Environ Earth Sci (2014) 71:3559–3570
DOI 10.1007/s12665-013-2747-7

ORIGINAL ARTICLE

Dynamics of the Kopački Rit (Croatia) wetland floodplain water regime

Lidija Tadić · Ognjen Bonacci · Tamara Dadić

Received: 12 February 2013 / Accepted: 19 August 2013 / Published online: 3 September 2013

Abstract Kopački Rit Nature Park is part of the Danube River natural floodplain and one of the last oases of wild life in the Danube River Basin. Due to its extraordinary value, it was inscribed on the list of Wetlands of International Importance in 1993. More than 2,000 species have been registered in this area, which consists of lakes, canals, grassland, marshland and forests. Even the number of investigations which have been performed on its biological and ecological features, hydrological and water resources characteristics, as a prerequisite for ecohydrological analyses, are still rather unknown in the scientific community. Mainly the Danube River and partly the River Drava cause flooding of Kopački Rit and inundations enter the area from both the northern and southern parts. Results of hydrological and meteorological analysis show a decreasing trend of both mean and minimum, annual water levels in the Rivers Drava and Danube (respectively 1.8 and 1.38 cm/year). These reductions in water level can reduce the replenishment periods of Kopački Rit Nature Park. In addition, a significant rise of mean annual air temperature and consequently water temperature (data 1988–2011) may be causing increasing evapotranspiration and loss of water within Kopački Rit. But an encouraging counteracting finding is that, the results of frequency analysis show, even a discharge of 5-years' return period on the River Danube inundates 70 % of the Danube floodplain and Kopački Rit Nature Park.

L. Tadić (✉) · T. Dadić
Faculty of Civil Engineering, University of Osijek,
Crkvena 21, 31000 Osijek, Croatia
e-mail: ltadic@gfos.hr

O. Bonacci
Faculty of Civil Engineering, Architecture and Geodesy,
University of Split, Matice hrvatske 15, 21000 Split, Croatia

Keywords Wetland · Floodplain · Water level · Water regime · Kopački Rit

Introduction

The Kopački Rit Nature Park was formed during Pleistocene and Holocene epochs and represents one of the most important and very well naturally preserved wetlands in Europe. During this time tectonic subsidence turned the Danube and Drava Rivers into their present stream directions. This Nature Park preserves floodplain ecosystems, hosts a wide diversity of life and earns its place as one of the treasures of the Danube river basin.

Wetlands can be defined directly or implicitly in a variety of ways given that several factors, including personal perspective, position in the landscape, wetland diversity and function, have influenced their definition (Kent 2001). This is especially true in case of Kopački Rit, which is at the same time: (1) wetland, (2) the Danube and Drava Rivers floodplain, and (3) inner delta. Bridge (2003) defined a floodplain as a strip of land that borders a stream channel, and that is normally inundated during seasonal floods. Amoros and Bornette (2002) explained particularity of connectivity and biocomplexity in water bodies of riverine floodplains. Floodplains are among the most valuable, and also the most degraded ecosystems in Europe. Floodplain-river ecosystems are natural fragmented systems with periodic hydrological connections (Thoms et al. 2005; Merz et al. 2009). For nutrient dynamics in these systems the most important factors are the location of the floodplain water bodies regarding the river (spatial dimension) and its hydrological connectivity (temporal dimension). To understand wetlands it is necessary to have detailed knowledge of water flow and sediment transport in their complex systems. The problem of excessive accumulation of organic and inorganic compounds in floodplains caused by anthropogenic activities has been recognized in many countries (Merz et al. 2009; Azevedo and Goncalves 2009; Slowik et al. 2010; Vandeberg et al. 2011; Zglobicki et al. 2011; Franz et al. 2012; Altdorff et al. 2013; Rodrigues et al. 2013). In particular the influence of surface drainage of agricultural land has been shown to be a significant source of the accumulation of trace elements in floodplains (Elwaseif et al. 2012; Magner et al. 2012; Castaldelli et al. 2013).

In Kopački Rit Natural Park floods of the Danube River play crucial biological and geomorphological role. They cause hydraulic disturbance, which is important in determining the composition of biotic communities in the analysed space. The hydrological, as well as the dynamic meandering processes of the two rivers, have turned Kopački Rit Nature Park into a mosaic of lakes, marshes, wet grasslands, reed beds and riverine forests. Water flow as well as sediment transport and deposition in the whole area of Kopački Rit are very complex due to the previously mentioned geomorphological and vegetation forms. At the same time the analyses of this, extremely dynamic system, in space and time, should consider structures produced by humans (and animals), as for example: construction of canals, operation of pumping stations, functioning of levees, etc. All anthropogenic interventions in this area are relatively small but very often uncontrolled.

Although the Danube and Drava water regimes are the basis of existence of Kopački Rit wetland, the first comprehensive investigations of its hydrological characteristics were only carried out at the end of seventies. They prevail until nowadays due to the extremely complex and dynamic hydrological and hydraulic behaviour of the area. Besides the moving of the Drava River mouth into the Danube and the moving of the main Danube watercourse too, inside the Kopački Rit, parts of the land and water areas change their magnitude, shape and function, depending on floods. Understanding the relationship between spatial (location of the floodplain water bodies regarding the river) and temporal (hydrological connectivity between the river and its floodplain) dimensions can contribute to the importance of healthy floodplains for the maintenance of water quality and environmental conditions in the Danube River.

Despite the global importance of the Kopački Rit in European ecological system, the number of papers published in international journals is not satisfactory. Mainly they considered ecological, chemical and biological aspects of this system (Hein et al. 2003; Peršić et al. 2005, 2009; Horvatić et al. 2006; Palijan and Fuks 2006; Čerba et al. 2009; Mihaljević et al. 2009; Peršić and Horvatić 2011). Papers dealing with water resources dynamic and hydrological and climatological aspects of this valuable and vulnerable area are rare and mainly published in the Croatian language (Đuroković and Brnić-Levada 1999; Maričić 2005; Schwarz 2006; Tadić et al. 2013). With this paper the authors wish to fill existing gaps and inform broader scientific community about these aspects of the Kopački Rit Nature Park, as a basis of all other processes.

The best management of wetlands and associated ecosystem services requires accurate and up to date knowledge of wetland location and character. In the face of climate and land-use change, wetlands must be monitored routinely. Wetland mapping is an essential part of this monitoring program. Lang et al. (2012) stressed that even the most accurate US wetland maps contain relatively high levels of error in areas that are difficult to map. Due to their dynamics and complexity, floodplain wetlands are one of the most difficult types of wetland to map. This is especially the case in low topographic relief areas such as Kopački Rit. This paper presents geomorphological features of Kopački Rit, which essentially influence water inflow, outflow and storage in this system. Special attention is given to analyses of water velocities in the system as these are a crucial parameter of sedimentation.

The main goal of the paper is investigation of Kopački Rit wetland and floodplain water regime to explain better, and understand its influence on the complex ecological processes. The purpose of this paper is to give ecologists crucial water resources, hydrodynamics and hydrological data and information of the Kopački Rit, which shall be essential and inevitable for their future investigations. Due to strong and uncontrolled anthropogenic influences as well as climate variability and/or changes, this is the only way to ensure sustainable development of this extremely important and endangered European wetland. Currently Kopački Rit looks like a wetland paradise when in fact it is very vulnerable space which should be better protected.

