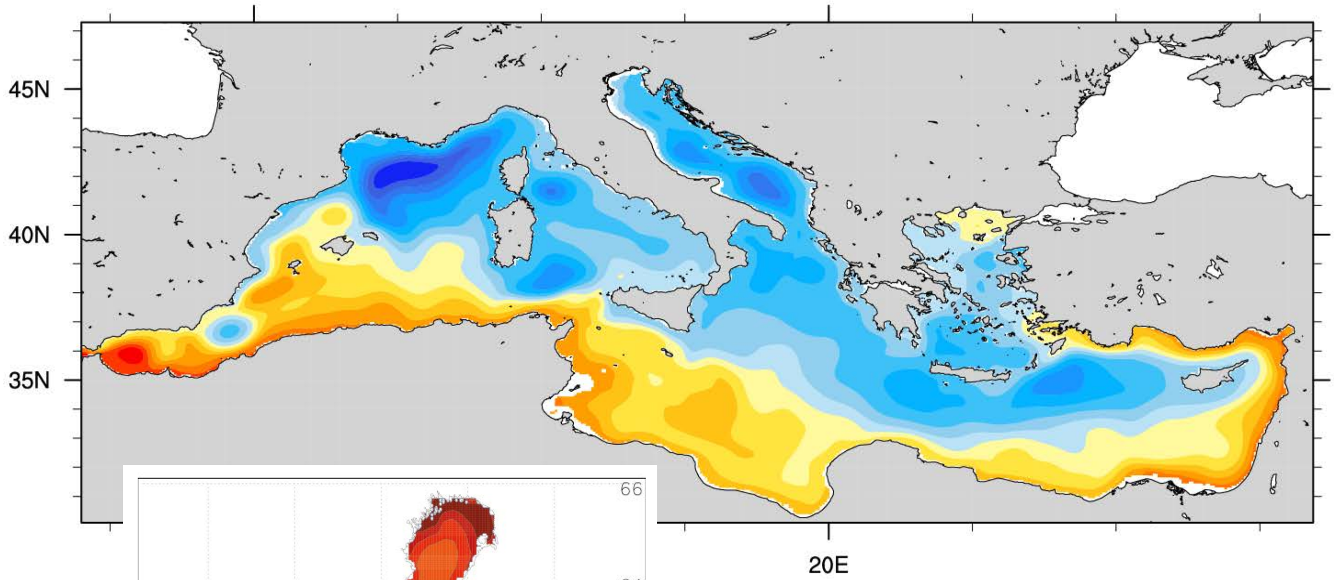

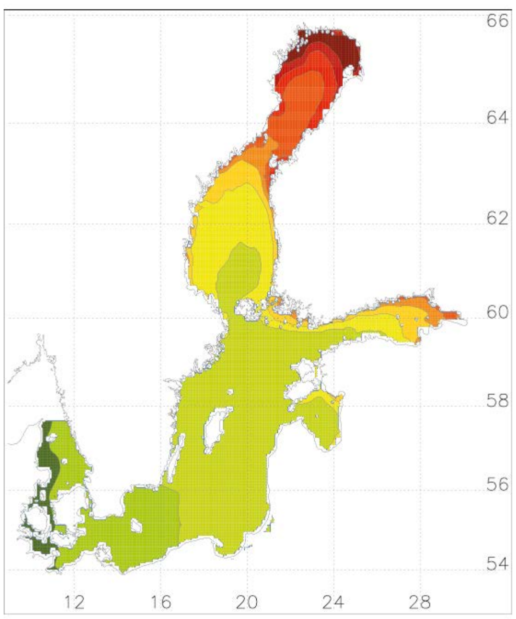

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Modelling climate change impact on hydroecological conditions of the Tyligulskyi Liman lagoon (north-western coast of the Black Sea)

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1. Physio-Geographic Description of the Tyligulskyi Liman lagoon

The Tyligulskyi Liman lagoon is located on the Ukrainian coast in the north-western part of the Black Sea (46°39.3′–47°05.3′N, 30°57.3′–31°12.7′E; see Fig. 1), and its basin area is 5420 km^2. The lagoon used to be a valley of the Tyligul River that was later flooded by seawater. The mean water-surface area and volume of the lagoon are 129×10^6 m^2 and 693×10^6 m^3, respectively. The Tyligul River is the main source (16.9×10^6 m^3 y^{-1}, i.e. > 90%) of freshwater into Tyligulskyi Liman.

