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# COASTAL LAGOONS IN EUROPE

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# Chapter 9

# The physio-geographical background and ecology of Tyligulskyi Liman Lagoon

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**Summary:** This chapter summarizes the knowledge base on the physio-geographical background and ecology of the Tyligulskyi Liman Lagoon. The lagoon is located between the Dnieper and the Danube Rivers and is one of many lagoons in the Ukrainian part of the north-western coast of the Black Sea. The lagoon is connected to the Tyligul River basin, which is the main freshwater source for Tyligulskyi Liman. The natural resources of Tyligulskyi Liman include a unique coastal landscape, a rich flora and fauna, and mineral therapeutic muds. It is also an important place for weight gain, nesting and rest of migrant birds. Tyligulskyi Liman is included in the Important Bird Areas List and is a Ramsar wetland site, primarily due to the waterfowl habitat of international importance. The areas adjacent to the lagoon are mainly used for agriculture. The lagoon's unique characteristics are threatened by anthropogenic and climate change pressures. Numerous artificial reservoirs in the lagoon's drainage basin decreased the river water discharge. During the last decades, water salinity in the lagoon increased considerably due to reduced freshwater inflow from the drainage basin and intensive summer evaporation. As a result, the composition of fresh-brackish and brackish species is being substituted by marine and brackish-marine species.

**Keywords:** Biodiversity, ecological status, ecosystem services, land use, water demands, water resources.

## 9.1 INTRODUCTION

This chapter describes the physio-geographical and ecological conditions of Tyligulskyi Liman and its drainage basin. The coast of Tyligulskyi Liman is a natural reserve of Ukraine. It is a unique natural system with numerous natural resources that can be useful for the socio-economic development of adjacent territories, particularly for recreation, eco-tourism, public health, aquaculture, and fishing. In addition, the Tyligulskyi Liman Lagoon provides ecosystem services that can be used for better planning and conservation of the Tyligulskyi landscape park.

## 9.2 STUDY SITE DESCRIPTION

### 9.2.1 Characterization of the Tyligul River drainage basin

The Tyligul River is the main source (>90%) of freshwater into Tyligulskyi Liman and has a drainage area of 3,550 km$^2$ and a length of 173 km (Shvebs & Igoshin, 2003; Figure 9.1). The Tyligul River valley is about 3–5 km wide, while its floodplain is around 300–400 m wide; the latter reaches a width of up to 800 m towards the river's outlet. The river slopes are interspersed with gullies and ravines that reveal Pontian limestone. At the bottom of the slopes, cone-shaped accumulations of debris were deposited as a result of fine material inflow from the ravines. The watershed is characterized by forest shelterbelts, and the slopes are planted with forests. Ravine and valley areas are used as pastures, whereas floodplains are used to grow vegetables, plant gardens and vineyards. More than three quarters of the Tyligul River basin are covered by agricultural land. The existence of a large number of artificial ponds in the catchment area influences the hydrological regime of the river and the lagoon. The northern part of the drainage basin is located in the Northern Steppe and the southern part is located in the Southern Steppe; the latter has a more arid climate. The Tyligul River basin is an area with low *soil moisture*, a condition which is more severe in its southern part.