Study area

Kopački Rit Nature Park was recognized 45 years ago and was protected by law in 1967 as a nationally valuable area. In 1993 Kopački Rit was protected by the Ramsar Convention and entered onto the list of the internationally important wetlands. The study area is located between 45°32′ and 45°47′ northern geographical latitude and 18°45′ and 18°59′ eastern geographical longitude. The lowest point is only 78 m a.s.l. and the highest is 86 m a.s.l. Figure 1 represents location map indicating the study area with the sites of water level and discharge gauging stations, meteorological station Osijek, pumping stations, main canals, lakes and embankments.

The total area of Nature Park Kopački Rit is about 18.000 ha and it is bordered by two mighty rivers: the

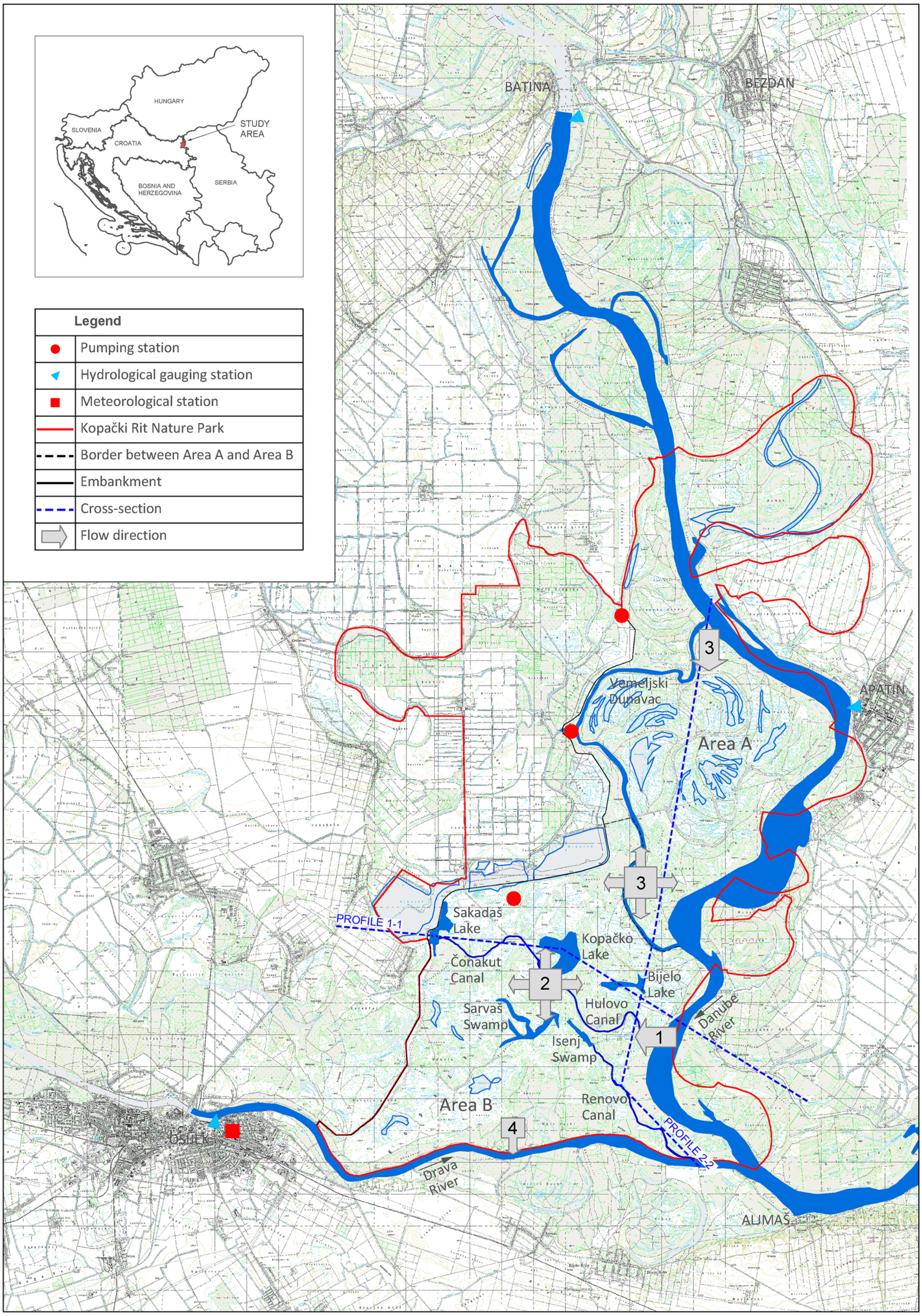


Fig. 1 Location map of the study area with the sites of water level and discharge gauging stations and meteorological station Osijek and inflow and outflow directions

Danube and Drava and the Drava-Danube embankments. The surface drainage system of the agricultural fields outside Kopački Rit conveys water by gravity to the Nature Park. Inside Kopački Rit, the water regime is managed by three pumping stations that pump water from the surface drainage system to the upper part of the Nature Park (area A) and lower part (area B) (Fig. 1). The total length of canals in the system is 965 km.

Fluctuating water levels in the area create a wide variety of habitats and generate high biological diversity. In the National Park area, more than 2,000 species are registered. There are over 460 species of vascular plant, 294 birds, 56 mammals, 55 fishes, 11 amphibians and 10 reptile species. The existence and ecological equilibrium of Kopački Rit Nature Park depends on flooding regime of the Danube River, while the Drava River has significantly less importance (Tadić et al. 2013). Kopački Rit has served as a shelter for many species in the past and is therefore a 'gene pool' for many healthy species as well as a refuge for endangered ones. Water level variability and alterations of canals, lakes and depressions size and shape and substrate characteristic, have been shown to have crucial impacts on benthic invertebrates and aquatic macrophytes (Brookes 1994). In this way they strongly influenced all other ecological processes. Peršić and Horvatić (2011) state that lateral flood pulse connectivity along with the duration of inundation period affects the input and the retention of nutrients, mostly of nitrogen.

The numerousness and variety of microorganisms, which have an essential role in the self-purification of Kopački Rit water, highly depend on water level fluctuations. Regular exchange of swampy water and the Danube River water suits development of phytoplankton. The more than 360 taxes of the algae offer an unlimited source of fish food (Mihaljević et al. 1999). So, the average annual fish production is about 90 kg/ha. Phytoplanktons are the most sensitive species to water velocity. During inflow and outflow of water the number of autochthon taxes in lakes decreases. Extreme flood events also endanger their lives, but incoming of water rich with nutrients acts favourably on their numerousness.

The basic ecological recognisability of Kopački Rit creates a great number of bird species. There are 294 bird species. About 140 species nest regularly in the area. The main value is the numerousness of some species. A similar situation exists with red deer, whose population is three times greater than in any other European habitat (Mihaljević et al. 1999). Vegetation cover also varies depending on water depth and its development is caused by the water regime during spring and summer. Forests have developed on topologically higher and drier areas. Reeds around lakes create the characteristic landscape.

Danube flooding and water stagnation are major pedogenetic (forming) factors and causes of specific soil type characterised by fine texture and low hydraulic conductivity. The most prevalent are hydromorphic soils, particularly gleysols. Excessive wetting by floods, high level of subsurface water and incoming water from the upper parts of the catchment are basic natural conditions needed for development of hydromorphic soils.

