The impact of atmospheric precipitation (rainfalls) on the sea-surface microlayer in the Sevastopol coastal waters (Crimea, The Black Sea)

LUDMILA SMYRNOVA1, ELENA KATUNINA2, ANATOLY RJABININ2, IREN ANNINSKAJA3

1Institute of Natural & Technical Systems, Lenin 28, 299011 Sevastopol, Russia
2Sevastopol Department of N.N. Zubov State Oceanographic Institute, Sovetskaya 61, 299011 Sevastopol Russia
3Department of Benthos Ecology, Kovalevsky Institute of Marine Biological Research Russian Academy of Sciences
Nakhimov 2, 299011 Sevastopol, Russia

Received 10 September 2017 │ Accepted 4 October 2017 │ Published online 30 October 2017.

Abstract
The results of determination of some hydrochemical characteristics and the diversity of microbiota in rain-water and sea-surface microlayer from the Sevastopol bays are presented. The connection between the level of rainfall contamination by surfactants and their accumulation into sea-surface microlayer has been established. In rain-water pH values varied from 4.2 to 8.2. As a result, the pH value and salinity in sea-surface microlayer decreased by 11–15% after storm and prolonged rains. Seasonal concentration variability of dissolved in rain-water Sr, Se, La, Nd, As, Sb, Mo, Ni, Mg, I, and Fe associated with the direction of the prevailing rainy winds. Potentially pathogenic micromycetes (genera Penicillium, Aspergillus, Cladosporium, Phoma) get into the surface microlayer and marine environment with the rain water. Cyanophyta (genera Synechococcus, Microcystis) and Chlorophyta (genus Closterium) were capable to grow both in rain-water with salinity 0.0–0.7‰, and in sea-surface microlayer (range of salinities 17.0–20.5 ‰).

Key words: The Black Sea, Sevastopol bays, rain-water, chemical and microbial pollution, sea-surface microlayer, wind direction.

Introduction
Sevastopol bays play the main role in the recreational and economical potential of the city. There are aquaparks, dolphinaria with marine mammals and the places for rest at the Sevastopol beach. In the coastal water areas of the Sevastopol bays mariculture farms are located. Ecological conditions of the coastal seawaters determine the quality of mariculture products and affect the human and marine mammals health (Pletenev et al. 2005; Smirnova et al. 2012; Chelyadina et al. 2015; Katunina & Smyrnova 2015). Meteorological factors, including aerosols and rainfall, are important sources of different pollutions (Brimblecombe 1986; Whiteaker et al. 2002). During the migration of rainy clouds the gaseous components of the atmosphere, organic and inorganic compounds migrating with aerosols are concentrated in raindrops (Facchini et al. 1999). Moreover, the composition of rain-water is affected by anthropogenic pollution in the urban atmosphere.

In the atmosphere above the city there are toxic components – trace metals, total petroleum hydrocarbons, phenols, anionic synthetic surface-active substances (surfactants), organo-chlorine pesticides,
micobiota and microalgae (Smyrnova & Rjabinin 2013; Wahid et al. 2013; Rjabinin et al. 2014). Raindrops passing through the atmospheric boundary layer dissolve and adsorb these components. Thus, rainfall at the Sevastopol coastal sea waters introduce both short-term and stable changes in the chemical-microbiological processes in the biotopes of the sea surface layer. The sea surface layer has a complex structure (Mikhailov & Pavlenko 1990). The surface sea microlayer (up to 400 μm) is its important component, because it is located in the zone of contact "atmosphere-sea surface". Surface sea microlayer concentrates biotic and abiotic components from the atmospheric precipitations and distributes them in deeper sea water (Smyrnova 2010; Katunina & Smyrnova 2015; Astrahan et al. 2016).

The purpose of the present study was to investigate influence of rainfall on the chemical and biotic composition of the Sea-Surface Microlayer (SML) in coastal water of the Sevastopol bays.