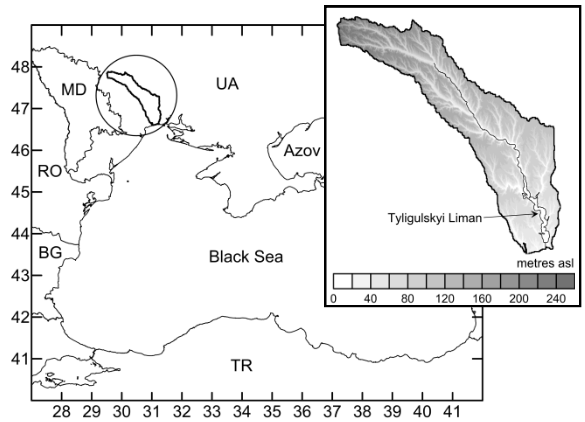

Figure 1. Location and topography of the Tyligulskyi Liman lagoon basin area.

The lagoon is separated from the sea by a natural sand isthmus, which is breached by 3.3 km long artificial channel connecting the lagoon and the sea. Usually, the channel is manually open in April–June. The northern part of the lagoon, where the Tyligul River falls, is shallow, with depths of up to 4 m, while the southern and central parts are deeper (10–16 m) and divided by a shallow-water spit.

During a few last decades there is a negative freshwater balance, which was estimated to be 32×10^6 m^3 y^{-1} in the period of 1991–2012, in response of regional climate change and anthropogenic forcings. This deficit can be only compensated by sea water inflow through the connecting channel.

2. Regional Climate Change Scenario

The outcomes of 15 RCMs from the FP6 ENSEMBLES Project were used in order to select single climate change scenario that can be considered as a most feasible at the Tyligulskyi Liman basin area during the nearest future. The analysis of differences between the observed seasonal temperature and precipitation with the modelled ones by each of 15 models was the basis for this selection (Wörner et al., 2012). It was revealed that the REMO model (Max Planck Institute for Meteorology, Hamburg, Germany) under A1B scenario provides the results with minimal differences from the observables.

3. Regional Modelling Approaches

The future freshwater inflow and nutrient inputs to the lagoon from the basin area have been simulated by the eco-hydrological model SWIM (Soil and Water Integrated Model; Krysanova and Wechsung, 2000; Hesse et al., 2015).

In order to assess the climate change impact on lagoon's hydroecological conditions we used the 3-D numerical model MECCA-OSENU-EUTRO, which is the modified hydrodynamic model MECCA (Model for Estuarine and Coastal Circulation Assessment) with the original chemical and biological unit of water eutrophication (Hess, 2000; Ivanov and Tuchkovenko, 2008). The 3-D model was run for four 'typical' years within each of the climatic periods, that is, 1971–2000 (p0) – the reference, and 2011–2040 (p1), 2041–2070 (p2), 2071–2098 (p3) for evaluation of climate impact. The typical, with respect to hydrometeorological conditions, years were selected by analyzing three variables – monthly air temperature, precipitation and runoffs from the lagoon's basin area.

The climate scenarios were analysed and evaluated comparing long-term temperature, precipitation and runoffs in three future periods to those in the reference period. By that, so called climate change signals were estimated. The climate change signals for temperature will amount to 2.2°C for period p1, 3.0°C for period p2 and 4.0°C for period p3. Comparing with annual precipitation 482 mm for period p0, that value will decrease to 413 mm for period p1, then will increase to 456 mm for period p2, and will again decrease to 411 mm for period p3. Similarly, the runoff was estimated as 85×10^6 m^3 y^{-1} for period p0, 14×10^6 m^3 y^{-1} for period p1, 110×10^6 m^3 y^{-1} for period p2, and 56×10^6 m^3 y^{-1} for period p4.

