

REVIEW ARTICLE

A key role of sandy beaches in the marine environment

Yuvenaly Zaitsev*

Odessa Branch of the Institute of Biology of Southern Seas of the National Academy of Sciences of Ukraine, 65011, Odessa, UKRAINE

*Corresponding author: yu.zaitsev@paco.net

Abstract

The well-known scientist V.I. Vernadsky met forth the concept of concentration of living matter at the outer boundaries of the ocean: sea surface, sea floor and, particularly, coastline where the former two boundaries meet. But in spite of environmental importance and accessibility for investigations, contour marine biotopes, in particular, the sandy beaches (psammocontour), remain to date much less studied than the open marine areas. Results of first task-oriented integrated investigations in the Black Sea confirm the ecological exceptionality of sandy beaches for the marine ecosystem, and point out information gaps which need further research in this promising line in marine ecology. Exceptional high concentration of organisms and detritus in sandy beaches is the main reason of littoral concentration of life. Fry and juvenile of about 90 species of the Black Sea fish are feeding just in the water line area up to the depth 2-3 m, where the interstitial water enriched with microorganisms and detritus is seeping from the sandy beaches. This is a typical ecological “hot spot”, a key biotope of great scientific and practical interest.

Keywords: Black Sea, sandy beach, psammocontour, interstitial organisms, ecological hot spots

Introduction

Among marine contour biotopes (Zaitsev 1986), the psmmocontour is perhaps the most familiar. According to the widespread opinion, the marine sandy beaches are the most open and coherent parts of the sea, the so well known rim of sand. But this is a rather superficial and poetic assessment. In fact, this biotope is an area of complicate physical, chemical and biological processes having a great environmental importance. Thus, sandy beaches are the greatest area of natural mechanochemistry and heterogenous catalysis reactions in the World Ocean (Aizatulin *et al.*1979). Their biological consequences are not yet elucidated. Geologically, the sandy beach is an unconsolidated aggregation of grains of different size, and mineralogical nature (mainly quartz). The factors which affect the porosity of the beach are complex and depend upon grain size,

grain shapes, method of deposition and the subsequent processes of compaction solidification. (Perkins 1974).

The passage of water through a sandy beach, i.e. the degree of drainage, depends upon porosity, permeability, compactness and capillarity. However, the amount of interstitial, or pore water present is affected by many additional factors. In non-tidal beaches of the Black Sea and the Mediterranean Sea wave action makes an important contribution to the amount and drainage of pore water. Each surface wave generated by the wind contains a significant amount of kinetic energy, which is converted in the sandy beach capillary filling with marine water, dissolved and suspended particles including detritus and microorganisms. In normal ecological conditions, this process leads to the accumulation of matter and energy in the splash and spray zones of sandy beaches and is the reason of development here of a great variety and number of interstitial organisms (Zaitsev 2008a).

Results

The life conditions in the interstices between sand particles are quite comfortable for aerobic organisms. It was an unfortunate misconception that light does not penetrate soil. For maximum photosynthetic activity, sediment dwelling-littoral diatoms require only 12 /cal/cm²/hr; on a cloudless noon in midsummer, the compensation depth is probably greater than 3,0 m, while at 2,0 m depth a photosynthetic efficiency of $\geq 90\%$ is attained (Perkins 1974). The salinity of pore waters represents an equilibrium between that of the sea water at the time of coverage, and fresh water seeping out from the land. But this basic system is subject to modification by many factors. Relatively large amounts of plant nutrients (phosphates, nitrates, sulphates and iron), presents in the sandy beach pore water, led to the conclusion that this biotope could be classified as extremely eutrophic (Perkins 1974).

First purposeful integrated investigations of ecological specificity of sandy beaches in the north-western part of the Black Sea were performed. Interstitial water and sand from deeper layers of the beach by means of prospect holes up to 1 m depth were obtained (Zaitsev 2008a). Some results of these investigations are shown in Table 1.

