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MORPHOLOGICAL CLASSIFICATION AND CHANGES OF ISLANDS ON THE DRÁVA RIVER, HUNGARY-CROATIA

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Abstract: In the 19th and 20th centuries channel regulation works (cut-offs, revetments and groins) and the hydroelectric power plants generated significant changes on the hydro-morphology of the Dráva River along its lower, 236 km-long reach. The aim of the present research is to study the long-term dynamism of islands on the Dráva and to evaluate the processes from the point of view of engineering works. Based on a series of maps and a satellite image (representing the period of 1882-2007) the number and area of islands were determined, and they were classified. During the last almost 130 years the number of real islands (formed of bars) increased (from 210 to 287), though their total area decreased (from 2381 ha to 1678 ha). Different tendency describes the evolution of floodplain islands (which were mostly created by cut-offs), as their number (32 to 8) and territory decreased (3797 ha to 976 ha). In the narrowing channel the islands became gradually more osculating and amalgamating into the bank or another island. Therefore, the frequency of non-amalgamated islands became lower, as it is indicated by the decrease of overlapping islands (from 52% to 30%) and the proportion of less frequent islands had increased (from 45% to 66%). During the studied period the different river engineering works altered considerably the island development. The floodplain islands almost disappeared and the channel became narrower, and more uniform. The originally anastomosing channel became straightened, therefore on the sediment-rich and steep-sloped Dráva intensive island formation started and its pattern became braided. However, due to the water-level drop caused by reservoir constructions and the blocking of side-channels by groins most of the islands osculated or merged to the banks. Thus, nowadays small islands develop behind the groins, and the main channel lost its diverse morphology.

Key words: island, water-level decrease, regulation works, effect of hydroelectric power plants, Dráva River

1. INTRODUCTION

The extensive regulation of most of the rivers of the Carpathian Basin begun in the 1800's, when flood protection works and meander cut-offs were made. In the 20th c. the engineering works aimed the stabilization of the river-bed by creating revetments and groins, and hydroelectric power plants (HPP) were built on several rivers (Ihrig, 1973; Szabó et al., 2012). These human impacts generated significant hydro-morphological changes, for example the water- and sediment discharge regime of the rivers were altered (Kiss & Andrási, 2011, Blanka & Kiss, 2011). In general, such hydro-morphological changes trigger ecological alterations as well, endangering riparian habitats (Graf, 2006).

Fluvial islands are sensitive to natural or human induced hydrological changes, therefore they are good indicators of fluvial alterations. Islands are important elements not only of the river system but also of the ecological network, as islands act as habitats with great ecological diversity (Gurnell & Petts, 2002). As an island is isolated by water, less disturbance could reach it from the mainland, though quite various aquatic associations could develop accommodating to the changeable fluvial environment. Hydroelectric power plants and their reservoirs break the continuity of the water- and sediment transport (Ristić et al., 2013), thus the naturalness of the river (Brierley & Fryirs, 2005), altering the connection between biological and hydro-morphological processes (Osterkamp, 1998). The resulted regime change will initiate the transformation of islands, and in extreme case they start to decay. Due to the morphological changes, the habitats degrade and the species composition transforms (Osterkamp, 1998; Neruda et al., 2012).

Channel-bars and islands are in close relationship with each other, as the bars play important role in the development of islands. On the surface of the bars there is no permanent vegetation and its level is under the bankfull water stage. In contrary, islands are covered by permanent, woody vegetation and their surface is higher than the bankfull stage (Bridge, 1993; Osterkamp, 1998). Islands could develop in different ways. Mostly they formed of bars, if the bars grow higher than the mean water level and the woody vegetation could stabilize their surface (Kollman et al., 1999; Sipos & Kiss, 2004b). Islands also could be dissected from the floodplain by avulsion or by chute cut-off. These so-called floodplain islands are usually larger (Gurnell et al., 2001), and on these isolated surfaces the habitats have greater ecological safety due to limited approachability for humans, predators, invasive species etc. Islands are more stable forms than bars, because a regular flood not necessarily could destroy them. Thus, the smallest islands have smaller stability and resistance of erosion, hence, a flood with higher destructive capability could significantly erode smaller islands (Joeckel & Henebry, 2008). Nevertheless large islands have greater resistance, thus floods could erode them to lower degree and these islands decay by amalgamating to the floodplain or another island, when the separating side channel is filled up (Baki & Gan, 2012). Due to the same process the existence of smaller islands could also terminate (Sipos & Kiss, 2004a,b).