Biological communities of natural wetlands, like Kopački Rit, are very sensitive to variations of different mutually connected processes that respond to external factors and influences. One of the most important is seasonal hydrological change which effects variations in water inflow and outflow from the system, number of biological species, sediment and nutrient transports etc. Flooding causes devastation of many terrestrial organisms and on the other hand, during the lowering of the water level and water outflow, many species are left stranded in isolated swamps and dried-up areas. Also, human impacts cannot be neglected because in the last 45 years numerous hydro technical works and structures have been executed. Some of them have had a negative impact on the water regime (Đuroković and Brnić-Levada 1999).

The dynamics of the Drava and Danube water bed shaping are very much different from their natural state. Regulation waterworks have shortened the watercourse and hydraulic gradients are bigger which has led to more intensive erosion processes. Also, depending on water quantity and flood intensity, water balance components are changing. During high water levels, inflows and outflows (which are influenced mostly by the Danube River and only to a small extent by the river Drava) are the dominant horizontal components of water balance. During small and average water levels, vertical components of water balance, such as precipitation, evaporation and transpiration become dominant.

Methodology

The data used in the proposed analysis was based upon historical meteorological and hydrological stations in the study area and its vicinity. Specifically, water levels and discharges on the Danube River were taken at the hydrological stations Bezdan and Apatin (1921–2008). Water levels only on the Drava River were taken from the Osijek hydrological station (1926–2010). Table 1 presents the main data observed at these hydrological gauging stations on the rivers Danube and Drava.

Precipitation, air temperatures and other meteorological parameters necessary for water balance calculation, were analysed on the basis of data measured at the meteorological station Osijek during the same periods.

Table 1 Main characteristics of three Danube and Drava Rivers hydrological stations

Station name	River	Datum plane *H* (m a.s.l.)	Catchment area A (km^2)	Distance from the mouth (km)
Bezdan	Danube	80.64	210,250	1425.50
Apatin	Danube	78.84	211,139	1401.40
Osijek	Drava	81.48	39,982	19.10

Table 2 shows characteristic (minimum, average and maximum) annual water levels and discharges measured at the three analysed hydrological gauging stations. Although no discharge measurements on the Danube are taken at the Apatin hydrological gauging station, this is not a problem because discharges are practically the same as at the Bezdan location, which is located about 25 km upstream. This is because there are no tributaries between these two hydrological gauging stations.

These data on precipitation and river discharges, was used together with evapotranspiration calculated by the Penman equation for free water surfaces were used to make water balance calculations. Drainage area inflow was estimated by discharge measurements at three pumping stations and water level measurements at the Sakadaš weir. Flow velocities in the Kopački Rit were measured twice during 2002 in Čonokut and in the Hulovo Canal: once during a period of water table lowering, and once during a period of filling of the Kopački Rit area.

Results

Understanding the influence of climatological and hydrological conditions on ecological processes in any ecosystem is one of crucial importance to ensure its sustainable development. The duration and timing of each hydrological and climatological phase is important, not only for ecosystem productivity, but also for species recruitment, which is related to thermal seasonality (Amoros and Bornette 2002). This is especially true for the Kopački Rit wetland floodplain.

The climate is continental. Figure 2 presents a time series of mean annual air temperature at the Osijek meteorological station, which is situated on the southern edge of the analysed system. It evidences a statistically significant trend of increasing mean annual air temperatures. The Rescaled Adjusted Partial Sums (RAPS) method (Garbrecht and Fernandez 1994; Bonacci et al. 2008; Bonacci 2010) was established 1988 as a beginning of a consistent trend in the study area. It was calculated that increase of average mean annual air temperatures in the period before and after warming is 0.64 °C. The mean annual air temperature during the period 1900–2011 is 10.99 °C, while the minimum and maximum annual temperatures vary from 8.83 to 12.88 °C. The mean annual air temperature in the first sub-period (1900–1987) was 10.85 °C, while in last sub-period from 1988 till 2011 was 11.49 °C (Fig. 2). Instantaneous air temperatures vary in a very large range from −27.1 to 40.3 °C, which is typical for a continental climate in the Pannonia region. Differences of monthly mean temperatures are presented in Fig. 3. Considering both the sub-periods for which data is available, monthly mean temperatures are increasing for all months except September and December.

Water temperature presents one of the most important physical characteristics of river water, which affects its other physical properties and influences the chemical and ecological reactions in its lotic system (Walling and Webb 1992). Figure 4 shows polynomial relationship between mean monthly water temperature in the river Danube at the Bezdan gauging station and mean monthly air temperature at the Osijek meteorological station (Jan 1955–Dec 1990). It can be concluded that there is a strong relationship between air and water temperature. Bonacci et al. (2008) found that water temperature behaviour at sections of the Drava and Danube Rivers near the study area is identical to air temperature. It should be pointed out that simultaneous changes of water temperature during the time in analysed sections of the Danube and Drava Rivers are practically identical. The coefficient of linear correlation is 0.967.

The mean annual precipitation during the period 1882–2011 measured at the Osijek meteorological station is 690 mm. Minimum and maximum precipitations in this period were 317 mm (2000) and 1.118 mm (1906). A trend has not been established.

Figure 5 depicts time series of maximum, mean and minimum annual water levels in the River Danube in Bezdan during period from 1921 to 2008, and includes linear trend lines and coefficients of linear correlations. It can be concluded that in time series of minimum and mean annual water levels there exists a statistically decreasing trend, while in

Table 2 Characteristic minimum, average and maximum water levels, *H*, and discharges, *Q*, measured at three analysed stations during the period 1951–2008

Station name	Water level, *H* (m a.s.l.)			Discharge, *Q* (m^3/s)		
	Minimum	Average	Maximum	Minimum	Average	Maximum
Bezdan	79.70	82.89	88.40	742	2,283	8,360
Apatin	78.41	81.75	87.08	–	–	–
Osijek	79.80	82.30	86.93	160	530	2,232

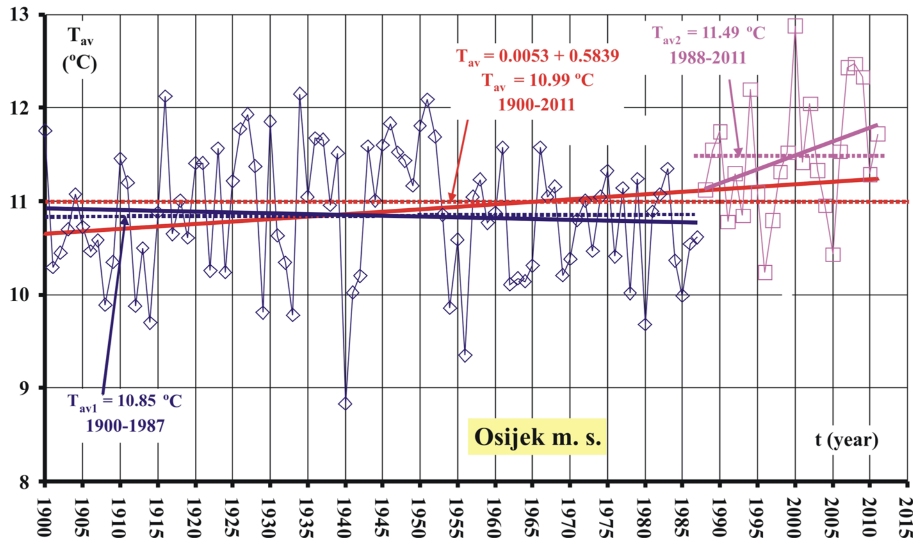


Fig. 2 Time data series of mean annual temperatures measured at the Osijek meteorological station with linear trend line for the period 1900–2011

