# Chapter 6
# Black Sea Environmental Status Improvement Through the Restoration of Wetlands Along the Danube River

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**Abstract** The Black Sea is heavily impacted by human activities, and a large contribution is made by the rivers. The Danube River provides almost 70% of the river inflow to the Black Sea and changes within the river basin are having an important contribution to the status of the sea. The once extensive floodplain of the Danube was severely diminished during the last two centuries. The Danube Delta is the largest wetland left along the Danube and acts as a buffer zone between the river basin and the sea, regulating the sediment and water transfer. The river, delta and marine basin function as a single geosystem. Restoration of the former wetlands will improve the quality of the aquatic resources, both freshwater and marine. Re-establishing the hydrological dynamics and connectivity is essential, since all other processes are influenced by the flow regime. The restored wetlands along the Danube floodplain and delta will then limit the carrier effect of the river and reduce the load of pollutants and nutrients transported to the sea.

**Keywords** Wetlands • Black Sea • Danube • Ecosystem improvement • Restoration • Impact

## 6.1 Introduction

Humanity has a long history of mismanaging aquatic systems throughout the world, be it marine or freshwater. While many issues related to water shortages, deterioration, overexploitation and overall decrease in the quality and quantity of goods and

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V. Lagutov (ed.), *Environmental Security in Watersheds: The Sea of Azov*, NATO Science for Peace and Security Series C: Environmental Security, DOI 10.1007/978-94-007-2460-0_6, 

services provided seem local, they are in fact global in scale [21]. Improving the management of aquatic resources requires understanding and accepting the complexity of the processes involved and their different time-space scales. Already large scale approaches are being implemented in water management: the integrated river basin management, based on the ecosystem approach developed under the Convention on Biological Diversity, and the regional seas programme of the United Nations Environment Programme (UNEP). For example the European Union (EU) has implemented the river basin management concept since 2000, within the EU Water Framework Directive. River basin and regional seas management approaches are an important step towards achieving proper us and status of aquatic resources. The river with its unidirectional flow connects even remote areas within the river basin with the sea and acts as a carrier for the outputs of most human activities (e.g. pollutants). Water discharge is the main factor controlling matter transfer from land to sea by rivers. These river basin-sea interactions require a large time-scale conceptual framework in planning and management.

One of the best examples documenting the impact of rivers on the coastal areas is represented by the Black Sea basin and its main tributary, the river Danube. The Black Sea was less than two decades ago considered a major environmental disaster [13], and this has triggered extensive studies and management and conservation measures. This included signing in 1992 the Convention on the Protection of the Black Sea against Pollution (Bucharest Convention). In a similar way, the Danube River benefited from a major regional conservation approach, the International Commission for the Protection of the Danube River (ICPDR). While both initiatives are encouraging, proper management requires a combined approach for the Danube River and Black Sea. In this chapter I will briefly discuss the need for a joint management program for the Danube River and Black Sea, and how restoring the functions of the wetlands associated with the floodplain helps to improve the status of the sea.

## 6.2 The Black Sea

The Black Sea is the largest land-locked sea, connected to the Marmara Sea by a narrow strait 35 km long, the Bosporus. There are three major parameters that characterize an enclosed sea: (1) the water budget, (2) the water retention time, and (3) the load of contaminants. The general nature of the enclosed seas depends on the water budget, i.e. the outputs of freshwater through evaporation versus the inputs from rain and runoff from land. If the evaporation rate is higher than the input, the surface waters become denser and sink, resulting in considerable vertical mixing of the water and in oxygen transport towards the deeper water bodies (e.g. the Mediterranean Sea). When freshwater inputs exceed evaporation the lighter water bodies remain floating over the higher density water bodies. Oxygen is not replenished and becomes depleted or even absent in the deeper parts. This is the case of the Black Sea that receives more freshwater than is lost through evaporation resulting in a positive budget. The differences in the density of water bodies results in a highly stratified water column that causes steep physical and chemical gradients. Thus, the largest proportion of the Black Sea waters (87%) lack dissolved oxygen [15].