The fluvial islands reflect the dynamism of the channel, as their development phase is in relation with sediment transport and erosional processes. A recently widened reach (braid) is characterized by mid-channel bars and island cores (juvenile stage). These forms develop into islands dividing the thalweg (mature stage), then the side-channels between them fill up and the islands amalgamate to each other or to the floodplain (senile stage) and finally a single channel will be formed (Sipos & Kiss, 2004a). Before the 19th river regulation works islands were common features on the rivers in the Carpathian Basin, however after the engineering works they had mostly disappeared (Sipos & Kiss, 2004b). However, the morphology of the Dráva River is continuously marked by islands and bars, and even nowadays there is huge number of islands and bars on its slightly regulated reach (between Őrtilos and Barcs). On its lowest section in the last 125 years the number of islands slightly increased, but their area decreased significantly (Andrási & Kiss, 2013). The major changes took place on the upper section of the studied reach in close relation with the decrease of water stages and decreased sediment load due to the construction of upstream reservoirs and HPPs (Kiss et al., 2011).

The aim of the present research is to evaluate the long-term dynamism of islands on the Dráva River. To reach this aim the islands will be classified based on their morphology and their development phase. The spatial and temporal frequency of the islands is also investigated and finally the changing fluvial energy conditions will be evaluated. The study is carried out on the lower section (0-236 km) of the Dráva River studying the changes of the last 125 years (1882-2007). The results could be applied in the active nature conservation of islands, maintenance of the protected habitats and restoration of the river. In this study just islands will be analysed and not the bars, because their size and shape is determined by the water level and the available dataset represents different water stages.

2. STUDY AREA

The Dráva River (length: 720 km; catchment area: 40 489 km^2) is one of the largest tributary of the Danube (Lovász, 1972). In the presented research a 236 km-long reach (Table 1) was studied between the conjunction of the Mura River (at Őrtilos) and the Danube (Fig. 1).

Table 1. The main hydrological parameters of the investigated reach of the Dráva River (data source: 1: Horváth, 2002; 2: Mantuáno, 1974; 3: www.dravamonitoring.eu).

Measuring station	Distance from the Danube (fkm)	Slope (cm/km)[1,2]	Mean discharge (m^3/s)[3]	Maximum discharge (m^3/s)[2]	Mean sediment discharge (t/year)[1]	Mean grain size of the sediment (mm)[1, 2]
Őrtilos	235.9	40-50	488	–	116.000	30-40
Barcs	154.1	20-25	496	3190	83.000	2-3
Drávaszabolcs	77.7	10-15	515	2500	206.000	0.3-0.4
Osijek/Eszék	19.2	5-6	653	–	–	0.2-0.02

Figure 1. The study area is the downstream section of the Dráva River. The 236 km-long reach was divided into 20 units. A: Dráva River; B: unit limit; C: unit number.

The flood protection works (levees) were built in the 18th-19th c. along the Dráva. Meanwhile the length of the river became shortened by 182 km, trough 62 meander cut-offs (Remenyik, 2005). The aim of the regulation works was to support shipping. Between the Danube and the town of Barcs the aim was to destroy the channel barriers (e.g. bars, woody debris), while upstream of Barcs the aim was to lengthen the shipping season. By the beginning of the 20th c. the regulation works had been finished downstream of Barcs, however on the upper reach (from Barcs to the Mura River) the works have not been finished because the I. World War began. After the war just local engineering works (e.g. revetments, groins) were made. In the middle of the 20th c. there was a plan was to build HPPs on the Hungarian-Yugoslavian border reach. Although they signed the agreement in 1955 (Polohn & Szappanos, 1980), but these power plants have not been built, though upstream of the Mura River several HPPs and reservoirs were created.

The river regulation works had significant effects on island development, therefore the regulation works will be presented in detail. Some cut-offs were also made in the 20th c: in 1979-82 at Vízvár (191 fkm) and in 1993-94 two meanders were cut off near Zaláta and Drávasztára (108-111 fkm; Remenyik, 2005). Between the Danube and Barcs the Dráva became highly regulated by revetments and groins until the 1980's. Upstream of Barcs due to the low number of regulation objects the reach stayed in almost natural state.