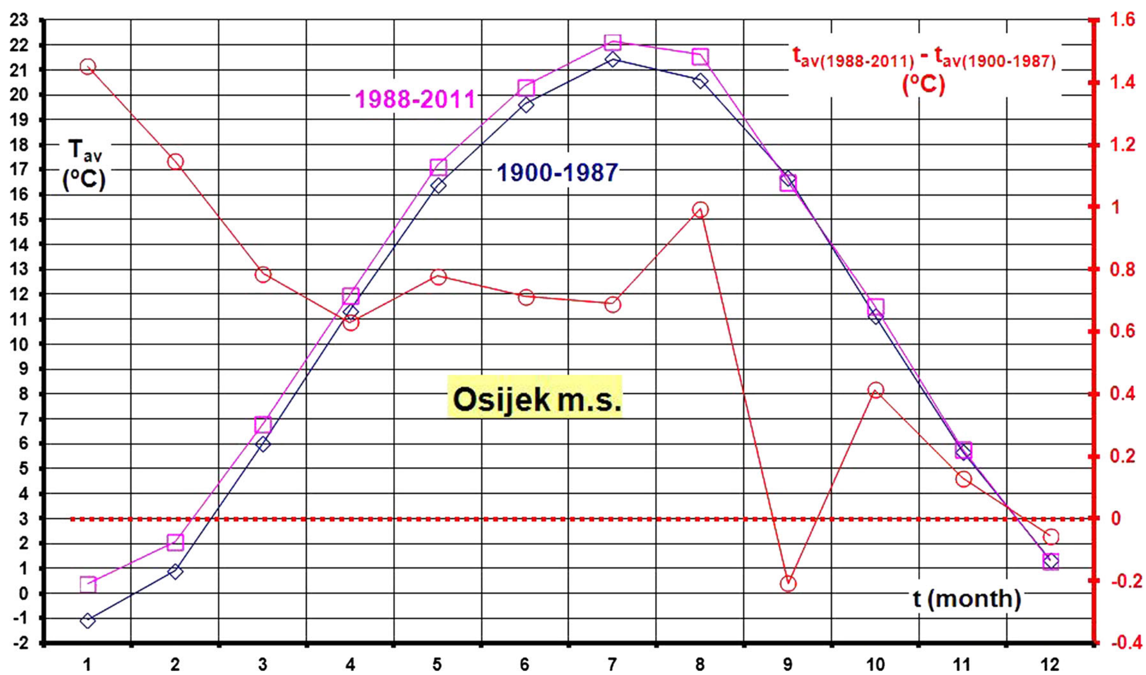


Fig. 3 Differences of mean monthly air emperatures measured in two periods (1926–1987 and 1988–2008)

time series of annual maximum water levels a decreasing trend is not established. To maintain current state of the Park, it is very important that intensity and frequency of high waters and floods don't decrease. This fact is of great importance for flooding of Kopački Rit Nature Park.

Behaviour of annual time series of characteristics (maximum, mean and minimum) discharges at the analysed stations on the Danube and Drava Rivers is practically the same. In time series of minimum and mean annual discharges there exists a statistically significant decreasing trend, while it is not established in the time series of annual maximum discharges decreasing trend (Tadić et al. 2003).

Decreasing trends in series of mean water levels are statistically significant for both the River Danube and the River Drava. The average reduction in water level over the 1926–2008 period is 1.8 cm/year for the River Drava at Osijek, making a total lowering of 1.5 m in 83 years (Fig. 6). Assuming a linear trend, the coefficient of linear correlation for this data is 0.715. A similar behaviour of mean annual water level is found at the station of the Danube River at Bezdan. In the same period lowering of mean annual water level is 1.15 m and—assuming a linear trend—with coefficient of linear correlation 0.464 (Fig. 6). Although water from the Drava River apparently plays a

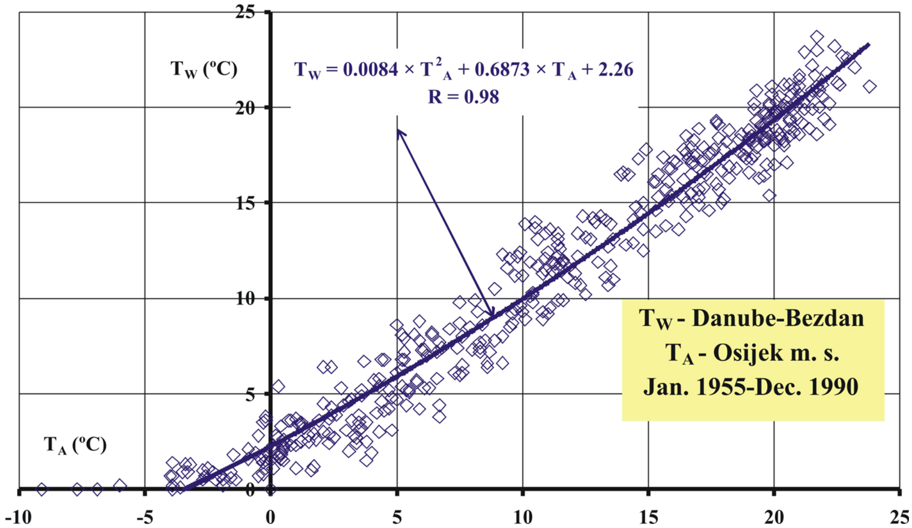


Fig. 4 Polynomial relationship between mean monthly water temperature in the River Danube at Bezdan and mean monthly air temperature in Osijek meteorological station (Jan 1955–Dec 1990)

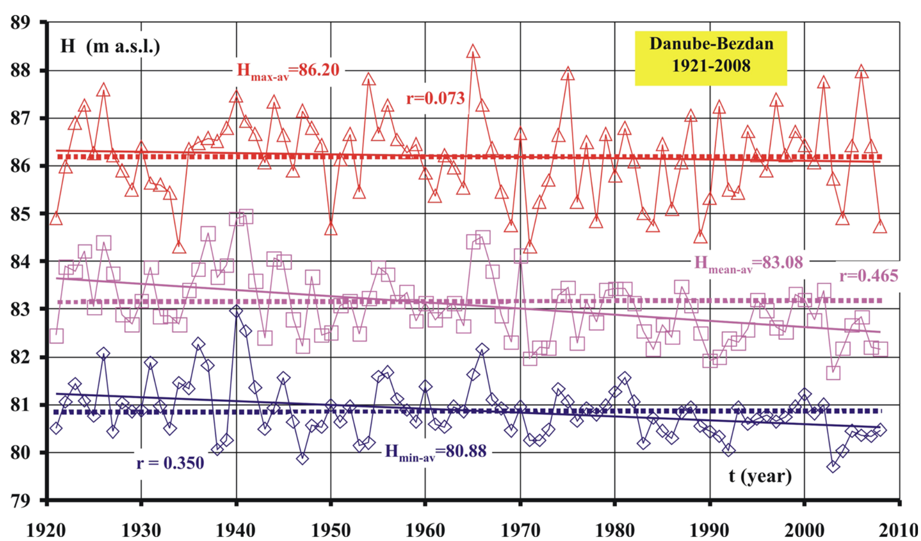


Fig. 5 Time series of maximum, mean and minimum annual water levels in the River Danube at Bezdan

smaller role than water from the Danube River in the filling and emptying of Kopački Rit Natural Park, the connectivity of surface and ground water lowering of water levels in both rivers has been shown to influence the decrease of ground water level (Singh et al. 2011).