Concerning unicellular algae, it is appropriate to mention here that these inhabitants of sandy beaches are living in the pore water (planktonic mode of life), and also being attached on the surface of sand grains (benthic mode of life). Even dry sand grains from the surface of the beach are covered by desiccate (“mummified”) unicellular algae and fungi, which are able to revive in water. This is a special state of dormancy in which viable unicellular organisms

fail to germinate under conditions favourable for germination and vegetative growth.

Table 1. Chemical and biological characteristics of sandy beaches interstitial water and sea water in the north-western Black Sea coast (from Zaitsev 2008a).

Parameters	Interstitial water	Sea water
P-PO ₄ (mcg.l ⁻¹)	138,201-138,20	53-67-55.67
N-NO ₂	142,71	9.96
N-NO ₃	1,661.50	11.61
Proteins (mg.l ⁻¹)	0.22	0.17
Nucleotide	0.27	0.28
Chlorophyll “a” (mg.m ⁻³)	5.63	3.06
Saprophytic bacteria (cells.ml ⁻¹)	4,100-6,500	20-250
<i>Thalassiosira parva</i> (cells.l ⁻¹)	1,986	0
<i>Skeletonema costatum</i>	250,200	680,000
Benthic Diatoms	5,957	0
<i>Prorocentrum micans</i>	1,493	0
<i>Heterocapsa triquetra</i>	7,943	0
<i>Katodinium</i> sp. (cysts)	21,842	0
Planktonic Chlorophyte	55,151	6,000
<i>Monoraphidium arcuatum</i>	37,728	6,000
Prokaryote	65,907	0

Data concerning chemical and biological characteristics of interstitial waters change as a function of temperature, season, local beach peculiarities, but in any case the amount of nutrients, different microscopic organisms – saprophytic bacteria, fungi (Zaitsev *et al.* 2010), unicellular algae and detritus in pore water is much greater than that in the sea. This is the reason of mass development of small invertebrate species in the beach pore spaces. In this sense, very significant components are Harpacticoida and Nematoda (Table 2).

Table 2. Number of Harpacticoida and Nematoda (specimens.m⁻²) in the sandy beaches splash and spray zones and in the north-western Black Sea shelf (Vorobyova *et al.* 1992; Vorobyova and Kulakova 2009; Garlitskaya 2010).

Taxons	Number of specimens per 1m ²	
	In sandy beaches	On the north-western shelf
Nematoda	38,000 – 616,000	32,869 – 189,774
Harpacticoida	28,000 – 2,414,000	3,100 – 189,000

These invertebrates jointly with microorganisms and detritus ensure the mass development of larger invertebrates and fish, feeding on detritus, bacteria, unicellular algae, fungi, protozoans and small metazoans. In the Black Sea and the Sea of Azov very characteristic inhabitants of the splash zone are the

amphipods, especially the brackish-water pontian relict species *Pontogammarus maeoticus* (Table 3). In the rush of turbulent water they carried up the beach; then, as the wave's force slackens, they instantly dig into the sand, by means of motion of legs and tail appendages.

Table 3. Number (spec.m⁻²) and biomass (g.m⁻²) of the amphipod *Pontogammarus maeoticus* in the Dnepro-Bug Rivers liman (estuary) of the north-western Black Sea (unpublished data of T.L. Alexenko).

In the sandy beaches splash zone	At the depth of 0.3 – 0.9 m
Number 3,130 – 101,600	Number 53 – 740
Biomass 33.58 – 1,040.00	Biomass 0.04 – 8.18

In the sandy beaches splash zone of the proper north-western Black Sea, the number of *P. maeoticus* reached up 3,300 ind.m⁻² in the Kinburn Spit area, 5,000 ind.m⁻² around the Berezan Island, and 11,800 ind.m⁻² in Western Crimea (Zakutsky and Vinogradov 1967), which is much more than at 1 m depth in the same areas. In the splash zone of the Sea of Azov the amount of this rather large amphipod species (up to 15 mm long) is even much more, so it is traditionally commercially explored for aquaculture purposes as a food of fish.