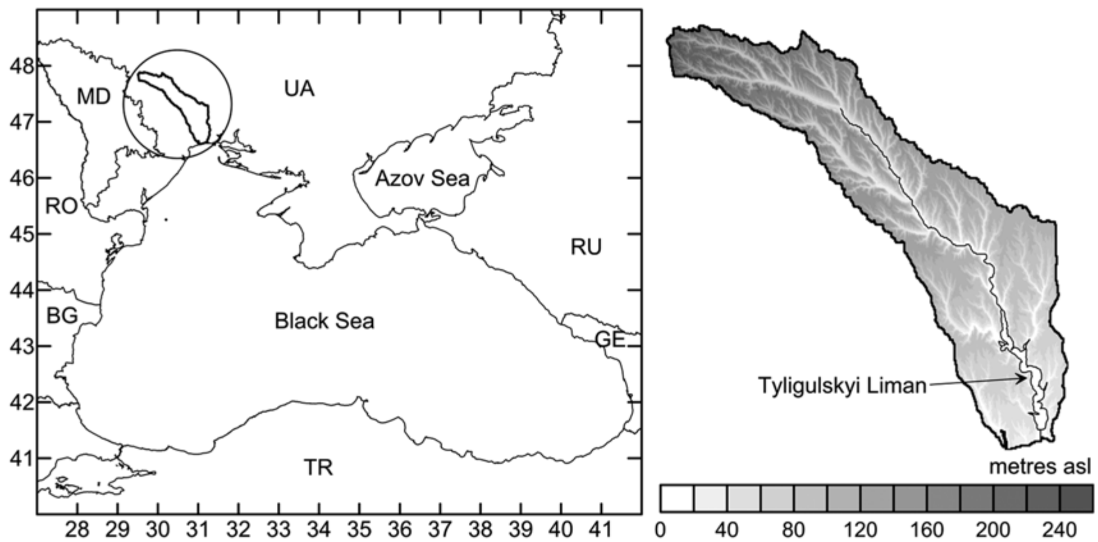


**Figure 9.1** Location and topography of the Tyligulskyi Liman lagoon basin area.

According to the hydrogeological zoning (Kamzyst & Shevchenko, 2009), the drainage area of Tyligulskyi Liman is located within the Black-Sea Coastal Artesian Basin. Aquifers are located between the layers belonging to the Quaternary and Neogene System, respectively. The first confining layer beneath the surface consists of marls and clays belonging to the Palaeogene System. The source of the Tyligul River is located at 260 m above sea level; from here, the landscape slowly descends into the coastal plains around the lagoon (see Fig. 7.1).

### 9.2.2 Characterization of the Tyligulskyi Liman lagoon

Tyligulskyi Liman is located on the Ukrainian coast in the north-western part of the Black Sea, 40 km from the city of Odessa at the border of the Odessa and Mykolaiv administrative regions (46°39.3′–47°05.3′N, 30°57.3′–31°12.7′E; see Fig. 7.1). The lagoon used to be a valley of the Tyligul River that was later flooded by seawater. It is 52 km long and 0.3 to 4.5 km wide. When the water level in the lagoon reaches 6.88 m (PSMSL, 2014), the estimated volume and surface area are $693 \times 10^6$ m$^3$ and $129 \times 10^6$ m$^2$, respectively. The mean depth of the lagoon is 5.4 m. However, the southern and central parts of the lagoon are deeper (10–16 m), and are divided by the shallow water close to the Chylova spit with a depth of only 4–5 m. The maximum depth in the southern part of the lagoon reaches 22.2 m, while the northern part is shallower with depths of up to 4 m.

Tyligulskyi Liman is separated from the sea by a sandy isthmus, which is up to 4 km wide and up to 6.6 km long. The isthmus is the result of wave-induced sand accumulations on the seashore, and has an area of about 14 km$^2$ and an annual debris accretion of $70 \times 10^3$ m$^3$. In the late 1950s, the isthmus was breached by an artificial channel connecting the lagoon with the sea. The aims were (i) to provide entrance for fish from the sea during spawning season, (ii) to control the water balance of the lagoon. Presently, the channel is 3.5 km long, 20–30 m wide and 0.25–1.5 m deep. Usually, the channel is opened manually during April–May by digging through its sea-side part, and is in use until the end of July–August, when sand accumulates again from the sea-side. Shallow salt lakes of 0.25–1.0 m depth are located in the low-lying areas of the isthmus, and these are fed with water from the channel.

The Black Sea areas adjacent to the lagoon are influenced by the Dnieper and the Southern Bug artificial waterways (the Dnieper-Bug connection). The total freshwater discharge from these rivers can vary from 650 m$^3$ sec$^{-1}$ during the summer to 2,100 m$^3$ sec$^{-1}$ during the spring floods. Therefore, the salinity of the sea water inflowing into the lagoon varies from 6–10 PSU in spring to 15–16 PSU in summer.

### 9.2.3 Hydrological regime

The water regime of Tyligulskyi Liman is determined by the water inflow from its drainage basin, the amount of atmospheric precipitation, the surface evaporation, the water exchange between the lagoon and the sea through the artificial channel.