Figure 7 shows the water level hydrograph measured during the driest year 2003, when only 65 days or 17.8 % of time water level in the Danube in Apatin was higher than critical altitude ($H = 81.50$ m a.s.l.). That year the ecological system of Kopački Rit was extremely endangered.

Table 3 gives an assessment of Kopački Rit water balance components for a dry and wet year.

Disscusion

Inside Kopački Rit, water comes from four sides, but the Danube River brings the biggest water volume, especially during its high water discharges (Tadić et al. 2003). That is the reason why this paper deals with area of Nature Park Kopački Rit and the Danube floodplain section from 1,380 river kilometre (rkm) to 1,433 rkm. This section corresponds to the area from the state border between Republic of Hungary and Republic of Croatia to the mouth of the Drava River to the Danube River (3 km downstream). Some parts of this Danube section are critical with respect to river bed stability, navigation conditions, and load and ice transport.

Figure 1 schematically presents process of water inflow and outflow in Kopački Rit. Filling of the system starts when water level exceeds 81.50 m a.s.l. (at the Danube in Apatin) by overflow of Hulovo Canal. Below this water level, water remains in canals and lakes (mark 1 at Fig. 1). Shallow canals and lakes begin to fill at water level 82.00 m a.s.l. (mark 2 at Fig. 1). At the same water level starts filling of Kopački Rit from the northern side through

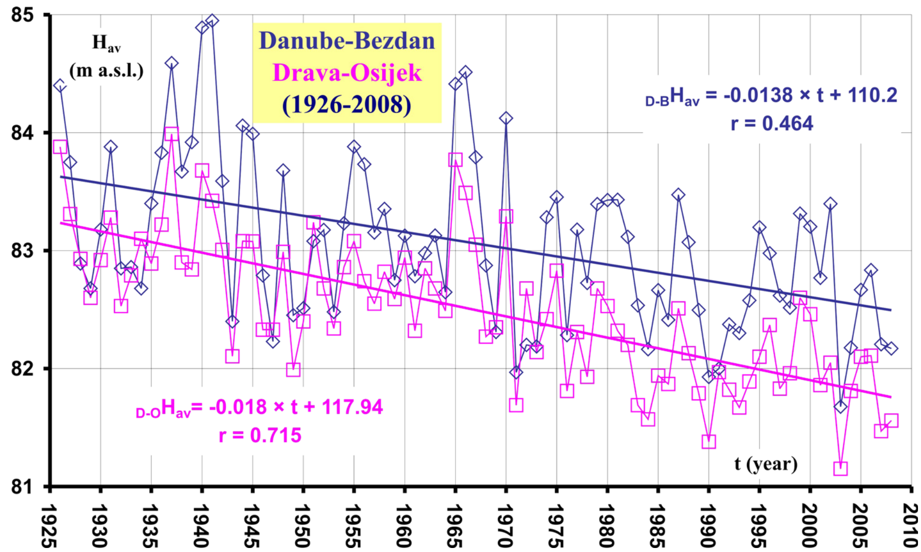


Fig. 6 Time series of mean annual water levels in the River Danube at Bezdan and River Drava at Osijek (1926–2008) with linear trend lines and coefficients of linear correlation

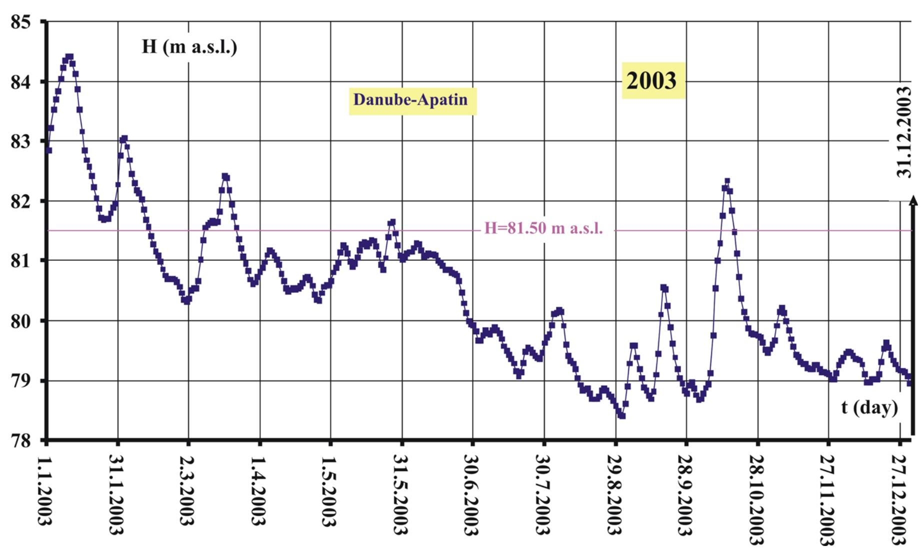


Fig. 7 Time series of daily water level measured in the River Danube at Apatin in 2003 year

Vemeljski Dunavac (mark 3 at Fig. 1). When water level exceeds 83.00 m a.s.l. the entire area is filled with water.

The important influence on filling and emptying of Kopački Rit has natural earth barriers (“beams”), dividing northern part (area A) from southern part (area B). Below a water level of 82.50 m a.s.l. these two parts area are separated. Increase of water level above this altitude causes overflow from the northern to the southern part and entire area is flooded by water.

The emptying of Kopački Rit starts due to decrease of the Danube River water level. First this happens in the northern part (area A), and afterwards in the southern part (area B). Outflow occurs through the Renovo Canal to Drava River at water level 83.50 m a.s.l. (mark 4 at Fig. 1) and it lasts until water level decreases to the height of the barrier at the Hulovo Canal (79.50 m a.s.l.). Further outflow is then no longer possible. Water stagnates and the components of vertical water balance such as evaporation, transpiration and local precipitation become dominant.

Figure 8 presents three duration curves of water levels of the Danube River at Apatin in the period 1987–2008. When the water level measured at Apatin reaches an altitude of $H = 81.50$ m a.s.l., the filling of Kopački Rit commences. The duration of water levels higher than this altitude is 65, 162 and 249 days for minimum envelopes, mean duration curve and maximum duration envelopes, respectively.