Amphipod species of Talitridae family e.g. *Orchestia gammarella*, *O. mediterranea*, *O. montagui*, *O. bottae*, *Talorchestia deshayesii* in the Black Sea, *Orchestoidea californiana* from the Pacific coast of North America, *Talorchestia megalophthalma* from the Atlantic coast are named beach fleas. At night these crustaceans can be seen on the sand above the breaking waves (in the supralittoral zone), leaping about and eating washed-up sea-weed and other wave-cast debris on beaches. All Talitridae species are effective scavengers.

In subtropical and tropical marine areas very characteristic macrobenthic inhabitants of the sandy beach splash zones are the sandbugs, or mole crabs (*Emerita analoga*, *E. talpoida*, *E. austroafricana*), living in the sand, moving in and out with the tide. Legs are adapted for digging. Plume-like antennae, held just above the sand, catch microorganisms and detritus on which these active stenotopic organisms are feeding. All movements – swimming, crawling or digging – are made backward. In favorable conditions the number of mole crabs reached several hundreds per 1 m² of the splash zone (Bacescu 1967). As rather large invertebrates (up to 35 mm), with soft carapace, they are eaten by birds, fish, blue crabs, and are also fished as bait.

The more active inhabitants of sandy beaches are fiddler and sand, or ghost, crabs. Fiddler (*Uca pugnax*, *U. crenulata*, *U. pugilator*, *U. urvillei*, *U. vocans*), an up to 75 mm long crab, prefer the drier parts of sandy beaches (the supralittoral zone) and salt marshes.

The ghost crab (*Ocypode quadrata*, *O. ceratophthalmus*, *O. ryderi*) lives in even drier sand than *Uca*. These active, inquisitive crabs, up to 45 mm long, and their burrows are a familiar sight of southern sandy beaches. These species are called ghost crab with good reason; they blend closely with the sand on which they live. They are absent in the Black Sea and the Sea of Azov, but are rather common in the Mediterranean, including the Aegean Sea. They are very swift and thanks to protective coloring seem to appear from nowhere, run, and suddenly disappear again (The National Audubon Society Field Guide 1987). Ghost crabs feed mainly on small invertebrate, amphipods, minute algae and other microorganisms, but occasionally are cannibalistic. The high number of active carnivore crabs in the marine splash zone is one of indirect evidences of considerable food resources of this area.

Especially stenobiotic visitor of warm-water sandy beaches is the atherinid fish California grunion (*Leuresthes tenuis*). From March to September during high tides, the grunion spawns at night on beaches. When high waves pass well up the beach, the fish lay few feet below the highest point reached. The eggs are buried in the moist sand and hatch when the new spring tide occurs. Each female may spawn from 4 to 8 times during season. At this time these fishes are traditionally captured by hands (Breder and Rosen 1966; The National Audubon Society 1983).

On the Black Sea sandy beaches rather common consumers are the carnivore tiger beetle (*Cicindella hybrida*) and the omnivore riparian earwig (*Labidura riparia*) (Zaitsev 2008b). The swift insect tiger beetle is feeding on amphipods and other invertebrates in the splash zone, and the earwig – on mixed diet of plant and animal material. In some areas of the splash zone the number of tiger beetles reached up 8-10 insects m⁻².

Exceptional high concentration of organisms and detritus in sandy beaches is the main reason of littoral concentration of life (Zaitsev 2006). Fry and juvenile of about 90 species of the Black Sea fish are feeding just in the water line area up to the depth 2-3 m, where the interstitial water enriched with microorganisms and detritus is seeping from the sandy beaches. This is a typical ecological “hot spot”, a key biotope of great scientific and practical interest.

Discussion

The eminent naturalist V.I. Vernadsky (1968, 1987) met forth the concept of concentration of living matter at the outer boundaries of the ocean: sea surface, sea floor and, particularly, coastline where the former two boundaries meet. According to Vernadsky's postulate, the highest concentration of living organisms is observed in films (boundary layers) of the ocean, the maximum concentration occurring where interfaces come close together. By introducing the term “concentration of life” and “concentration of living matter” Vernadsky

apparently proceeds from the concept set by J.W. Gibbs, one of the founders of thermodynamics, concerning concentration of all properties at interfaces (Lebedev *et al.* 1989).

Vernadsky attached special importance to the littoral aggregation because it is the concentration of life that has left its imprint on the entire history of our planet as the zone of most intensive biogeochemical transformations.