The total annual surface water inflow into Tyligulskyi Liman is currently estimated to be $24 \times 10^6$ m$^3$. The annual surface evaporation is $93 \times 10^6$ m$^3$, and the input from precipitation is $58 \times 10^6$ m$^3$. Therefore, there is a negative water balance (about $11 \times 10^6$ m$^3$) even in an average year. This imbalance increases significantly in years with low precipitation and high evaporation. When the artificial channel is closed and there is no water inflow from the sea, the water level in the lagoon decreases. When the channel is open, the long-term mean annual amplitude of water level in the lagoon is 0.35 m. The water level rises from January to April and, in the following months, the level decreases, reaching the lowest water level in November. Maximum water levels in the lagoon can reach up to 7.58 m (PSMSL, 2014); this is usually observed in years with very high spring floods (e.g., March 2003). Whenever the connection of the lagoon with the sea is very weak (e.g., if the channel is not dug open or its discharge capacity is small) during a period of few years, the water level can decrease to 7.18 m (PSMSL, 2014) as it was registered during the period from 2006–07.

In the course of one year, the water temperature in the lagoon can vary widely; from −0.1–0.2°C in winter to 30–33°C in summer at shallow water (Polischuk *et al.* 1990). The highest water temperatures are usually registered in July and August. During these months, the diurnal variation of temperature in the shallow areas can reach 6°C. The annual variability of the thermohaline structure in Tyligulskyi Liman is characterized by the development of a seasonal thermocline in May. If hydrometeorological conditions are favourable (decreasing salt levels, intensive surface warming, lack of prolonged storm winds), the thermocline in the deep areas of the lagoon can be maintained until August. For example, by the end of July 2010, the water temperature in the deepest central part of the lagoon reached 28°C near the surface and 8–10°C at a 15 m depth. Nevertheless, in most cases, the sharp seasonal thermocline usually decreases by the end of June.

Another feature of the hydrological regime in Tyligulskyi Liman is the long-term trend in terms of increasing salinity. This increase can be explained by reduced freshwater inflow from the drainage basin and by the accumulation of salt from the sea through the connecting channel. In the 1960s, when the Tyligul River runoff constituted a considerable part of the water balance in the lagoon, the average water salinity was 8.7 PSU, 11.4 PSU, and 13–15 PSU in the northern part, the central part, and the southern part of the lagoon, respectively (Rozengurt, 1974). In the most recent years, water salinity in both the southern and the northern parts of the lagoon has increased to 19–23 PSU in late summer/early autumn. For example, during the period between May–October 2012, the water salinity in the central part exceeded 20 PSU, and reached a maximum of 23 PSU in October.

A certain decrease in water salinity was registered in years with heavy spring and short-term floods. For example, in March 2003, when the water level in the lagoon rose to 7.58 m (PSMSL, 2014), the salinity in the surface layer decreased to 6 PSU. The sharp seasonal pycnocline that followed these events was a result of the low salinity in the surface layer and the high water temperature in the summer, which did not allow a significant decrease of water salinity in the lagoon as a whole. In the late autumn of 2003, the salinity of the surface water layer increased to 17–19 PSU.

### 9.2.4 Meteorological characterization

The climate of Tyligulskyi Liman is temperate and continental, with low rainfall, short mild winters and long hot summers. Climatic variations can be quite extreme, but the vicinity of the Black Sea moderates summer temperatures and humidity fluctuations. During July and August, the daily air temperature usually exceeds 20°C. Also, there are long dry spells that can last for up to two months. On average, there are 27 dry days with a relative humidity lower than 30% (Passport, 1994). Winter (which lasts for about 80 days) is characterized by variable weather conditions with frequent thaws; daily temperatures can range from −20 to +15°C and precipitation is relatively low (70–90 mm). The coldest period is from 11 January to 10 February, with a monthly mean temperature of −4.7°C. Snow cover occurs on less than 40 days with a mean depth of 50 mm. Frost can penetrate the soil to a depth of 1 m (Passport, 1994).

## 9.3 WATER RESOURCES AND QUALITY STATUS

### 9.3.1 Water resources and demands

The results of the water-heat balance model (Loboda & Bozhok, 2014) showed that the mean long-term annual surface freshwater inflow from the drainage basin into Tyligulskyi Liman under natural, undisturbed by water dependent economic activities was $56 \times 10^6$ m$^3$. This value includes the annual runoff of the Tyligul River of $46 \times 10^6$ m$^3$. However, the actual annual runoff of the Tyligul River measured during 1992–2007 was $21.2 \times 10^6$ m$^3$, a value conditioned by the abundance of artificial reservoirs (ponds) in the drainage basin. The ponds are filled naturally with water during the spring floods, that is, thus reducing the river runoff. During the following summer, the ponds act as huge landscape evaporators and the water is permanently lost.