Figures 9a and b present two cross-sections through Kopački Rit designated in Fig. 1. The cross-section 1-1, is situated in part A of the Natural Park, and is generally parallel to the Drava River. Cross-section 2-2, is situated in parts A and B of the Natural Park, and is generally parallel to the Danube River. From these two cross-sections can be seen the range of water volume between starting water

Table 3 Estimation of water balance in the area of Kopački Rit

Description		m^3/year
Dry year		
I1	Precipitation	6.3
I2	Danube river inflow	358.5
I4	Drainage area inflow	2.5
O1	Evapotranspiration	−17.6
O2	Outflow to Danube River and Drava River	−355.4
Wet year		
I1	Precipitation	22.4
O2 + O3	Dunube river and Drava river inflows	79,000
O4	Drainage area contribution by pumping station	950
I1	Evapotranspiration	−22
I2 + I3	Outflow to Danube River and Drava River	−79,940

I inflow, *O* outflow

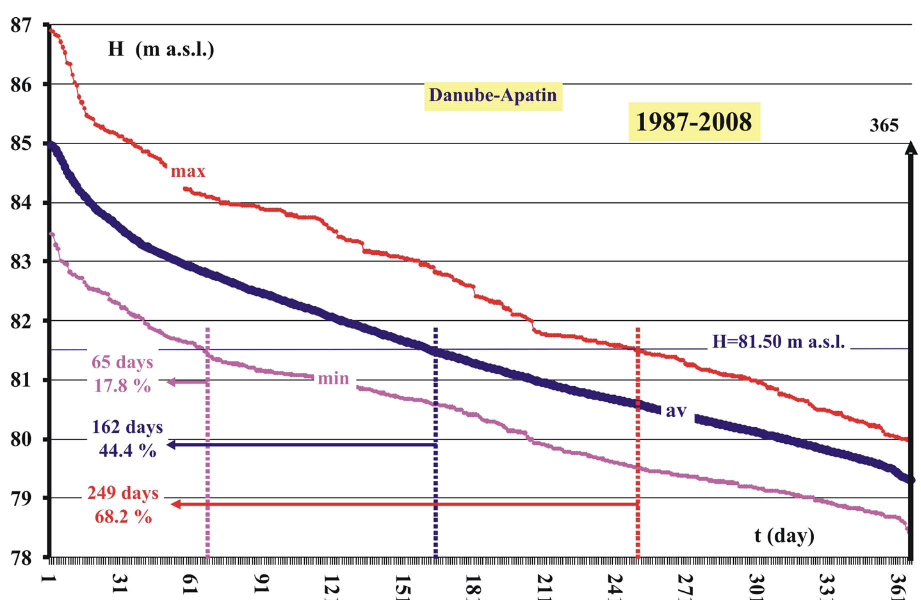
level of filling and starting level of Kopački Rit empting. In addition, it shows all the geomorphological complexity of the analysed system, which strongly influences dynamics of water flow and storage and by this way influences ecological processes.

Flow velocity in the study area has an essential importance for morphological changes and it is an extremely variable parameter depending on many factors (inflow/outflow, anthropogenic influences, vegetation cover, relief etc.). Considering man-made structures (barriers on the Hulovo Canal and at Vemeljski Dunavac) and existing topography as fixed parameters, flow velocity can be analysed as a function of the Danube River water level fluctuation. There are no comprehensive velocity measurements in the area, but general directions of flow are known. The main watercourse for water inflow and outflow to Kopački Rit is the Hulovo Canal. Its meandering shows severe erosion due to the rather big velocities of water in both directions. The wide amplitude of velocities is caused by artificial barriers in the Hulovo Canal mouth to the Danube River and Čonakut Canal (connection of Kopačko Lake and Sakadaš Lake) designated in Fig. 1. The Čonakut Canal water also provides water inflow and outflow, but here erosion is not so developed because its width is much larger. The Renovo Canal is the main watercourse responsible for outflow to the Drava River with dominant flow in one direction.

During 2002, flow velocities were measured twice and measured values were between 0.2 and 0.8 m/s. Those velocities are instantaneous, real velocities are more variable. In the northern part (area A), where there is dominantly one-way flow, a diagram of velocities is presented in Fig. 10a. It is obviously unsteady flow and the highest values of velocities occur in the water bed just before overflow. After that, velocities rapidly decrease due to enlargement of discharge profile followed by sedimentation of suspended loads. During total flooding of the area velocities are very small. Falling of water level causes water movement back to the water bed and increasing of flow velocity. The intensity of emptying Kopački Rit and consequently flow velocity depends on the Danube River water level decreasing.

In the southern part (area B), water flows in the both directions. Figure 10b presents scheme of water velocities in area B. It is generally same as in area A, but during outflow, velocities become negative. The process of outflow is symmetrical to the process of inflow, depending on velocity of water level fall.

Fig. 8 Duration curve for daily water levels in the River Danube at Apatin in 2003 year



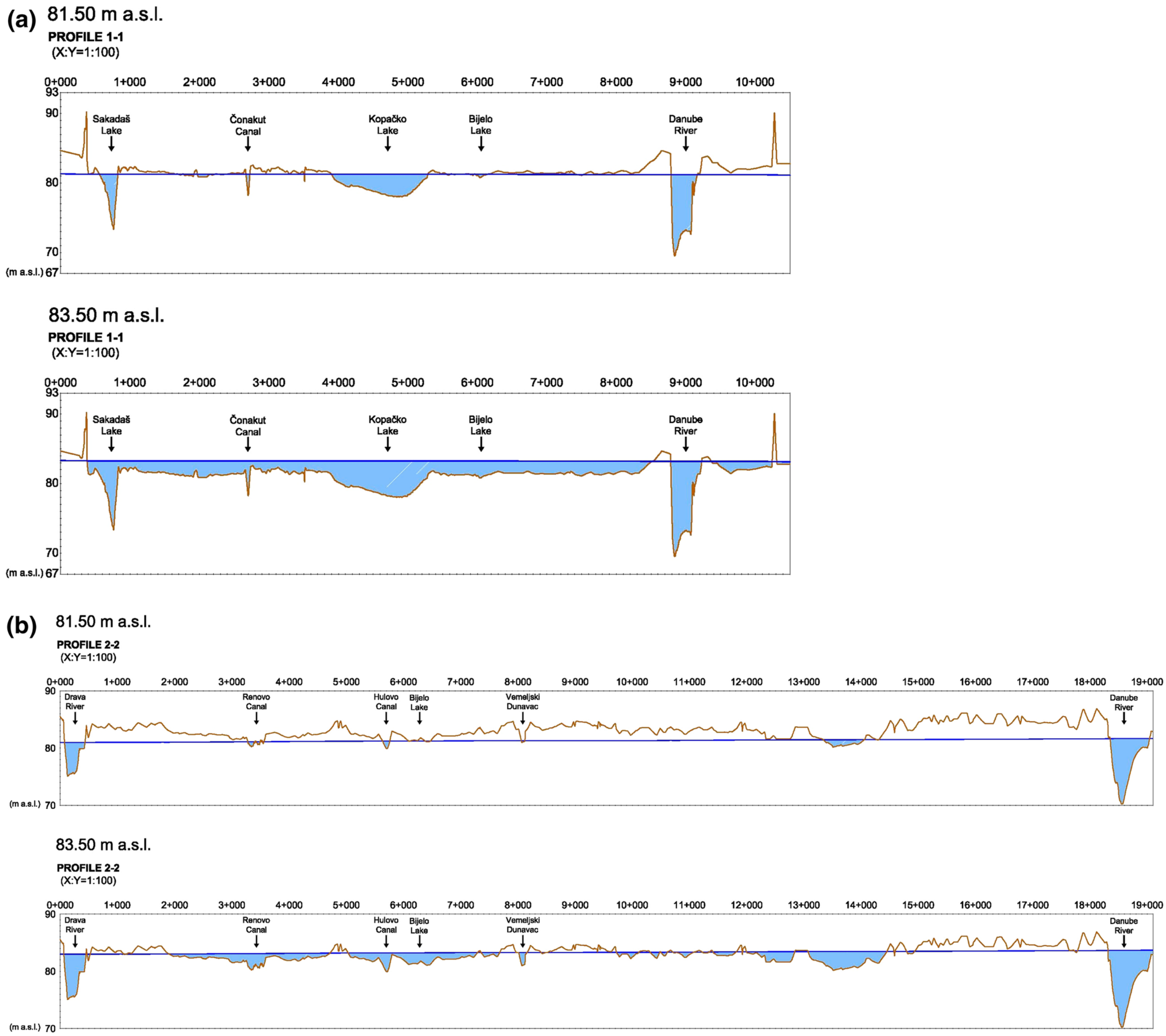


Fig. 9 Cross-sections *1-1* (**a**), and *2-2* (**b**) designated in Fig. 1

Flooded areas in km^2 for different return periods for floodplain of the observed section of the Danube River and for area of Kopački Rit Nature Park are given in Table 4. The same table shows volume of flooding water in 10^6 m^3 for the floodplain of the observed section of the Danube River and for area of Kopački Rit Nature Park (Tadić et al. 2013).