The water retention time refers to the time period required to replace completely the water from a water body, as the sum of the inputs and outputs. The retention time is of major importance in how contaminants are retained or accumulated in the water body. If the retention time is short, contaminants do not accumulate, while for high retention time the load of contaminants can become significant. Of equal importance in estimating the water quality and impact of pollution is the load of contaminants. This parameter is influence by both the amount (i.e. contaminant load) and the persistence and toxicity of each compound. The total amount of contaminants entering a sea depends on the population size within its catchment, on the industrial and agricultural development, and on the level of treatment of wastewater treatment. The Black Sea has a huge drainage basin of 2,405,000 km$^2$ that includes parts of 21 countries, with over 170 million inhabitants. This means that the load of contaminants reaching the sea is extremely high. The ration between the sea surface and drainage basin is about 1:6, indicating that each square km of sea drains 6 km$^2$ of land, indicating a major contribution of surrounding ecosystems.

The Black Sea suffered numerous changes in size, salinity, and connectivity during the geological periods: initially it was an arm of the ocean, then part of a large inland sea, it then almost dried out and after being refilled became a deep freshwater lake [10]. During the last Ice Age it was a shallower freshwater lake until the rising ocean level reconnected it through the Marmara Sea to the Mediterranean and then to the Atlantic Ocean. There are still debates regarding the timing and way the connection was made. The gradual inflow model suggests that the first connection was made about 9,000 years ago, with the depth of the Bosporus Strait deepening slowly, causing an increased exchange of water with the Black Sea that gradually became brackish [27]. The catastrophic flood model states that about 7,160 years ago the connection was abruptly made and water from the Marmara flooded the present day Black Sea basin [28]. The reconnection of the Black Sea to the ocean triggered both an increase in the sea level and an increase in salinity that reached rapidly the present concentration of 18–22‰, making it a brackish sea, well below the ocean salinity level of 35%.

Presently the Black Sea (excluding the Azov Sea) covers an area of 436,400 km$^2$, has a water volume of 547,000 km$^3$ and a maximal depth of 2,212 m. After the initial increase in salinity, it achieved the mineral budget equilibrium about 1,000 years ago and natural changes still take place. Therefore it is difficult to separate natural processes from man-induced ones.

The Black Sea is heavily impacted by human activities that resulted in heavy pollution and eutrophication [16], overexploitation of fish stocks, introduction of alien species [8], coastal wetland destruction and coastal erosion and the subsequent coastal engineering works [34], off-shore oil and gas production [26]. High levels of riverine nutrient input during the 1970s and 1980s caused eutrophic conditions in nearby coastal areas. This in turn triggered frequent and intensive algal blooms resulting in hypoxia and the subsequent collapse of benthic habitats on the northwestern shelf [16]. Coastal areas are one of the most important and valuable areas from a human perspective. They provide nonrenewable (e.g. oil, gas, sand, gravel) and renewable resources (e.g. food and animal feed, raw materials for pharmaceutical industry), transportation, waste disposal and recreation. Coastal erosion and degradation require extensive restoration measures, usually at high costs [14, 34].

Some of the human-induced impacts are related to marine shipping and coastal development, but others are carried by rivers (e.g. pollutants and nutrients). Thus changes within the river basin are having an important contribution to the status of the sea. My focus will be on the Danube River which provides almost 70% of the river inflow to the Black Sea [11].

## 6.3 The Danube River

The Danube River is the second largest European river after the Volga. It is 2,860 km long and has a drainage basin of 801,500 km$^2$ that includes territories of 19 countries, with more than 83 million inhabitants. The average water flow of the river upstream the delta is 6,300 m$^3$/s, ranging between extreme values of 1,500 and 19,000 m$^3$/s. The Danube, unlike the other European rivers, is only slightly developed, especially downstream Vienna (Austria). This constitutes one of the river's most valuable assets.