However, in spite of this basic theoretical proposition, the beaches remain to date much less investigated than the open sea, and the most up-to-date research methods from vessels and from space are inefficient to discern biological and ecological peculiarities of sandy beaches. With that end in view, special methods and approaches are needed.

Results of the first task-oriented integrated investigations in the Black Sea confirm the ecological exceptionality of sandy beaches and point out the information gaps which need further research in this promising line of marine ecology.

Both surface waves, generated by the wind and tide waves, caused by the gravitational attraction of the moon and sun, rolled on the sandy beach, are a permanent source of marine water, dissolved matter and suspensions of mineral and organic nature (detritus and living organisms) from the pelagic surface microlayer, or neustal (Zaitsev 1971), including the sea foam, from the water column (pelagial) and from the bottom (benthal). Part of this water and suspensions are penetrating in the interstitial cavities of sand, where the small organisms have the possibility for further successful development in favourable life conditions. Such auspicious conditions are ensured by the abundance of nutrients and the sea foam, which in ecological norm has a significant stimulatory effect on the growth and development of marine plants and animals (Zaitsev 1971). The sea foam, one of the most characteristic elements of the surface microlayer, is a complex of biologically active external metabolite, which explains its particular ecological role. The stimulatory influence of sandy beaches interstitial water, enriched with sea foam on the growth of unicellular algae was recently reaffirmed (Garkusha 2009). But, in case of pollution by toxic surfactants, the sea foam loses its useful properties and become an inhibitory substance for living organisms.

The World Ocean sandy beaches are the greatest natural absorbing filter on the planet. The filling of sand interstices is a permanent process, and in the absence of efficient consumers of microorganisms and detritus inside of the beach, in accordance to the law of the conservation of energy, it must be a permanent outflow of water and suspensions from the sandy beaches. This outflow is realized through the efflux (seeping) of pore water in the splash zone and in the water edge. It is a striking example of outwelling (Odum 1971), the most large-

scale one in the world. Such is a very simplified explanation of the natural mechanism of sandy beach enrichment with matter and energy, including accumulation of substances influencing the reproduction and feeding of plants and animals. The outburst in number of bacteria, unicellular algae, fungi, and small invertebrates in sandy beaches interstices is a direct consequence of this. In this connection it should be noted, that ecologically of paramount importance is not the number (density) or biomass of organisms, but the linear distance between consumer and food particle, prey and predator, male and female, between members of a population or community, for better exchange of external metabolites and more effective perception of different signals by means of chemical transmitters. This is the field of a new science – Biochemical Ecology (Telitchenko and Ostroumov 1990).

The attractiveness of sandy beaches for marine organisms is the main reason of littoral concentration of marine organisms, especially of fry of fish, including commercially important species (Zaitsev 2006). The main feeding grounds of the fish fry are just in the water edge area in front of sandy beaches of the Black Sea and of coastal wetlands.

Among the characteristic inhabitants of the Black Sea sandy beaches, sensitive indicators of change of environmental conditions are the bivalve mollusk *Donacilla cornea* and the bristle worm *Ophelia bicornis*. Both prefer coarse-grained and medium-grained sands and are very sensitive to the modifications of the structure of substrata due to engineering works and turbidity generated by sand extraction and other man-made impacts causing changes in the granulometric structure of sand through the closing the interstitial spaces between grains of sand. In the 1960s, on the north-western sandy beaches densities of *D. cornea* from 5,100 to 21,700 ind.m⁻³ were found (Zakutsky and Vinogradov 1967), and on the Crimean sandy beaches splash zone, densities of more than 3,000 individuals·m⁻² were found in the 1950s (Mokyevisky 1949). In the southern Romanian littoral, *D. cornea* was frequent till 1975-1980, forming a specific community together with polychaete *O. bicornis*, both species prevailing in the midlittoral (splash zone) fauna with coarser sands (up to 10,000 ind.m⁻²). After 1980 it became extremely rare, and in the 1990s it was not found at all (Bacescu *et al.* 1971; Gomoiu 1976; Gomoiu and Petranu 1999). The fate of *Donacilla* and *Ophelia* is a striking example of ecological degradation of the modern Black Sea psammocontour, which is shortening and changing under the increasing man-made impact.