The sizes of the Kopački Rit flooded area depend on return period, but their variations are very small. For 5 and for 100 years return period the flooded area of the Danube floodplain is 128 km^2, and 155 km^2, respectively. Increase of the total size of flooded area is less than 18 %. Obtained values are regarded to right side of the Danube floodplain. That means that every time when flood comes, regardless return period, almost the entire area of Kopački Rit Nature Park, from bank to bank, is under water. The increase of volume of water is much more noticeable than the size of the flooded area.

According to the observed data from period 1951–2008, the average water level of the Danube River at the Apatin station is 81.75 m a.s.l. During that and lower water levels, there is some water just in some depressions and lakes. In other words, 1.35 km^2 of the Danube River floodplain is under water and only 0.7 km^2 of Kopački Rit Nature Park, which is not enough for survival and life of many species. During average water levels, volume of water in Kopački Rit is about 0.47×10^6 m^3. For Kopački Rit Nature Park, the size of flooded area is more or less constant after a flood of 25 years return period which means that the entire area of Kopački Rit Nature Park is under water. During floods of 5 and 10 return periods, only elevated terrain remains above water (Tadić et al. 2013).

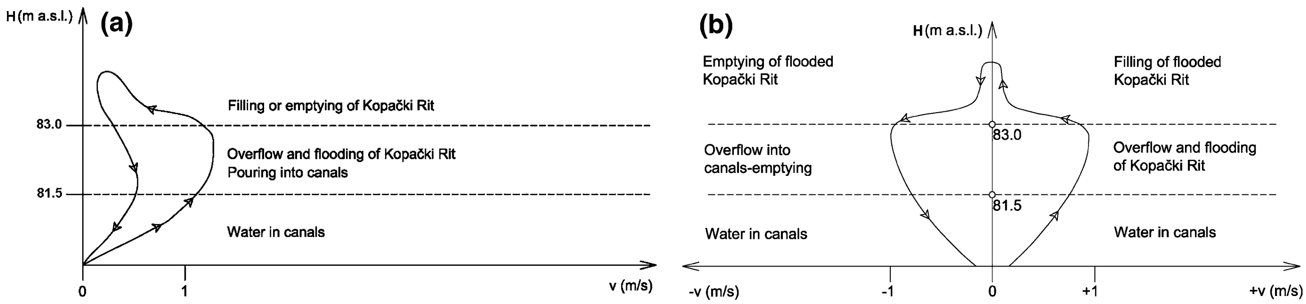


Fig. 10 Schematic presentation of water flow velocities in part A of Kopački Rit **(a)** and water flow velocities in part B of Kopački Rit (**b**)

Table 4 Flooded areas and corresponding water volumes for different return periods for floodplain of the observed section of Danube River and area of Kopački Rit Nature Park

Return period (year)	Danube floodplain		Kopački Rit Nature Park	
	Area (km^2)	Vol. (10^6 m^3)	Area (km^2)	Vol. (10^6 m^3)
5	127.91	329.83	94.82	252.51
10	147.33	460.84	112.81	363.8
25	153.83	571.78	118.88	454.00
50	154.91	643.83	119.87	510.81
100	154.98	710.13	119.90	562.24

Conclusions and recommendations

Because of the fact that Kopački Rit Nature Park exists due to the Danube and the Drava River and Danube flooding periods, high water levels and maximum discharges are extremely important. The great biodiversity of that area is also the result of the exchange of floods and water withdrawal. Water depth and duration of floods have significant influence on the life of all present species in the Park.

Hydrologic, hydraulic and morphological variability through space and time determine the different habitats found in Kopački Rit area. Depressions, lakes and channels change in a variety of ways through the processes of erosion and deposition as well as vegetation development (in seasonal time scale and over decades). Exchange of flood and dry periods in the area causes continuous competition between terrestrial and aquatic organisms.

Maintaining good water quality can create more serious problems. Water drained from agricultural fields comes to the protected area and potentially can endanger ecosystem by eutrophication and depth reduction of the lakes and swamps. Although the incoming surface drainage water contributes only a small quantity to the overall water budget, its quality must be continuously monitored owing to the fragility of the wetland ecosystem. Parameters of water quality (mainly concentrations of nitrates and phosphorus) have been observed in the period from 2000 to 2011. The main aim of the research was to detect necessity of wetland constructions in the entrance of the protected area. According to the results, there is still no need for this kind of measures because the vegetation in the canals and ditches act as a constructed wetland (Barišić-Lasović 2012).

Anthropogenic actions in Kopački Rit Natural Park should be avoided, or should be planned with extreme caution to ensure its long lasting sustainable development.

From 1988 a statistically significant increasing trend of mean annual air and water temperatures in the analysed region has been established, that points out the necessity of carefully following and analysing this process, which can be very dangerous to Kopački Rit from the ecological point of view. The dangerous phenomenon of decrease of minimum and mean water levels and discharges at both rivers should be carefully monitored. For more detailed and accurate results, flow in all directions should be observed. It is obvious that a considerable part of the Park is under the water even during 5 years return period floods.

The Danube and Drava Rivers management and Kopački Rit restoration strategies should be process-oriented and embedded within a holistic framework that takes into account the driving processes and their interactions that operate at different spatial and temporal states (Amoros and Bornette 2002). The environmental problems of Kopački Rit cannot be managed any longer in isolation. Sustainable solutions need to be based on close interdisciplinary analyses and much better organized, continuous monitoring of many different biological, ecological, geomorphological, chemical, hydrological and climatological parameters. As the Danube is an international river, intergovernmental cooperation between at least Hungary, Serbia and Croatia is crucial to protect this valuable space located in the heart of Europe.