The predominant part of the annual runoff is usually registered during the spring flood period. In years when the snow cover is unstable or missing, the spring flood period can be totally absent. On the contrary, years with accumulation of snow in the drainage area and deep frost penetration result in high spring water discharges.

The subsurface supply of water to the rivers is insignificant, with $8.8 \times 10^6$ m$^3$, and is part of the reason why the rivers are drying out. For example, the downstream section of the Tyligul River runs dry during 90–240 days; particularly during summer and autumn (Passport, 1994). To secure water availability for irrigation, artificial reservoirs (ponds) were created, mainly along the riverbanks. There are 105 ponds down the Tyligul River with a total capacity of $10.2 \times 10^6$ m$^3$. Taking into account the other rivers in the region such as the Balaichuk, Tsarega and Khutorska, the total number of ponds is 140 with a total volume of $14 \times 10^6$ m$^3$. The technical standards of the ponds are very low; for example, the bottom and banks are not impermeable enough to avoid infiltration, self-action weirs often do not operate, and dams are poorly reinforced and partially destroyed. As a consequence, about 80% of these reservoirs dry up. The runoff losses incurred through the filling of the ponds and additional evaporation from their surface result in a decrease of the total water input to the lagoon of about 30–35% (Table 9.1).

**Table 9.1** Water resources of the rivers at Tyligulskyi Liman drainage basin under natural and under human activity (until 1989).

| **Rivers, inflows** | **Annual inflow into Tyligulskyi Liman ($\times 10^6$ m$^3$)** | |
|---|---|---|
| | **Natural conditions** | **With artificial reservoirs** |
| Tyligul | 46.00 | 33.00 |
| Tsarega | 3.90 | 1.91 |
| Balaichuk | 4.10 | 2.75 |
| Khutorska | 0.46 | 0.00 |
| Lateral inflow | 1.60 | 1.06 |
| **Total** | **56.06** | **38.72** |

Since the late 20th century, the water resources of the rivers are significantly impacted by aridity. Comparing the periods of 1989–2011 and 1953–1988, the mean annual runoff of the Tyligul River decreased by 37%. Thus, human activity (artificial reservoirs in the drainage area) together with climate change result in a decrease in the annual surface water inflow into Tyligulskyi Liman of about $24 \times 10^6$ m$^3$ (see Section 9.2.3).

Given the general shortage of surface water, groundwater is used for drinking and domestic water supply, meeting 92% of the water need. About 150 registered water consumers use groundwater in the Tyligul River drainage basin. They extract $3.62 \times 10^6$ m$^3$ of groundwater, of which $2.93 \times 10^6$ m$^3$ are for drinking and domestic purposes, $0.60 \times 10^6$ m$^3$ are for agriculture, and $0.09 \times 10^6$ m$^3$ are for industry. The groundwater is returned into the Tyligul River without any treatment as there are no waste water treatment plants.

## 9.3.2 Water quality status

In the case of Tyligulskyi Liman, the methodology used to estimate the quality of surface water was approved by the Ministry of Ecology and Natural Resources of Ukraine (Hritsenko *et al.* 2012). The methods used are based on the calculation of various indices concerning the content of biogenic elements and organic matter content. These methods classify the lagoon as a 'eutrophic β″-mesosaprobic weakly polluted reservoir with a water quality of class 4′. This is due to a high content of mineral and total phosphorus, organic nitrogen, and dissolved organic matter in the lagoon's water. The primary production of organic matter by algae is limited by the low content of mineral nitrogen. The overall ecological condition of the water in the lagoon classified as satisfactory.

According to the E-TRIX index (Moncheva & Doncheva, 2000), the trophic level of the lagoon corresponds to the 'middle' class.

The lagoon's ecological status was assessed using the use of the EBI index (Estuarine Biotic Integrity Index; Deegan *et al.* 1997) and the TFCI index (Transitional Fish Classification Index; Coates *et al.* 2007) based on data on fish assemblages. These two assessments showed that the lagoon is 'Medium' (EBI = 30) and 'Moderate' (TFCI = 33, EQR = 0.58).