Material and Methods

Experimental works were carried out with rain-water, SML and sea water (up to 0.2 m) sampling at the coast of the Sevastopol Bay (station 1), the Yugnaya Bay (station 2) and the Kazachya Bay (station 3). The sampling was done from 2010 to 2016. The location of the sampling stations is shown in Figure 1.

The rain-water samples were collected using plastic vessels. The sampling was continued from several minutes to several hours during the periods of rainfall. Sampling of SML was carried out by means of Garrett net (Garrett, 1967) This method allows to select the SML thickness of 250 – 350 μm. Samples of SML and sea water from the Sevastopol bays were selected monthly and after rainfall.

In rain-water, SML and sea water samples the concentration of anion surfactants, pH value, salinity (S‰) and dominant groups of microalgae, cyanobacteria and microscopic micromycetes were determined. The pH value and salinity were measured by means of "Sansion-5" (Hitachi) standardized with Reference-Composition Salinity Scale (OC, SCOR and IAPSO, 2010). The concentration of anion surfactants in rain-water and samples of SML were determined by spectrophotometric method using [bis(ethilendiam) Cu(II)] (Mass concentration of …, 2006). After evaporation of the rain-water samples (volume from 100 to 500 ml) at room temperature in a special box, in the dry residues rare earth, toxic microelements and heavy metals (40 chemical elements) were determined by the multielement neutron activation method (Miklishinskii & Jakovlev 1980; Rjabinin et al. 2014).

After incubation of rain-water and SML samples (1–3 ml) in light room at 18 – 23°C during 7 – 21 days the microalgae taxonomic diversity was investigated by direct light microscopy. Cyanobacteria, Bacillariophyta and Chlorophyta genera are identified by standard morphological characteristics which have taxonomic importance. The micromycetes diversity was studied in samples of SML, rain-water, sea water, smears of microfouling from different anthropogenic surface (wood, metal, concrete) and in smears from the
dolphin skin (*Tursiops truncates ponticus* Barabash, 1940). The number of microscopic micromycetes in SML and rain-water samples was determined on Chapeek-Doxs medium.

The temperature of SML and sea water (up to 0.2 m) was determined by a mercury thermometer using the "contact measurement" method. The data on basic meteorological parameters were obtained from the Sevastopol automatic weather station.

### Results

**General chemical characteristics of rain-water and their influence on the composition of SML**

Sevastopol is located on the South-Western coast of the Crimean Peninsula. The Sevastopol climate is close to the subtropical climate of the Crimean Southern Coast, but in the foothills it is moderately continental (Voskresenskaya & Vyshkvarkova, 2016). The frequency of rainfall and the precipitation level in Sevastopol region have significant seasonal and interannual fluctuations (Fig. 2). In abnormally hot year (2013) the amount of rainfall and the precipitation level decreased, especially in July, September and December. On the surface of Sevastopol bays both sea winds (Southern, South-Eastern, North-Western directions) and continental winds (Northern, Eastern, North-Western directions) bring rainfall with different types of pollution.

![Figure 2. Seasonal distribution of precipitation level (mm/month) and mean monthly temperature during 2016 (A) and 2013 (B).](image)

Anionic surfactants are those the most widespread pollutants in environment (Roslan *et al.* 2010; Wahid *et al.* 2013). Throughout the period of observation the content of anionic surfactants in rain-water varied in the range of 0.11 – 0.23 mg/l. In the coastal waters of Sevastopol bays these compounds are concentrated into SML. The obtained results showed that their content in SML was 4 – 10 times greater than in sea water at depth 0.2 m (Table 1). During January and February after rainfall brought by North-Eastern winds in SML from the Kazachya Bay maximum concentrations of this pollutant have been noted.