References

Altdorff D, Epting J, Kruk J, Dietrich P, Huggenberger P (2013) Delineation of fluvial sediment architecture of subalpine riverine systems using noninvasive hydrogeophysical methods. Environ Earth Sci 69(2):633–644. doi:10.1007/s12665-013-2304-4

Amoros C, Bornette G (2002) Connectivity and biocomplexity in waterbodies of riverine floodplains. Freshw Biol 47:517–539

Azevedo TM, Goncalves MA (2009) Geochemistry of core sediments from the Middle Tagus alluvial plain (Portugal) since the last glacial: using background determination methods to outline environmental changes. Environ Earth Sci 59(1):191–204. doi:10.1007/s12665-009-0016-6

Barišić-Lasović A (2012) Impact of agricultural drainage system on water quality on Kopački Rit. Master Thesis, University of Osijek

Bonacci O (2010) Analiza nizova srednjih godišnjih temperatura zraka u Hrvatskoj [Analyses of mean annual air temperature series in Croatia]. Građevinar 62(9):781–791 (Croatian)

Bonacci O, Trninić D, Roje-Bonacci O (2008) Analyses of the water temperature regime of the Danube ant its tributaries in Croatia. Hydrol Process 22(7):1014–1021

Bridge JS (2003) Rivers and Floodplains—Forms, processes, and sedimentary record. Blackwell Pbl, Malden

Brookes A (1994) River channel change. In: Calow P, Petts GE (eds) The rivers handbook, vol 2. Blackwell Sci Pbl, Oxford, pp 55–75

Castaldelli G, Colombani N, Vincenzi F (2013) Linking dissolved organic carbon, acetate and denitrification in agricultural soils. Environ Earth Sci 68(4):939–945. doi:10.1007/s12665-012-1796-7

Čerba D, Bogut I, Vidaković J, Palijan G (2009) Invertebrates in Myriophyllum spicatum L. stands in Lake Sakadaš, Croatia. Ekologia—Ecology 28:94–105

Đuroković Z, Brnić-Levada D (1999) Utjecaj izvedenih hidrotehničkih radova na vodne resurse u Kopačkom ritu [Influence of hydrotechnical works on Kopački Rit water resources]. In: Proceedings of 2nd Croatian conference on water, Dubrovnik, pp 661–666 (Croatian)

Elwaseif M, Ismail A, Abdalla M, Abdel-Rahman M, Hafez MA (2012) Geophysical and hydrological investigations at the west bank of Nile River (Luxor, Egypt). Environ Earth Sci 67(3):911–921. doi:10.1007/s12665-012-1525-2

Franz C, Makeschin F, Roig H et al (2012) Sediment characteristics and sedimentations rates of a small river in Western Central Brazil. Environ Earth Sci 65(5):1601–1611. doi:10.1007/s12665-011-1498-6

Garbrecht J, Fernandez GP (1994) Visualization of trends and fluctuations in climatic records. Water Resour Bull 30(2): 297–306

Hein T, Baranyi C, Herndl G, Wanek W, Schiemer F (2003) Allochthonous and autochthonous particulate organic matter in floodplains of the River Danube: the importance of hydrological connectivity. Freshw Biol 48:220–232

Horvatić J, Peršić V, Mihaljević M (2006) Bioassay method in evaluation of trophic conditions and nutrient limitation in the Danube wetland waters (1388–1426 rkm). Hydrobiologia 563:453–463

Kent DM (2001) Applied Wetlands Science and Technology, 2nd edn. CRC Press, Boca Ratom

Lang M, McCarty G, Oesterling R, Yeo L-Y (2012) Topographic metrics for improved mapping of forestry wetlands. Wetlands. doi:10.1007/s13157-012-0359-8

Magner J, Hansen B, Sundby T, Kramer G, Wilson B, Nieber J (2012) Channel evolution of Des Moines Lobe till drainage ditches in southern Minnesota (USA). Environ Earth Sci 67(8):2359–2369. doi:10.1007/s12665-012-1682-3

Maričić S (2005) Analyses of one of the rare natural retention in the Middle Danube. In: Proceedings of the Ninth international symposium on water management and hydraulic engineering. Ottenstein, Austria, pp 383–395

Merz C, Winkler A, Pekdeger A (2009) Trace elements in streambed sediments of floodplains: consequences for water management measures. Environ Earth Sci 59(1):25–38. doi:10.1007/s12665-009-0001-0

Mihaljević M et al (1999) Kopački Rit—overview of investigations and bibliography. Croatian academy of science and art, Osijek

Mihaljević M, Stević F, Horvatić J, Hackenberger Kutuzović B (2009) Dual impact of the flood pulses on the phytoplankton assemblages in a Danubian floodplain lake (Kopački Rit Nature Park. Croatia). Hydrobiologia 618:77–88

Palijan G, Fuks D (2006) Alteration of factors affecting bacterioplankton abundance in the Danube River floodplain (Kopački Rit. Croatia). Hydrobiologia 560:405–415

Peršić V, Horvatić J (2011) Spatial distribution of nutrient limitation in the Danube River floodplain in relation to hydrological connectivity. Wetlands 31(5):933–944. doi:10.1007/s13157-011-0208-1

Peršić V, Horvatić J, Mihaljević M (2005) Bioassay method in the trophic evaluation of a wetland area-case study in the Danubian region (1426–1388 rkm). Period Biol 107:293–298

Peršić V, Horvatić J, Has-Schön E, Bogut I (2009) Changes in N and P limitation induced by water level fluctuations in Nature Park Kopački Rit (Croatia): nutrient enrichment bioassay. Aquat Ecol 43:27–36

Rodrigues ASL, Malafia G, Costa AT, Nalini HA (2013) Evaluation of the mineral exploration influence on sediment composition in the Gualaxo do Norte River Basin (MG-Brazil) based on geochemical and stratigraphic data. Environ Earth Sci 68(4):965–972. doi:10.1007/s12665-012-1799-4

Schwarz U (2006) Genesis and typology of riparian and fluvial landforms of the Kopački Rit within the Danube floodplain corridor in Croatia and Serbia. In: Proceedings 36th international conference of IAD. Austrian Committee Danube Research, Vienna. ISBN 13: 978-3-9500723-2-7, pp 318–321

Singh CK, Satyanarayan S, Singh A, Mukherjee S (2011) Quantitative modeling of groundwater in Satluj River basin of Rupnagar district of Punjab using remote sensing and geographic information system. Environ Earth Sci 62(4):871–881. doi:10.1007/s12665-010-0574-7

Slowik M, Sobczynski T, Mlynarczyk Z (2010) Types of sedimentary environment in alluvial sediments distinguished on the basis of its chemical constitution: the example of the lower course of the Obra river (Western Poland). Environ Earth Sci 59(5):957–966. doi:10.1007/s12665-009-0089-2

Tadić Z, Bonacci O, Radeljak I, Tadić L (2003) Vodni režim Parka prirode Kopački rit [Water regime of Kopački Rit Nature Park]. In: Proceedings of 3rd Croatian conference on water. Osijek, pp 941–950 (Croatian)

Tadić L, Dadić T, Barač B (2013) Flood frequency modelling of Kopački Rit Nature Park. Tehnički vjesnik-Technical Gazzete 20(1):51–57

Thoms MC, Southwell M, McGinness HM (2005) Floodplain-river ecosystems: fragmentation and water resources development. Geomorphology 71:126–138

Vandeberg GS, Martin CW, Pierzynski GM (2011) Spatial distribution of trace elements in floodplain alluvium of the upper Blackfoot River, Montana. Environ Earth Sci 62(7):1521–1534. doi:10.1007/s12665-010-0637-9

Walling DE, Webb BW (1992) 3: Water quality I. Physical characteristics. In: Calow P, Petts GE (eds) The River Handbook. Blackwell Sci, Oxford, pp 48–72

Zglobicki W, Lata L, Plak A, Reszka M (2011) Geochemical and statistical approach to evaluate background concentrations of Cd, Cu, Pb and Zn (case study: Eastern Poland). Environ Earth Sci 62(2):347–355. doi:10.1007/s12665-010-0529-z