The AZTI Marine Biotic Index, AMBI (Borja & Muxika, 2005), defines the assemblages of macrozoobenthos as 'Unbalanced', 'Slightly disturbed' with the ecological status of 'Good', and classifies the lagoon as 'Slightly polluted' (WFD CIS Guidance Document No. 5, 2003). Biotic indices show the negative influence of many factors on the lagoon's ecosystem such as the considerable seasonal and interannual variability of water salinity, the probable summer hypoxia, and the imbalance of the ecosystem with regard to nitrogen and phosphorus content.

## 9.4 NATURAL RESOURCES

The coast of Tyligulskyi Liman is, to a large extent, characterised by its landscape and rich biodiversity, including wave-cut niches, coastal benches, sandy spits and islands, shallow waters and water meadows, reed beds, steppe areas and woodlots, which offer favourable conditions for biological diversity.

The flora of the lagoon's coast includes more than 650 species of vascular plants. At least 70 plants are dominant in plant associations, and 22 species are in the National and International Red Books. The importance of vegetative cover at the Tyligulskyi Liman coast is mainly due to the representativeness of the steppe zone of southern Ukraine, the occurrence of plant associations registered in the Green book of Ukraine due to their rareness, and to the fact that these species are included in several lists of protected plants of international, national or local importance.

Tyligulskyi Liman is also characterized by a high level of faunal biodiversity. It represents 70% of the habitat for Ukraine's wetland avifauna; during the migration, nesting and wintering period, about 300 bird species can be found here. Among these, 26 species are registered in the Red Book of Ukraine, and three species (*Phalacrocorax pygmeus* (Pallas, 1773), nester; *Haliaeetus albicilla* (Linnaeus, 1758), bird of passage, wintering *Rufibrenta ruficollis* (Pallas, 1769), bird of passage) are listed in the European Red List. During the migration periods in spring and autumn, more than 70 species of wading birds dwell in the lagoon, in shallow waters and reaches (Integrated Land Use of Eurasian Steppes, 2008). The total number of birds varies between 2,000 and 7,000 couples. The population of wintering birds amounts to about 10,000 birds, and migrant birds contribute with about 8,000 individuals (Loieva, 2011).

More than 1,500 species of invertebrate inhabit the lagoon's coast. Twenty-three species of insects are listed in the Red Book of Ukraine, and two species, *Saga pedo* (Pallas, 1771) and *Zerynthia polyxena* (Denis & Schifermuller, 1775), are registered in the European Red List. In addition, seven species of amphibians, seven reptile species, and 31 species of mammals, can be found in the lagoon area; six of the mammal species are listed in the Red Book of Ukraine (Integrated Land Use of Eurasian Steppes, 2008).

A total of 118 species of planktonic algae, 51 species of bottom-living vegetation, including multicellular water-plants and flowering macrophytes, 30 species of meso- and macrozooplankton, 46 species of macrozoobenthos, and 25–30 species of fish are found in the waters of Tyligulskyi Liman (Zaitsev *et al.* 2006).

Tyligulskyi Liman is one of the few wetlands that have preserved its natural seaside landscapes; the ecosystem offers unique conditions for fauna and flora, and the lagoon is of great significance for the maintenance of the region's biological equilibrium.

### 9.4.1 Land use

Agricultural land occupies about 70–85% in the upper and lower parts of the Tyligulskyi Liman basin area and about 85–90% in the middle part. Around the lagoon, the percentage of arable land varies from 75 to 85% (Atlas, 2002). In the tilled areas, cereals and leguminous crops are prevailing (about 60%), fodder and industrial crops including sunflower and rape account for 20%, while the remaining 20% are comprised of cucurbitaceous species (Atlas, 2002). The typical cereal crop is winter wheat, but areas under winter barley and corn constitute a considerable share. Presently, there are 205 agricultural enterprises registered in the basin area, but only 54 of them cultivate areas of more than 1,000 ha. The slopes near the lagoon are used as pastures for grazing animals (for non-commercial use by local residents).

In the 1990s, numerous suburban, horticultural and gardening associations consisting of small plots of 0.06–0.12 ha adjacent to small buildings (summer cottages) were created along the western coast of Tyligulskyi Liman. During spring and summer, the population of these associations can increase up to 50,000 individuals.