Humans have always settled along large rivers that provided water, food, shelter, construction materials and a transportation route. For centuries humans attempted to control flood levels and erosion to protect their settlements and agriculture fields [9]. Impacts along river banks are old and huge transformations occurred along the Danube River.

Draining a territory almost twice the Black Sea area, the Danube River is the most important sediment provider of the sea, its influence extending down to the deep sea floor [25]. The freshwater input of the Danube River and its associated contaminants are transported by gyres throughout the Black Sea. Thus the river acts as a "carrier" of human impacts over large distances, finally impacting the sea.

The connectivity of the Danube River and its tributaries was disrupted by more than 500 larger dams and reservoirs with a capacity over five million m$^3$ [23]. In the nineteenth century before the major rectification and dam building started along the Danube and its main tributaries, the river carried an estimated 65 million tons of sediments per year, of which almost 5 million tons (7.5%) were retained in the delta [4]. After the construction of the Iron Gates dam was completed in 1971, sediment discharges diminished by 30–40% [24], creating a sedimentary deficit in the littoral zone. Combined with the extended damming and rectification works along the Danube and its tributaries, the sediment load transported and reaching the Black Sea littoral zone was reduced to 38 million tons (58%) [24]. These changes affected not only the amount but also the quality of the sediments, with average sediment size shifting from large to small sized particles [4]. The construction of the Iron Gate Dam also contributed to a reduction in the dissolved silicate load of the river by 2/3.

This caused a similar decrease in wintertime dissolved silicate in central Black Sea surface waters [11]. Due to the gentle slope of the lower floodplain of the Danube, the construction of dams below the city of Turnu Măgurele is not possible, thus at least 850 km (30%) are free flowing, but still impacted by levees and draining of associated wetlands. Over the 1960–2000 periods, river freshwater discharge to the Black Sea remained more or less constant [18].

Floodplain Rivers are non-equilibrium systems, depending on the shifts in water level. Their ecological integrity depends upon a certain level of disturbance. Flood events are vital in shaping and maintaining the complex landscape structure of terrestrial, aquatic and semi-aquatic ecosystems [33]. The hydrological connectivity facilitates the exchange of matter and energy between different landscape elements and promotes the functioning of the system. In addition, the floodplain provide shelter for the biota during harsh conditions (e.g. drought, pollution events, high floods) while riparian corridors play a key role in facilitating migration [17].

The Danube had a large floodplain that expands into a delta before reaching the Black Sea. The large floodplain of the Danube provided a huge water storage capacity in the associated wetlands, where water was retained during high floods and slowly released afterwards. The associated wetlands also ensured water purification, sediment and pollutant trapping, greatly improving the quality of water that reached the Black Sea. Almost two centuries of channelization, damming, confining by levees and draining of associated wetlands have severely diminished it. Presently most of the length of the main stem of the Danube River and the major tributaries are confined by flood control dikes [23]. For example, over the past 50 years more than 90% of the Upper Danube and its major tributaries have been dammed for hydropower production [29]. Thus there are virtually no free-flowing sections left upstream Vienna [29]. Only during the last 50 years the natural alluvial flood plain areas have declined from about 26,000 km$^2$ to a mere 6,000 km$^2$ (about 23%) [23]. This has resulted in a severe reduction in surface connectivity and the fragmentation of the once continuous riparian and floodplain ecosystems (Table 6.1). At present, later exchange processes of matter are restricted to short-term flood pulses, while most of the year backwater processes are disconnected from the river system [33]. The reduction of wetlands associated to the floodplain coupled with an increase in the load, diversity and toxicity of pollutants, resulted in an additional impact for the Black Sea already affected by coastal, shipping and off-shore activities.

## 6.4 Danube Delta

The Danube Delta is one of the main components of the Danube River system and is of recent origin, perhaps less than 7,000 years ago, starting after the reconnection of the Black Sea to the ocean. Its genesis and later rapid expansion are due to the low tidal oscillation of the Black Sea (5–7 cm), the large and shallow continental platform, the strong North-South littoral current and the high sediment load transported by the Danube. The delta was described as diverse, dynamic and fragile [2].