It is a general rule that because of natural and man-made factors, the marine ecosystems can degrade and as a last resort are dying out starting from the contour biotopes, and the psammocontour is among the most representative areas in this respect. During extremely cold winter days in February 2012, the northern Black Sea coastal waters and especially the splash and spray zones of the north-western part were covered by ice crust and their inhabitants were

killed by frost. During special scuba visual observations in the subglacial water in the Odessa Gulf area at depths 1-3 m in February 2012, many dead gobies (e.g. toad goby, *Mesogobius batrachocephalus* and round goby, *Neogobius melanostomus*), crabs and other organisms were observed (personal communication of A. Kurakin). The fate of marine coastal wetlands is a typical example of vulnerability and instability of marine psammocontour biotopes and communities.

As a zone of rich, diverse and accessible food, the sandy beach area had a strong influence on the evolution of morphological structures of organisms (ecological morphogenesis) and on the speciation – formation of new and distinct species in the course of evolution. The result of these processes is the perfect adjustment of morphological, physiological, developmental and behavioural characters of many organisms to the peculiarities of marine psammocontour, as a specific biotope. Nearly all invertebrate phyla have at least some interstitial and sandy beaches preferring species. All of them are perfect, stenobiontics, but this is a special topic. In this article it is appropriate to give barely several examples.

According to Boaden and Seed (1985), some common sand meiofaunal adaptations are the following: 1) Either attenuation, for progressing through intertices, or leaf-like form for moving around individual sand grains, 2) Possession of tactile sensorial, photoreceptors and statocysts, with photonegative response to keep out of the immediate surface layer of sand in which there are physical and biological dangers. 3) Extensive ciliation or body flexion for locomotion, 4) Appendage reduction, 5) Integumental cuticular structures or internal spicules to protect against mechanical damage, 6) Hermaphroditism, suppression or reduction of larval stages and provision of brood care.

Amphipods and mole crabs are outstanding diggers in the sandy splash zone and effective filter-feeders. Ghost crabs are active, inquisitive and blend closely with the sand on which they live, and are very swift. The bivalve *Donacilla cornea* has no planktonic larvae. Its smooth external surface of valve and powerful foot make it possible to move in the sand. The mode of reproduction of California grunion *Leurestes tenuis* and of horseshoe crab *Limulus polyphemus*, *Carcinoscorpius rotundicaud*, *Tachypleus gigas* and *T. tridentatus*, which are burying their eggs in the moist sand after high tides are an example of perfect behavioural adaptation to sandy beaches.

The tiger beetles are a large group of insects known for their aggressive predatory habits and running speed. The fastest species of tiger beetle can run at a speed of 10 km/h. About 2,600 species and subspecies were known, on the Black sea sandy beaches the most common is *Cicindela campestris* (Zaitsev 2008b). Tiger beetles often have large bulging eyes, long, slender legs and large curved mandibles. All are predatory, both as adults and as larvae. The genus

Cicindela has a worldwide distribution. The larvae of tiger beetles live in cylindrical burrows as much as a meter deep. They are large-headed, hump-backed grubs that flip backwards to capture prey crustaceans and insects, that wander over the ground. They live along sea and lake shores, on sand dunes.

Among birds, very characteristic species on the Black Sea sandy beaches are the waders (Charadriiformes). A notably variable feature among waders is the length of the beak. These variations are related to the predominant feeding habits of different species (Green 1968). The curlew and the godwits can use their long beaks to penetrate down to considerable depths in the sand to reach worms such as *Nereis* and *Arenicola*. The plovers, with their short bills, often pick up surface-dwelling animals, such as the gastropod *Hydrobia* and amphipods. Avocets with their upturned beaks, feed by wading in shallow water and swinging the head from side to side, or else they stir up the surface layers of bottom and catch crustaceans and worms as they are disturbed. The black-winged stilt has long legs, and normally feed by wading and catching animals swimming near the surface.