### 9.4.2 Environmental conditions and issues

Due to the fact that the Tyligulskyi Liman area does not have large cities and large industrial enterprises, the lagoon can, to a large extent, preserve its natural features. However, the natural landscape and environmental conditions are influenced by agricultural practices (see previous sub-section). Soil tillage and grazing in the coastal protective strip and the application of fertilizers and pesticides contribute to the pollution of waters. Severe summer storms can cause an additional inflow of suspended sediments and organic matter into the lagoon. This leads to a reduced water transparency, an increased water temperature in the surface layer, and to the development of eutrophication with all its negative effects.

Additional anthropogenic pressure on the lagoon's ecosystem occurs due to intensive suburban settlements in the territories adjacent to the lagoon. There are now 16,000 suburban horticultural and gardening plots along the western coast of the lagoon. The negative consequences of these activities include the disturbance of the natural landscapes, bird habitats and nesting sites, destruction of unique flora and fauna, formation of landfills along the shore due to a lack of recycling facilities, domestic waste, and discharge of untreated sewage into the lagoon.

The present water management regime has transformed Tyligulskyi Liman into a stagnant reservoir. On the one hand, the water containing biogenic matter and salt flows into the lagoon from upstream rivers and streams, and from the sea through the connecting channel. A small volume of water also flows out to the sea. The significant summer evaporation contributes to water loss in the lagoon. The time of total water renewal from external sources is estimated to be 8 years. This results in long-term accumulation of salt and biogenic matter in the lagoon. At present, the concentration of both mineral and organic phosphorus and organic nitrogen in the water of the lagoon exceeds the concentrations in the upstream surface freshwater (rivers and streams) and the downstream sea water. The ecosystem of Tyligulskyi Liman is out of balance due to the relative share of the two main biogenic elements – nitrogen (N) and phosphorus (P). For example, the ratio of nitrogen and phosphorus concentrations, mgN/mgP, is 1:5 on average for inorganic forms, 14:1 for organic forms, and 4.5:1 for total nitrogen and phosphorus. Thus, the primary production of organic matter is evidently limited by the availability of nitrogen (Zaitsev *et al.* 2006).

As a result of increasing water salinity in Tyligulskyi Liman (Figure 9.2), the composition of fresh-brackish and brackish species has been replaced by marine and brackish-marine species. In comparison to the early 1980s, the percentage of phytoplankton marine species increased from 14 to 64%, marine and brackish-marine macrophytobenthos from 40 to 83%, and marine zooplankton from 40 to 90% (Zaitsev *et al.* 2006; Kovtun, 2012). Only four species of freshwater fish were found in 2013 in comparison to 12 to 25 during the period from 1960–80. The expected climate change can result in an increase of salinity of up to 40–50 PSU by 2050, and in a considerable reduction of water flora and fauna biodiversity (Loboda & Bozhok, 2014).