**Table 6.1** Major human activities and impacts in the Danube river floodplain

| | Type of activity | Purpose | Impact | Ecological services lost or diminished |
|---|---|---|---|---|
| 1 | Wetland drainage | Agriculture and urban development | Destruction of wetlands and fragmentation of floodplain connectivity | Sediment retention<br>Water storage<br>Maintaining high biodiversity<br>Nutrient retention and cycling<br>Pollutants retention and breakdown<br>Climate regulation<br>Recreational and aesthetic |
| 2 | Dykes | Protecting localities and economic activities from floods | Isolation and fragmentation of wetlands associated with the floodplain | Sediment retention<br>Water storage<br>Maintaining high biodiversity<br>Nutrient retention and cycling |
| 3 | Channelization | Navigation, flood control, erosion prevention, infrastructure | Disrupts the floodplain structure and destroys the riparian habitats | Diffuse pollution control by riparian vegetation<br>Maintaining high biodiversity<br>Water storage |
| 4 | Dam construction | Water supply and hydroelectric power | Creation of reservoir disrupts the connectivity of the river and limits dispersal of biota | Sediment transport<br>Maintaining high biodiversity |
| 5 | Water abstraction | Water for domestic, industrial or agricultural use | Decrease in water flow and floodplain water table, increased salinity at sea level | Biological productivity of aquatic habitats<br>Aquifer recharge |
| 6 | Dredging | Gravel and sand extraction, facilitating navigation | Bank instability, increased erosion and water flow | Sediment retention<br>Maintaining high biodiversity |
| 7 | Fishing, forestry and reed harvesting | Food and animal feed, wood and timber, construction materials | Decrease in biodiversity, overexploitation | Maintaining high biodiversity<br>Carbon sequestration |
| 8 | Introduction of alien species | Improve yields in fisheries and forestry | Decrease in biodiversity | Maintaining high biodiversity |

Adapted after Mant and Janes [19]

Activities 1–3 cause deterioration, destruction and fragmentation of natural habitats, while activities 4–8 represent exploitation of natural renewable resources

It is a disturbance-dominated system, with seasonal floods covering large areas within the delta and controlling most of its processes and functions. The delta has a typical triangular shape, having 65–85 km from the apex to the coast, and is up to 70 km wide between the branches. There are about 3,500 km of natural channels and artificial canals, connecting more than 450 lakes.

The Danube Delta represents the interface between the Danube River Basin and the Black Sea and acts as a buffer area by regulating the water and sediment transfer. These three factors combined: river, delta and marine basin function as a single geosystem [25]. The delta has an area of 5,500 $km^2$ that represents only 0.67% of the Danube River Basin and only 1.2% of the Black Sea area. The delta fulfills a number of important ecological services: hydrological, biological productivity, high biodiversity, ethno-cultural diversity, tourism and recreation. With regards to the Black Sea the delta provides important ecological services by purifying, detoxifying and overall improving the quality of the Danube waters reaching the sea.

### *6.4.1 Human Impact in Time*

For over 150 years the Danube Commission has supervised, regulated and controlled navigation. In the nineteenth century, the Danube Commission dredged and enlarged the Sulina arm for navigation. At the beginning of last century two canals were dredged to increase the influx of freshwater in the Razelm lagoon. Later, during 1938–1940 3,400 ha of Tataru Island were dyked and in the early 1950, the industrial exploitation of reed was started. During 1983–1989 the most complex and destructive activities in the delta started under the “Programme for the remodeling and integral use of the natural resources in the Danube Delta”. The Danube Delta was affected by increased pollution and accelerated eutrophication, habitat destruction due to hydro-engineering works that decreased the ecotonal areas along the river branches and channel banks, overfishing, and introduction of alien species. The dyked areas represented 97,408 ha, of which 39,974 were drained for agriculture [31]. These negative effects were amplified by the destruction of almost 450,000 ha of wetlands associated to the floodplain upstream the delta of a total floodplain area of 540,000 in Romania only [30]. Hydro-engineering works also impacted water flow throughout the delta. The total length of the channels doubled as a result of hydrotechnical works from 1,743 to 3,496 km [7], causing an increase in the discharge of the river from an estimated 167 $m^3$/s before 1900 to 620 $m^3$/s in 1989 [3]. This induced the siltation of lakes and accelerated eutrophication. Thus the ability of the delta to cope with the increasing load of contaminants was severely diminished by the huge engineering works. The Danube Delta is divided between Romania (80%) and Ukraine (20%). The cooperation between the two countries for the proper management of the delta and nearby coastal areas are hindered by a conflict over territorial water delimitation around the Snake Island, and the alleged environmental impacts of the construction of the Bastroe canal by Ukraine.