In tropical zone of Central America very common is the turkey vulture (*Cathartes aura*). It can often be seen on the beaches, feeding on washed-up fish and invertebrates. The turkey vulture forages by smell, an ability that is uncommon among birds. It often flies low to the ground to pick up the scent of ethyl mercaptan, a gas produced by the beginning of decay in dead animals (Snyder 2006). Once, this bird found a dead fish specially buried in sand on a beach of the Gulf of Mexico after only 20 minutes (author's experiment). Like some other birds, it plays an important role in the ecosystem by disposing of carrion which would otherwise be a breeding ground for disease. In the Black Sea area similar ecological function is inherent for the white-tailed eagle and some other birds.

The community of psammocontour organisms and their abiotic environment are inseparably interrelated and interact upon each other. An exchange of materials between living and nonliving parts in the sandy beaches occurs. There is an ecological unit, an ecosystem, which can be designated as psammocontour ecosystem (Figure 1). This ecosystem has an autotrophic component in which fixation of light energy, use of simple inorganic substances, and buildup of complex substances predominate, and a heterotrophic component, in which utilization, rearrangement, and decomposition of complex materials predominate (Odum 1971).

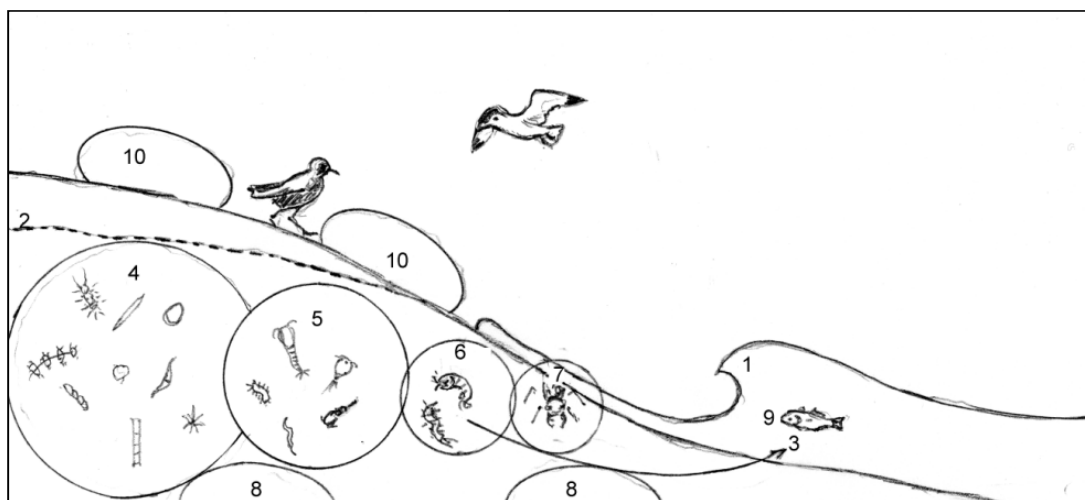


Figure 1. The Black Sea psammocontour ecosystem (an original conceptual diagram). Basic units are as follows: 1. The wind waves are sorting the sand grains and filling the interstices with marine water, dissolved nutrients and suspended particles; 2. Thanks to the effect of capillary lift, the interstitial water in sandy beaches is raising above the sea level; 3. Seeping of interstitial water with microorganisms from the sandy beach in the sea; 4. The autotrophic element of the ecosystem is composed by unicellular algae (diatoms and other), synthesizing complex organic substances from simple inorganic substrates, and producing oxygen; 5. Herbivore consumers (primary consumers) that feeds on microalgae (protozoans, worms, copepods etc.). These invertebrates feed also on bacteria, fungi and detritus; 6. Secondary consumers (carnivores) that feeds, among other food, on primary consumers (amphipods, bivalve *Donacilla*, bristle worm *Ophelia* etc.); 7. Tertiary consumers (secondary carnivores) that feeds on secondary consumers (tiger beetle, other insects); 8. Metabolic degradation of organic matter into simple organic and inorganic compounds in the ecosystem, with consequent liberation of energy is carried out by decomposers or reducers – heterotrophic bacteria, fungi, and scavengers, animals that feed on carrion and organic refuse. The last are mainly external consumers of food from the psammocontour – birds and mammals. 9. Marine origin consumers of organisms and detritus from the psammocontour (shrimps and other invertebrate, young fish). 10. Terrestrial origin consumers of organisms and detritus from the psammocontour (beetles, earwigs, waders, gulls and other).