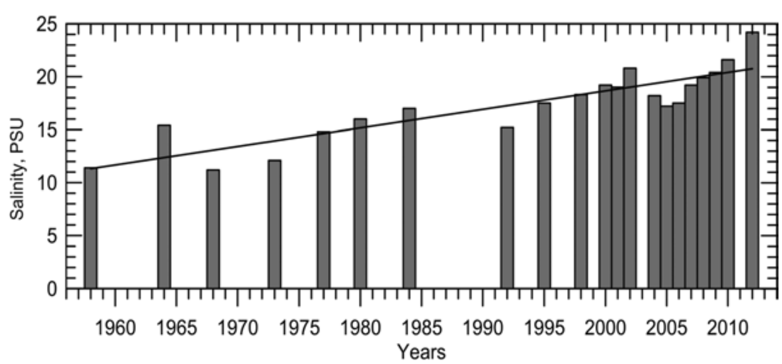


**Figure 9.2** Annual mean salinity in the Tyligulskyi Liman lagoon.

Significant storage of biogenic matter in the water and bottom sediments of the lagoon favours a high rate of organic matter production by phytoplankton and benthic macrophytes during spring and summer. When conditions are favourable, phytoplankton biomass in the photic layer can reach 40–160 g $m^{-3}$ (e.g., 2010). The amount of biomass of bottom-living macrophytes in the shallow (2 m depth) coastal area of the lagoon can reach mean values of more than 2 kg $m^{-3}$ during summer. Zaitsev *et al.* (2006) showed that the monthly mean concentrations of oxygen equivalent for the dissolved organic matter can vary from 6.0 to 11.3 mg $O_2$ $dm^{-3}$. It was also shown that the representative concentration of oxygen equivalent for the organic matter in the pore water of bottom sediments can reach up to 23–33 mg $O_2$ $dm^{-3}$. High content of organic matter in the water and the bottom sediment results in another problem the for lagoon's ecosystem: hypoxia and anoxia in the bottom layer of the deep parts as well as in the shallow parts in hot calm nights due to the 'bloom' of the phytoplankton and the benthic macrophytes. The lack of oxygen causes the death of hydrobionts. Massive fish kills in some parts of the lagoon were registered in the summers of 1999, 2000, 2001, 2006, 2007, 2010, and 2013. For example, in the summer of 2010, about 20 kg of dead fish per square meter were observed in some parts of the lagoon's coast.

The relative isolation of Tyligulskyi Liman from the Black Sea facilitates the preservation of the population of brown algae *Cystoseira barbata* (Agardh, 1820) that vanished in the north-western part of the Black Sea in the 1980s. Among the macrophytes inhabiting the lagoon, the species *Chara canescens* (Loiseleur Deslongschamps, 1810) is listed in the National Red Book, and two species of aquatic flowering plants, *Zostera noltii* (Hornemann, 1832) and *Zostera. marina* (Linnaeus, 1753), are in the Red Book of the Black Sea. The species *Vaucheria litorea* (Agardh, 1820) as well as the red algae *Rhodochorton purpureum* (Lighthfoot) (Rosenvinge, 1900) on the *Cystoseira barbata* (Agardh, 1820) are rare in Ukraine but are still dominant in the Tyligulskyi Liman area.

## 9.5 MARINE ECOSYSTEM SERVICES (CICES CLASSIFICATION)

The application of the Common International Classification of Ecosystem Services (CICES) to the Tyligulskyi Liman lagoon, as applied by Maes *et al*. (2014), is presented in Table 9.2. In order to simplify this representation we organized the ecosystem services provided by Tyligulskyi Liman into 'sections' and 'classes'. The CICES hierarchical classification table can also be seen in Chapter 19 (Table 19.2).

**Table 9.2** Ecosystems services delivered by Tyligulskyi Liman.

| | Class | Tyligulskyi Liman |
|---|---|---|
| Provisioning | Wild animals and their outputs | Fish (41 species, about 400 tons per year). Unknown quantity of edible mussels can be caught by local residents |
| | Fibres and other materials from plants, algae and animals for direct use or processing | Reeds are harvested, August through October, to be used in construction as an eco-material. |
| | Ground water for non-drinking purposes | Domestic and livestock brackish water (salinity lower than 4PSU) |
| Regulation and maintenance | Bio-remediation by micro-organisms, algae, plants, and animals | Seagrasses have the ability to bio-remediate, reducing availability of pollutants in the sediment and water column (organic pollutants). Decomposition/mineralisation processes of plant material mediated by micro-organisms; decomposition of waste materials for example, waste water cleaning, (phyto) degradation, (rhizo)degradation and so on. |
| | Filtration/ sequestration/ storage/ accumulation by micro-organisms, algae, plants, and animals | Sequestration and storage of nutrients through incorporation in biomass is performed by seagrasses and algae. Seagrasses accumulate pollutants (e.g., organic compounds) in their biomass and rhizosediment, thus removing or decreasing its availability in the environment. The macroinvertebrate communities perform an important function of organic substance transformation in the 'water column – bed silt' system that determines their significant role in self-purification of the lagoon. They play an important role in the biogeochemical turnover of biogenic elements in the lagoon specifically, removal of nitrogen and phosphorus from the bed silt as well as replacement of biogenic elements from the water environment to a surface through imago of amphibiotic insects. The benthic macroinvertebrates regulate gas regime and texture of soils. |
| | Filtration/ sequestration/ storage/ accumulation by ecosystems | Biophysicochemical filtration/sequestration/storage/accumulation of pollutants by seagrasses (plants and rhizosediment); adsorption and binding of organic compounds in ecosystems, as a result of combination of biotic and abiotic factors. |
| | Dilution by atmosphere, freshwater and marine ecosystems | Hydrodynamic dilution of pollutants inflowing into the lagoon with the river and the lateral runoffs, household sewage, sea waters, and precipitation. |