### 6.4.2 Wetland Restoration

Wetlands and coastal areas are some of the most valuable ecosystem types of the world [6], with estuaries valued at 22,832$ $ha^{-1}$ $year^{-1}$, followed by wetlands with 14,785$ $ha^{-1}$ $year^{-1}$, lakes and rivers with 8,498$ $ha^{-1}$ $year^{-1}$ and coastal areas 4.052$ $ha^{-1}$ $year^{-1}$. For comparison grasslands were valued at only 232$ $ha^{-1}$ $year^{-1}$. The value of a wetland varies largely and one of the important parameters that must be accounted for is the hydrogeomorphic location, with connected wetlands having higher values than isolated ones [22].

In the past, the wetlands associated with the Danube floodplain including the delta contributed to the improvement of water quality. To improve the status of the Black Sea, restoration of the wetlands upstream and within the delta is needed. Restoring wetlands along the Danube floodplain and delta will limit the "carrier effect" of the river. The necessity and feasibility of different restoration projects are considered for different former wetlands (e.g. [5, 12, 29, 32, 33]). Re-establishing the hydrological dynamics and connectivity is considered the most important step, since all other processes are influenced by the flow regime [33].

After 1990, several major restoration projects were started in the Danube Delta, promoting the restoration of wetlands dyked and dammed in the past: Babina, 2,100 ha (polder for agriculture), Cernovca, 1,580 ha (polder for agriculture), Holbina-Dunavat, 5,630 ha (ponds for fish farming), Fortuna, 2,115 ha (polder for agriculture/forestry), Popina, 3,600 ha (ponds for fish farming) [31]. Most of the restoration activities were focused on reconnecting the area to the river by rehabilitating the hydrological system. This in turns allows the rehabilitation of the transformed ecosystems and the reintegration into the complex natural landscape. The restoration of the natural resources and ecological functions should enable the local populations to proceed to their traditional and sustainable use. Restored wetlands have generated important direct economic benefits, resulting in higher yields of fish, reed, medicinal plants and increased value for tourism [30].

The economic collapse of the former Socialist countries followed by improved wastewater management, and the recent restoration of wetlands has lead to a decrease in the loads of pollutants and nutrients entering the Black Sea. Signs of recovery became evident rapidly, within 5 years after the intensive farming ended [20]. Nevertheless, a recent study has forecasted that if regional development follows as predicted, the Black Sea ecosystem will likely return to its highly eutrophic state of the 1980s and the recent recovery will be reversed [16]. The Black Sea states made considerable progress in coastal planning and management leading to more sustainable use of the coastal zone (e.g. [1]). The Black Sea countries have agreed on the necessity of reconstruction of existing management systems in compliance with ICZM principles in the Ministerial Declaration on the Protection of the Black Sea, Odessa Declaration (1993), the Strategic Action Plan for the Rehabilitation and Protection of the Black Sea, Istanbul (1996), and in the new Strategic Action Plan for the Environmental Protection and Rehabilitation of the Black Sea, Sofia (2009). Environmental management of the Black Sea is further complicated by the fact that 9 of the 16 countries comprising the majority of its catchment are non-EU states. Nevertheless the progresses made so far have paved the road for an integrated management of rivers and seas.

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