagic animals in the bulk water below. In order to solve this problem, we sampled both the surface water and the bulk water below simultaneously and compare the concentration of animals in both pairs of samples overnight.

Here we (1) propose a criterion based on respective concentration of animals in the neustal zone and in the bulk water below and test it, (2) analyze samples of major taxa taken with relatively high temporal resolution 10–14 samples between sunset and sunrise. In order to put results in a wider context, we start with general information describing input of benthopelagic animals in the neustonic communities in terms of total biomass as well as species composition and structure of neustonic communities and the overnight dynamics in the Black Sea. We also tried to obtain data under various light conditions at different moon phases.

2. Material and methods

Samples were taken at the northeast coast of the Black Sea in the Golubaja ('Blue') Bay near Novorossijsk (Fig. 1) between 7 and 10 m depth. This site was characterized by typical environmental parameters for the northeast coast of the Black Sea (Lebedeva et al., 2003; Vinogradov et al., 2005; Vereshchaka and Anokhina, 2014). The local seafloor harboring benthohyponeustonic animals by day is covered with sand interspersed with scattered rocks and algae dominated by *Cystoseira barbata* C.Agardh, 1820.

We took four overnight stations to determine the dynamics of the benthopelagic animals (precision 1–2 h) at four main lunar phases: the new moon, the full moon, and two crescents (Table 1). Stations were taken in the late summer-autumn when the benthopelagic biodiversity at the site was the highest (Vereshchaka and Anokhina, 2014). During all stations, water and air temperature were similar, sky clear, no waves (and no tides in the Black Sea). During the new moon (starlight clear moonless night sky) and crescents, surface illumination varied from 0.001 to 0.01 lux, while at the full moon nighttime luminance levels were significantly higher, 0.25 lux. Therefore, we put the new moon and crescent observations into the 'dark night' dataset and consider them separately from the full moon dataset.

We took two sets of samples: in the water column (from the surface to the near-bottom layer) and in the neustal zone (upper 10 cm). Water column stations were taken at a distance of 170 m from the coast with a Judey net (mouth area 0.1 m^2, mesh size 180 μm), towed at 50 cm s^{-1} from 6.5 m depth to the surface. At the same site and concurrently we took neustonic stations with neustonic net (frame 10 × 65 cm, mesh size same as in Judey net). The net was towed for a distance of 10 m along the sea surface filtering a volume of water equal to that of the Judey net. All samples were accompanied by measurements of surface temperature with Shpindler thermometer and meteorological data. A total of 48 bulk water and 48 simultaneous neustonic samples were taken.

Samples were preserved in 4% seawater-formaldehyde solution and identified to species level using a stereomicroscope. Species were identified with use of Mordukhai-Boltovskoi (1968, 1969; 1972), recent taxonomy was checked with the Word Register of Marine Species (http://www.marinespecies.org). For each taxon, the numbers of specimens in the sample and individual sizes (length) with the precision of 0.1 mm were recorded. On the basis of this primary dataset the individual weights, species abundance and biomass, and the total abundance and biomass were calculated with use of the Plankton samples treatment program PLANKTY (Dyakonov 2002). When abundances and biomass (individuals and wet weight per m^3) were calculated, the filtration coefficient was assumed to be 1.0.

To quantify the degree of association with the neustal, we used a parameter $L = \log (N_1/N_2)$, where N_1 and N_2 are simultaneous abundances of the identified unit (sex/age stage, species, major taxa) in the neustal zone and in the bulk water, respectively. If L ~0, the group is evenly distributed in both zones. If L significantly differs from 0, the group prefers either the neustal zone (L positive) the bulk water (L negative). In order to show distance between L and zero, we used 95% confidence intervals. To examine the possible correlation between L and other parameters, we used the Pearson product-moment correlation coefficient.