The content of chemical elements in rain-water is shown in Table 2. When comparing the elemental composition in rain-water of the rainfall brought by the winds from the Black Sea-Mediterranean region, high concentrations of I, Br, Sr, Hg, As, Cd and W were noted. In addition, in the rainfall brought by sea winds there is a variety of rare-earth elements and radioactive Th, U which appeared in the atmosphere due to geochemical processes.
Table 1. Hydrochemical parameters in surface layer of the contact zone "atmosphere–sea water " in Sevastopol bays, 2016.

| Measured parameters | Sevastopol Bay | Yugnaya Bay | Kazachya Bay |
|---------------------|---------------|-------------|--------------|
|                     | Sea water     | Sea water   | Sea water    |
|                     | SML (up to 0.2 m) | SML (up to 0.2 m) | SML (up to 0.2 m) |
| Surfactants, µg/l   | 48.0–51.4     | 8.4–10.0    | 45.1–60.8    | 6.3–20.0    | 17.7–90.5 | 8.1–1.6 |
| pH value            | 7.9–8.1       | 8.1–8.2     | 8.0–8.1      | 8.1–8.3     | 7.8–8.1  | 8.1–8.3 |
| Salinity, ‰         | 18.5–18.7     | 17.6–18.1   | 18.1–18.9    | 17.3–18.4   | 18.6–19.9 | 17.5–18.0 |

The cold season (December to April), sea water temperature 6.0–8.0 °C

| Surfactants, µg/l   | 30.8–50.1     | 10.3–15.6    | 40.2–60.5    | 12.4–20.7   | 11.3–1.5  | 2.8–0.0 |
| pH value            | 8.0–8.2       | 8.2–8.4      | 8.0–8.2      | 8.2–8.4     | 8.1–8.5   | 8.3–8.4 |
| Salinity, ‰         | 18.9–20.4     | 17.9–18.4    | 19.5–20.5    | 17.8–8.7    | 19.4–20.0 | 18.4–19.0 |

The warm season (May to November), sea water temperature 12.5–28.5 °C

In the Sevastopol region, the pH value in rain-water varies in the range from 4.2 to 8.2 and salinity varies from 0.0 to 0.7 ‰. Variability of the chemical composition in rain-water has an influence on the pH value fluctuation (Table 1). The pH value decreased in the cold periods of the year with the dominance of continental winds which bring rainfall. As a rule extremely acidic rains (pH value from 3.7 to 4.2) fall in January and February. The distribution of salinity in sea surface layer of the coastal zone is defined by interaction between rain-water, SML and sea water (up to 0.2 m). In SML salinity variability was high and varied in the range of 17.0 – 20.5 ‰. The tendency in decreasing salinity with depth has been noted (Table 1).

Figure 3. Effect of rainfalling on the pH value in SML from Yugnaya Bay. I – the pH value in rain-water; II- a short-term effect on the pH value in SML after rainfall; III - seasonal background the pH value in SML.
Table 2. The content of the chemical elements in rain-water, and the direction of winds bringing rains (the coast of the Sevastopol Bay, 2010).