Information gaps

In spite of its environmental importance and accessibility for investigations, the sandy beaches remain to date much less studied than the open sea areas. The ecological imperative is to fill in the gaps in our knowledge. Among them there are following questions, concerning contour biotopes and communities:

- What is the general length of undisturbed by human activities marine psammocontour in different national sectors of the Black Sea coastline? In Ukraine it is about 900 km (Zaitsev 2008c).
- How many coastal wetlands are situated along the marine psammocontour, and what is their importance as feeding grounds for Black Sea fish and aquatic birds?

Along the Ukrainian sandy beaches there are more than 30 coastal wetlands (river deltas, lagoons and limans) of different size, depth and water salinity (Zaitsev 2008c). The main part of these wetlands are important feeding grounds of marine fish, especially grey mullets, flounder, gobies and aquatic birds. Some of them are sources of medicinal mud.

- What is the granulometric characteristic of sandy beaches in different areas of the Black Sea psammocontour?
- In what areas of the Black Sea psammocontour are present the bivalve *Donacilla cornea* and the polychaete *Ophelia bicornis*, as indicators of coarse sand?
- In what areas of the Black Sea psammocontour there are mass development of amphipods, as indicators of favourable feeding conditions?
- In what areas of the Black Sea psammocontour (splash zone and the adjacent upper sublittoral zone up to the depth of 1-2 m) are there concentrations of young fish (grey mullets, gobies, flat fishes, blennies, silversides, *etc.*), as indicators of favourable feeding conditions?
- What wader's species are feeding in different areas of the Black Sea psammocontour?

Acknowledgement

I am grateful to Prof. Dr. Bayram Öztürk for the invitation to prepare this article and to my colleagues from the Odessa branch IBSS for their published and unpublished data on the topic.

References

Aizatulin, T.A., Lebedev, V.L., Khailov, K.M. (1979) The Ocean. Active Surfaces and Life. Leningrad, Gidrometeoizdat, 192 pp. (in Russian).

Băcescu, M. (1967) Decapoda. Fauna Republicii Socialiste Romania. Crustacea, vol. IV, Fasc. 9. București: Editura Acad. Rep. Soc. Romania, 353 pp. (in Romanian).

Băcescu, M., Müller, G.I., Gomoiu, M.T. (1971) The quantitative, qualitative and comparative analysis of Black Sea benthic fauna. *Ecologie marină (Marine Ecology)* 4: 357 pp. (in Romanian)

Boaden, P.J.S., Seed, R. (1985) An Introduction to Coastal Ecology. Glasgow, Blackie and Son Ltd., 218 pp.

Breder, M. Jr., Rosen, D.E. (1966) Modes of reproduction in fishes. New York, Natural History Press, 941 pp.