4. Results and Discussion

The average long-term results of model calculations testify that the present-day period (p1) is characterized by minor volumes of lateral fresh flow into the lagoon, which results in an increase of water salinity, diminishing concentrations of NH_4-N, the deficit of which leads to limited primary water-weed production in summer months and an overall biomass reduction, and a raise in concentrations of PO_4-P. The deep southern and central parts of lagoon, the volume of waters in which comes up to 80% of the total volume of waters in the lagoon, pose a considerable damping effect as regards the influence of the river flow (2% of the total volume of water in the lagoon). However, even in these parts, a few unit increase in salinity of water is observed in course of an annual cycle, which in a few decades will result in an increase in salinity of water in the lagoon of some tens of PSU. The most intensive increase of salinity takes place in the shallow northern part of the lagoon. In view of a lack of fresh flow and intensive evaporation in summer months the salinity here could reach 27 PSU by the end of the year. These salt waters get to the central and the southern parts of the lagoon thus contributing to their salinization. The obtained results of hydrodynamic modeling are substantiated by independent calculations with the use of a model of water-salt balance in the lagoon according to which average salinity of waters in the lagoon will rise to reach 30–40 PSU by the end of the period p1.

In the scenario period p2 a considerable increase of lateral fresh water flow into the lagoon is expected. The inflow of mineral compounds of nitrogen will increase together with the flow, which will entail an increase of water-plant biomass in the lagoon as well as intensification of their 'blooming' (at the maximum values of the biomass). In spite of an increase of utilization of PO_4-P by the water plants, their concentration will also increase on the average due to additional input through the river flow. Considerable incidental diminishing in the concentration of PO_4-P is however possible in periods of 'flashes' of the biomass, especially in the shallow northern part of the lagoon. The mean values of phytoplankton biomass and concentrations of NH_4-N will restore to those of the reference period. The mean concentrations of PO_4-P and especially NO_3-N will rise.

The scenario period p3 is characterized by a lower river flow as compared to p2 and p0, which is, however, higher than p1. In the same period the temperature of water and air and, consequently, evaporation from the water surface in the lagoon will attain the maximum values. To set off the deficit of fresh water balance the inflow of salt waters into the southern part of lagoon through the channel will increase. Spatial distribution of phytoplankton biomass in this period will be characterized by the maximum values in the southern part of lagoon and minimum ones in the northern, where development of the water plants will be restrained by the lack of NH_4-N. The mean values concentrations of NH_4-N will be smaller and PO_4-P and NO_3-N will be greater than those for the period p0.

Parallel to a general tendency of increasing water temperature and phytoplankton biomass in the deep southern and central parts of the lagoon in the 21st century, the oxygen regime will also get worse, and the minima of oxygen in the benthic layer, especially in the central part, turn deeper.

Table 1 summarizes the above mentioned results.

Table 1. Relative changes (in %) of modelled hydroecological characteristics in lagoon for scenario periods p1-p3 comparing with reference period p0

Scenario	C-Phyto	NO_3-N	NH_4-N	PO_4-P	O_2	Salinity
p1/p0	−26.9	5.8	−32.5	9.9	−9.3	10.1
p2/p0	−1.0	30.6	−1.1	3.4	−11.2	3.9
p3/p0	−10.6	28.0	−12.1	6.0	−13.4	3.4

5. Conclusions

For the Tyligulskyi Liman lagoon, its biodiversity and fish productivity during the period p1 will be endangered by the gradual increase in the water salinity up to the mean values of 30–40 PSU. The increase will arise from the reduction in the freshwater inflow into the lagoon. Nevertheless, the mineral nitrogen will limit the production of organic matter by algae. During the period p2, the increasing freshwater inflow will diminish the problem of water salinity. However the additional input of mineral nitrogen will enlarge the primary production of organic matter; as a result, the eutrophication with all its negative effects, for example, hypoxia and anoxia, will develop. The high evaporation rate will be registered during the period p3. This will result in the inflow of sea water together with the mineral nitrogen that can deteriorate ecological conditions in the southern part of Tyligulskyi Liman.

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