| Chemical elements | The concentration of the chemical elements, nM/m²·month |
|-------------------|-------------------------------------------------------|
|                   | Continental winds (January, February) | Sea winds (May, June, August) |
| **Rock-forming elements** | | |
| Na                | (3.1–4.1)·10^7 | (1.1–1.9)·10^7 |
| K                 | (2.2–3.7)·10^6 | (0.6–1.2)·10^6 |
| Ca                | (0.9–1.7)·10^4 | (6.3–8.5)·10^2 |
| Mg                | (1.8–2.1)·10^1 | (1.1–1.2)·10^3 |
| Br                | (2.2–2.4)·10^1 | (2.0–2.2)·10^2 |
| I                 | <2.1·10^1 | (1.9–2.3)·10^1 |
| **Heavy metals and toxic elements** | | |
| Cr                | (2.0–2.3)·10^6 | (8.6–9.3)·10^3 |
| Mn                | (3.1–3.2)·10^6 | (3.5–3.9)·10^1 |
| Co                | (6.1–6.5)·10^2 | (1.5–1.7)·10^4 |
| Fe                | (1.3–1.7)·10^8 | (7.7–8.3)·10^4 |
| Ni                | (3.3–3.5)·10^4 | (1.1–1.3)·10^2 |
| Cu                | (1.0–1.6)·10^5 | (6.3–6.5)·10^4 |
| Zn                | (1.2–1.4)·10^3 | (4.2–4.8)·10^4 |
| Mo                | (1.8–2.3)·10^7 | (1.3–1.4)·10^6 |
| Sb                | (3.7–3.8)·10^1 | (1.4–1.8)·10^1 |
| Hg                | (2.1–2.5)·10^1 | (8.6–8.8)·10^9 |
| Cd                | (5.2–5.4)·10^4 | (1.5–1.7)·10^4 |
| As                | (5.4–5.5)·10^4 | (2.3–2.7)·10^2 |
| Ba                | (0.8–1.1)·10^4 | (2.0–2.2)·10^4 |
| Sr                | (8.1–8.5)·10^1 | (9.4–9.8)·10^4 |
| W                 | (2.8–3.1)·10^7 | (0.8–1.1)·10^3 |
| **Rare earth elements** | | |
| Sc                | (2.0–2.1)·10^1 | (3.9–4.1)·10^2 |
| La                | (4.2–4.3)·10^1 | (4.2–4.8)·10^2 |
| Ce                | (2.1–2.5)·10^1 | (7.5–7.8)·10^2 |
| Nd                | (5.0–5.2)·10^2 | (4.0–4.2)·10^3 |
| Sm                | (7.0–7.4)·10^4 | (4.4–4.9)·10^4 |
| Eu                | (1.3–1.4)·10^2 | (3.5–3.7)·10^6 |
| Tb                | (2.7–2.9)·10^3 | (8.8–9.0)·10^2 |
| Yb                | (6.4–7.0)·10^4 | (1.3–1.4)·10^4 |
| Lu                | (7.9–8.0)·10^2 | (2.9–3.1)·10^9 |
| Ta                | (3.8–3.1)·10^1 | (5.4–5.6)·10^3 |
| **Trace elements** | | |
| Cs                | (8.1–8.4)·10^1 | (2.7–2.9)·10^4 |
| Rb                | (1.3–1.5)·10^2 | (8.1–8.7)·10^3 |
| Se                | (2.1–2.5)·10^6 | (7.4–7.9)·10^1 |
| Ag                | (2.7–2.9)·10^6 | (2.0–2.2)·10^1 |
| Au                | (7.3–7.6)·10^1 | (1.6–1.9)·10^9 |
| Hf                | (8.8–9.0)·10^1 | (3.0–3.2)·10^1 |
| **Radioactive elements** | | |
| Th                | (2.5–2.6)·10^0 | (3.9–4.1)·10^1 |
| U                 | (7.2–7.3)·10^1 | (2.8–3.0)·10^0 |
Phototrophic and heterotrophic microorganisms in rain-water

With streams of rain-water spores, cysts and living cells of microorganisms fall on the surface of Sevastopol bays. They are concentrated in SML and under favorable temperature conditions begin to vegetate. Table 3 shows the diversity of microbiota in coastal zone of the Kazachya Bay. Filamentous cyanobacteria and diatoms dominate in the rain-water during the cold period of the year. And small cyanobacteria genus Synechococcus are a constant component of rain-water both in the cold and warm periods. In rain-water during the summer – autumn period the number of anamorphic micromycetes (the genera Penicillium, Aspergillus, Cladosporium) varies from 450.0 to 34.0 cells/ml. After rainfall their content in SML varied in the range of 111.5–15.0 cells/ml.