- Dumitrache, C., Zaitsev, I.P. (1999) *Ophelia bicornis*. Black Sea Red Data Book (H.J. Dumont, Ed.), The United Nations Office for Project Services, p. 295-296.
- Garkusha, O.P. (2009) The influence of interstitial water on the growth of microalgae from sandy beaches of Odessa coast. *Marine Ecological Journal* 78: 34-39 pp. (in Russian).
- Garlitskaya, L.A. (2010) Ecology of Haracticoida of the north-western part of the Black Sea. Cand.Sc. thesis. Sebastopol, Inst. Biol. South. Seas. (in Russian).
- Gomoiu, M.T., (1976) Ecological studies regarding psammobiontic molluscs from the Black Sea Romanian littoral. *Ecologie marina (Marine Ecology)*, 5: 173-339. (In Romanian).
- Gomoiu, M., Petranu, A. (1999) *Donacilla cornea*. Black Sea Red Data Book (H.J. Dumont, Ed.), The United Nations Office for Project Services. 195-196 pp.
- Gosner, K.L. (1987) A Field Guide to the Atlantic Seashore. Boston, Houghton Mifflin Co. 329 pp.
- Green, J. (1968) The Biology of Estuarine Animals. London, Sidgwick and Jackson. 401 pp.
- Lebedev, V., Aizatulin, T., Khailov, K. (1989) The Living Ocean. Moscow, Progress Publishers, 327 pp.
- Leschen, A.S., Grady, S.P., Valiela, I. (2006) Fecundity and spawning of the Atlantic horseshoe crab, *Limulus polyphemus*, in Pleasant Bay, Cape Cod, Massachusetts, USA. *Marine Ecology* 27: 54-65.
- Mokyevisky, O.V. (1949) Fauna of Western Crimea littoral soft bottoms. Trudy Inst. Okeanologii AN SSSR. 124-159 pp. (in Russian).
- Odum, E.P. (1971) Fundamentals of Ecology. Philadelphia, London, Toronto, 574 pp.
- Perkins, E.J. (1974) The Biology of Estuaries and Coastal Waters. London. New York, Academic Press. 678 pp.
- Serbinova, I.V., Kopytina, N.I. (2011) 3rd Bi-annual BS Scientific Conference and UP-GRADE BS-SCENE Project Joint Conference. Odessa, 1-4 November 2011. 220-221pp.

Snyder, F.R., Snyder, H. (2006) Raptors of North America: Natural History and Conservation, Voyageur Press. p.40.

Telitchenko, M.M., Ostroumov, S.A. (1990) Introduction to the problems of biochemical ecology: biotechnology, agriculture, environment. Moscow, Nauka, 288 pp. (in Russian).

The National Audubon Society Field Guide to North American Fishes, Whales and Dolphins. (1983) Knopf, New York, 858 pp.

The National Audubon Society Field Guide to North American Seashore Creatures. (1987) Knopf, New York, 813 pp.

Vernadsky, V.I. (1968) The Biosphere. Moscow, Mysl, 374 pp. (in Russian)

Vernadsky, V.I. (1987) Chemical structure of the Earth biosphere and its surroundings. Moscow: "Nauka", 340 pp. (in Russian).

Vorobyova, L.V., Kulakova, I.I. (2009) Contemporary state of the meiobenthos in the western Black Sea. Odessa, "Astroprint", 126 pp.

Vorobyova, L.V., Zaitsev, Yu.P. Kulakova, I.I. (1992) Interstitial meiofauna of the Black Sea sandy beaches. Kiev, Naukova Dumka, 144 pp (in Russian).

Zaitsev, Yu.P. (1986) Contourbionts in Ocean Monitoring. *Environmental Monitoring and Assessment* 7: 31-38.

Zaitsev, Yu.P. (1971) Marine Neustonology. Translated from Russian. Published for the National Marine Fisheries Service, National Oceanic and Atmospheric Administration, U.S. Dept. of Commerce and the National Science Foundation. Springfield, 207 pp.

Zaitsev, Yu.P. (2006) Littoral concentration of life in the Black Sea area and coastal management requirements. *J. of the Black Sea/Mediterranean Environment* 12 (2): 113-128.

Zaitsev, Yu.P. (2008a) Microorganisms community of marine sandy beaches pore waters. Data and hypotheses. *Microbiology and Biotechnology* 2: 8-19 (in Russian).

Zaitsev, Yu. P (2008b) An Introduction to the Black Sea Ecology. Odessa, Smil Editing and Publishing Agency Ltd. 227 pp.

Zaitsev, Yu.P. (2008c) Black Sea coasts of Ukraine. Kiev, Academperiodica, 241 pp (in Ukrainian).

Zaitsev, Yu.P., Kopytina N., Garkusha O., Serbinova I. (2010) Preliminary observations on the Samsun Bay splash zone biodiversity. *J. Black Sea/Mediterranean Environment* 16(3): 245-252 pp.

Zakutsky, V.P., Vinogradov, K.A. (1967) Macrozoobenthos. Biology of the North-Western part of the Black Sea. Kiev, Nauk. Dumka: 146-157 (in Russian).

Received: 28.02.2012

Accepted: 16.04.2012