(*Continued*)

**Table 9.2** Ecosystems services delivered by Tyligulskyi Liman (*Continued*).

| | Class | Tyligulskyi Liman |
|---|---|---|
| Regulation and maintenance | Mass stabilisation and control of erosion rates | Stabilisation of water level in the lagoon by means of water exchange regulation with the sea through the connecting channel and, as a consequence, the decrease of erosion rate. |
| | Buffering and attenuation of mass flows | The lagoon acts as a buffer in the case of the lateral and the river runoff impact on the offshore strip. The connecting channel acts as a buffer in the case of sea water impact, wind-induced sea level variations, salt fluxes and sand drift into the lagoon. |
| | Flood protection | The lagoon is the water inlet during the spring high water and floods and prevents land floods in the basin. In the case of very high spring water, the channel is naturally washed out, and excess water outgoes into the sea. |
| | Maintaining nursery populations and habitats | Maintaining favourable environment for rare and endangered species of algae and xeropolum. |
| | Decomposition and fixing processes | Water flow induced erosion of tilled soils in the coastal zone of the lagoon during heavy rains, and humus inflow into the lagoon. |
| | Chemical condition of salt waters | Salinization of water in the lagoon, inflows of biogens and organics into the lagoon and their accumulation. |
| Cultural | Experiential use of plants, animals and land-/seascapes in different environmental settings | *In situ* bird watching |
| | Physical use of land-/seascapes in different environmental settings | The lagoon and the adjacent sea area are used for recreational activities, including swimming, fishing and kiting. |
| | Scientific | Tyligulskyi Liman is subject matter for research. |
| | Educational | The natural environment of the lagoon has an important value as an educational resource (tours, out-of-doors lessons). |
| | Heritage, cultural | Museums, archaeological excavations. |
| | Aesthetic | Sense of place; Artistic representations of nature; Inspiration for some painters and writers. |
| | Existence | Enjoyment provided by landscape |
| | Bequest | Willingness to preserve the Ramsar site for future generations |

## 9.6 FINAL REMARKS

Tyligulskyi Liman has unique environmental features. The landscape park located in the Tyligulskyi Liman area allows the preservation of diverse flora and fauna, representative of the steppe zone of southern Ukraine. However, several unfavourable conditions occasionally occur in the lagoon. For example, eutrophication quite often deteriorates water quality in the lagoon during its summer isolation from the sea, resulting in fish kills and the death of other living organisms. Also, the long-term increase in water salinity in Tyligulskyi Liman has resulted in the replacement of freshwater species by marine and brackish-marine species. The anthropogenic influence often plays a crucial role. The existence of many artificial reservoirs in the drainage basin resulted in considerable runoff losses. Therefore, more participative and sustainable management policies are needed, which will be discussed in Chapter 10.

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# COASTAL LAGOONS IN EUROPE

## Integrated Water Resource Strategies

Lagoons represent nearly 13% of the shoreline globally and around 5% in Europe. Coastal lagoons are shallow water bodies separated from the ocean by a barrier (e.g., narrow spit), connected at least intermittently to the ocean by one or more restricted inlets, and usually geographically oriented parallel to the shore-line. Coastal lagoons are flexible and usually able to cope with environmental change, yet nowadays they are under threat. This is partly due to climate change impacts (for example, sea-level rise and hydro-meteorological extreme events) but also due to more direct human activities and pressures.

The book focuses on addressing these challenges through integrated management strategies seen in a land-sea and science-stakeholder-policy perspective. Pan-European management challenges are seen from the context of the perspectives of Policy, Environment and Modelling. Four case study lagoons in different geographical locations in Europe provide examples of some of the practical experiences and results around these challenges. Possible impacts on drainage basins and lagoons are introduced through integrated scenarios which were developed through a multi-science and land-lagoon science perspective combined with interactions and contributions from stakeholders and citizens.

Issues around climate change impacts on environmental conditions in both drainage basins and lagoons are also included.

The book derives from a collaborative EC-funded project entitled *Integrated Water Resources and Coastal Zone Management in European Lagoons in the Context of Climate Change* comprising nine partner institutes with a wide diversity in the scientific disciplines covered.

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