| Genus and Species in rain-water | Marine habitats | | | |
|---|---|---|---|
| | SML | Sea water, phytoplankton* | Skin of bottlenose dolphins | Microfouling on anthropogenic surfaces |
| **Cyanobacteria** | | | | |
| Synechococcus sp | + | + | – | – |
| Microcystis sp | + | + | – | – |
| Nostoc sp | + | + | – | – |
| Calothrix sp | + | – | – | – |
| Oscillatoria sp. | + | + | – | – |
| Spirulina sp. | + | + | + | + |
| **Chlorophyta** | | | | |
| Coelastrum sp. | + | + | – | – |
| **Bacillariophyta** | | | | |
| Navicula sp | + | + | + | + |
| Pinnularia sp | + | + | – | – |
| Melosira sp | + | + | + | + |
| **Fungi** (Ascomycota) | | | | |
| Aspergillus flavus | + | – | + | – |
| Link 1809 | | | | |
| Aspergillus sp. | + | – | + | + |
| Cladosporium | + | + | – | + |
| Cladosporioides (Fresen) | | | | |
| G.A.de Vries 1952 | | | | |
| Penicillium sp | + | + | + | – |
| Phoma sp. | + | + | – | – |

* – (Senicheva, 2008)

**Discussion**

Dormant cell forms, individual species and associations of heterotrophic and autotrophic microorganisms are transferred to atmospheric boundary layer as part of dust particles, from the marine and freshwater surface (Deane & Stokes 2002). As a result of atmospheric circulation, they migrate over significant distances and rain drops become temporary habitat for them. The representatives of Cyanobacteria (genera Microcystis Lemm., Spirulina Turp., Synechococcus Nag., Oscillatoria Vauch,) Bacillariophyta (genera Pinnularia Ehrl., Navicula Bory, Melosira Ag.) and Chlorophyta (genus Coelastrum Nag.) were found both in rain-water and SML (Table 3). Species of diatoms Navicula spp., Pinnularia spp., and Melosira spp. occur in cold-time phytoplankton and periphyton communities (Senicheva 2008), and
develop on the skin of bottlenose dolphins in dolphinariums during autumn to spring periods of year. Cyanobacteria of genera Microcystis, Spirulina, Oscillatoria and Synechococcus, microalgae of the genus Coelastrum found in the summer phytoplankton communities in the Sevastopol bays (Senicheva 2008).

On the other hand rains are the source of chemical and biological pollution of the marine environment of Sevastopol bays. Rain-water removes from the urban atmosphere moldy micromycetes (genera Penicillium, Aspergillus, Cladosporium, Phoma) into SML. These micromycetes belong to the terrigenous microorganisms, but they can develop in SML, are common in microfouling on wooden, metal, concrete surfaces in the contact zone "atmosphere-sea water", on the skin of bottlenose dolphins in dolphinarium and in bottom sediments of Sevastopol bays (Table 3). As it was established in the works (Pletenev et al. 2005; Smirnova et al. 2012) these potentially pathogenic microorganisms can cause intoxications, micotoxicoses and allergic diseases in humans and marine mammals.

In Sevastopol region, the maximum amount of anionic surfactants is brought by rainy clouds formed over the Black Sea where the concentration of surfactants in the sea surface layer reaches 0,10 – 0,40 mg/l (Gubanov & Rjabinin 2006). In addition the Oil terminal located on the coast of the Kazachya Bay is source of anionic surfactants flux into urban atmosphere and rain-water (Fig. 1). As a result, the anionic surfactants content in the SML of Kazachya Bay is variable and depends on air temperature and direction of winds bringing rainfall (Table 1). Surfactants are able to penetrate from SML in deeper sea water, bottom sediments and accumulate in soft tissues of the Black Sea cultivated mussels M. galloprovincialis (Cserhati et al. 2002; Katunina & Smyrnova 2015). According to Gubanov V.I. and Rjabinin A.I. studies under favorable weather conditions (high air and sea surface water temperature and strong winds), surfactant molecules are evaporated from SML and secondary contamination of the near-water layers of the atmosphere takes place (Gubanov & Rjabinin 2006). Thus the SML performs an important function in anionic surfactants exchange between the atmosphere and upper water layer. Moreover anionic surfactants, diatoms and moldy micromycetes are initiators of fouling and affect the corrosion of metals and alloys in the area of the variable waterline of ships (Schiriffin & De Sanchez 1985).

According to the obtained data (Table 2) rain-water is the source of toxic elements (Cu, Zn, Hg, Cd, As, Sb, Ba, Sr, Th). The chemical elemental composition in rain-water associated with the season, and direction of the prevailing rainy winds. With the dominance of continental winds (the cold season), rain-water was enriched with a complex of toxic elements. In their composition, heavy metals of technogenic origin (Cu, Zn, Sb, Mn, Ni) dominated. Heavy metal and toxic elements have an impact on the quality of the marine environment and various hydrobionts including market marine culture (Ryabinin et al. 2014; Chelyadina et al. 2015).

Rainfall have a short-term effect on the pH value in the SML of coastal waters (Fig. 3). It should be noted that the precipitation level also affects the pH value change in SML of the coastal waters of the Sevastopol bays. When the precipitation level increases to 8 – 13 mm, the pH value changes to considerable extent (Fig. 3, June and August 2016).

The obtained results allow to consider rainfall as a factor preserving the diversity and abundance of autotrophic microorganisms in phytoplankton communities of Sevastopol bays. At the same time rain-water is the source of chemical and biological pollution of the marine environment, have a short-term effect on the pH value in SML.

References

Astrahan, P., Herut, B., Paytan, A. & Rahav, E. (2016) The Impact of Dry Atmospheric Deposition on the Sea-Surface Microlayer in the SE Mediterranean Sea: An Experimental Approach. Frontiers in Marine Science 3: 222. doi: 10.3389/fmars.2016.00222.

Brimblecombe, P. (1986) Air Composition & Chemistry. School of Environmental Sciences. Cambridge University Press of Cambridge, England, 348 pp.

Chelyadina, N., Pospelova, N. & Kopytov, Yu. (2015) Distribution of Copper in the Tissues of Males and Females of Mytilus galloprovincialis. Hydrobiological Journal, 51, 74–79.

Cserhati, T., Forgace, E. & Oros, G. (2002) Biological activity and environmental impact of anionic surfactants. Environmental Interaction, 28, 337–348.

Deane, G. & Stokes, M. (2002) Scale dependence of bubble creates on mechanisms in breaking wave. Nature, 418, 839–844.
Facchini, M., Mircea, M., Fuzzi, S., Charlson, R. (1999) Cloud albedo enhancement by surface-active organic solutes in growing droplets. *Nature*, 401, 257–259.

Garret, WD. (1967) The organic chemical composition of the ocean surface. *Deep-Sea Reserch*, 14, 221−227.

Gubanov, V.I. & Rjabinin, A.I. (2006) Detergent pollution of the Black Sea In: Dem’yanova, T., Yangolenko, S., and Tikotova, T. (Eds), *Atlas of the Black Sea and Sea of Azov nature protection*. Saint Petersburg, Navy Charts Division, pp 127−153.

IOC, SCOR and IAPSO, (2010) The international thermodynamic equation of Seawater-2010: Calculation and use of thermodynamic properties Intergovernmental oceanographic Commission, Manuals and Guides No.56. UNESCO- 196p. Available from: http://www.TEOS-10.org. (Date of access 20.12.16).

Katunina, E.V. & Smyrna, L.L. (2015) Atmospheric precipitation (rain-water) as a source of contamination of the Sevastopol coastal waters by detergents and microalgae. In: Geographic-information technologies and prediction of extreme events. (Collection of articles of the III International Conference September 5 − 12, 24 − 28, 2015, Durso − Rostov-on-Don, Russia). Rostov-on-Don: Publishing house SSC RAS, pp. 70−79.

Mass concentration of anion synthetic surface-active compounds in water. In: Technique of measurements by extraction-photometric method. (2006) Available from: meganorm. ru/ Data2 /1/ 4293837 / 4293837328. htm. (Date of access 4.3.16).

Miklishinskii, A. & Jakovlev, Yu. (1980) Neutron activation analysis of atmospheric aerosols. On the issue of global atmospheric pollution. In: Nuclear-physical methods of analysis in the environmental monitoring. Leningrad: Gidrometeoizdat. pp. 32−52. (in Russian)

Mikhailov, V.I. & Pavlenko N.E. (1990) Surface micro layer and the system of boundary layers in the ocean. In: Simonov, A., Mikhailov, V. Eds. Proceedings of the State Oceanographic Institute. The results of the Ecological studies in the ocean and driving atmosphere. Moscow: Gidrometeoizdat 186, 6−14. (in Russian)

Pletenev, S.S., Lapshin, V.B., Goncharuk, V.V., Kolesnikov, M.V., Smirnov A.N. & Syroeshkin, A.V. (2005) The global novel transboundary source of coastal ecosystems’ pollution and methods of monitoring and minimization of damage to human health of the sea megapolesis. Proceedings book. Clean Black sea Working group. Varna: BAS, pp. 45−46. Available from: meganorm. http://www.igic.bas.bg/clean_black_sea (Date of access 12.3.17).

Roslan, R., Hanif, N., Othman, M., Azmi, W., Yan, X. & Ali, M. (2010) Surfactants in the sea-surface microlayer and their contribution to atmospheric aerosols around coastal areas of the Malaysian Peninsula. *Marine Pollution Bulletin*, 60, 1584–1590.

Rjabinina, A.I., Bobrova, S.A., Danilova, E.A., Malchenko, Yu.A. & Erkushov, V. (2014) Chemical and radiation situation and atmospheric deposition of aerosols in the Sevastopol region during the period 2008−2011 gg. *Marine Ecological Journal*, 4, 29−39. (in Russian)

Schiffrin, D. & De Sanchez, S. (1985) The effect of Pollutants and bacterial microfouling on the corrosion of copper alloys in seawater. *Corrosion- Nace*, 41, 31−38.

Senicheva, M.I. (2008) Species diversity, seasonal and interannual variability of microalgae in the plankton communities at the coast of Crimea In: Tokarev, Yu.N., Finenko, Z.Z., Shadrin, N. (Eds), *The Black Sea Microalgae: Problems of biodiversity preservation and biotechnological usage*. Sevastopol: EKOSI-Gydrophysika, pp. 5–18, 118−130. (in Russian)

Smirnova, L.L., Kopytina, N.I., Teliga, A.V. (2012) Micobiota from the bottlenose dolphins’ (Tursiops truncatus) skin, seawater, and bottom sediments in coastal marine enclosure (Black Sea, Sevastopol). Marine mammals of the Holarctic. Collection of Scientific Papers After the Seventh International Conference. Suzdal, Russia. Moscow, 2, 239−244.

Smyrna, L.L. (2010). Association of the heterotrophic microorganisms in coastal biotopes of Kazachia Bay (Black Sea). *Marine Ecological Journal*, 2, 81−88. (in Russian)

Smyrna, L.L. & Rjabinina, Al. (2013). Microbiological and Elemental Composition of Aerosols Falling on the Crimean Coast of the Black Sea. *Paleontological Journal*, 47, 1−7.

Voskresenskaya, E. & Vyshkvarkova, E. (2016) Extreme precipitation over the Crimean peninsula. *Quaternary International*, 409, 75−80. doi:10.1016/j.quaint.2015.09.097
Wahid, N.B.A., Latif, M.T. & Suratman, S. (2013) Composition and source apportionment of surfactants in atmospheric aerosols of urban and semi-urban areas in Malaysia. *Chemosphere*, 91, 1508–1516.

Whiteaker, J., Sues, D. & Prather, K. (2002) Effects of meteorological conditions on aerosol composition and mixing state in Bakersfield, CA. *Environmental Scientific Technology*, 36, 2345–2353.