In the 20th century 22 HPPs were built upstream of the Mura River's conjunction in Austria, Slovenia and Croatia. The Croatian HPPs located the closest to the study reach, therefore they have the greatest hydro-morphological effect on it. The last three HPPs started to operate in 1975, 1982, and 1989 (Szekeres, 2003). The lowest of them (at Donja Dubrava) started to work in 1989, and as it is only 20 km from the study reach it has significant impact on the channel. As the result of the HPPs operation the typical water stages remarkable dropped (Fig. 2). As far as the lowest HPP operates just in the peak hours, 1.0-1.5 m-high flood-waves generated on each day (Kiss & Andrási, 2011).

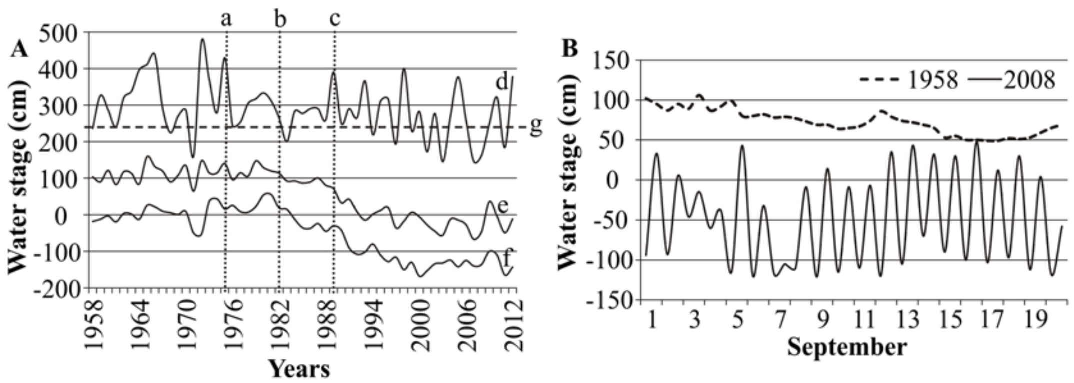

Figure 2. Water level changes based on the data of Őrtilos gauging station (Kiss & Andrási, 2011). A: between 1958 and 2012 and B: daily water level changes before the construction of the HPPs (1958) and after (2008) in an optional 3 week-long period. a: Varazdin HPP; b: Cakovec HPP; c: Donja Dubrava HPP; d: yearly highest water-level; e: yearly mean water-level; f: yearly lowest level; g: bankfull water stage (240 cm)

Gravel mining is also a significant factor in the development of the hydro-morphology of the river, but this activity was finished in 2011 because of environmental considerations. The mining resulted in intensive incision (0.8-1.0 m) on the reach between Őrtilos and Vízvár, and the rate of incision decreased towards Barcs (Horváth, 2002).

3. METHODS

As a first step it had to be defined what is a fluvial island on maps and satellite images. Through-out the research island was determined as fluvial form surrounded by water and covered by trees or bushes. Sometimes on the youngest deposits of the islands vegetation could not established yet, but these surfaces are part of the islands. Therefore, in these cases the definition of Zanoni et al., (2008) was followed, according to which if 75% of the surface is covered by perennial vegetation, it could be considered as an island.

During the study the III. Military Survey (1878-1882), the Hydrological Atlas of the Dráva (1966-1968), the Croatian topographical map (1977-1979) and GoogleEarth images (2006-2007) were applied. (To make the evaluation easier, just the last year of each data-set was used for calculations). The geo-correction of the data base and digitalisation of banklines and islands were made under ArcGIS 10. The studied Dráva reach was divided into 20 units, 10 km-long each. The borders of the units were on the same location in all studied periods (Fig. 1). If an island was on the border line between two units, then the form belonged to that unit where it had greater area. In case of a permanently narrowing side-channel the islands gradually amalgamate to the riverbank. Therefore, just those side-channels were considered as part of the channel, which are wider than 10% of the main channel, in these cases the islands were also separable from the banklines. The location of the thalweg compared to the island's influences the energy conditions and development of the island, therefore it was also evaluated. On the satellite image the location of the thalweg could be easily identified, but on a map it could be determined just indirectly considering the distribution of islands and bars, and channel width.

The islands were classified from different point of views. At first they were separated based on their ***origin***. Real islands evolved from bars, therefore they have small territory, and the width of the channel is at least three times wider than the maximum width of the island along the same cross-section. Floodplain islands were formed by avulsion, cut-off or amalgamation of smaller islands. There are wider and their territory larger by an order than of the real islands.

Secondly, the islands were classified based on their location compared to the thalweg, which determines the ***further evolution*** of an island. *Islands in the thalweg* are actively develop, as their split and divert the thalweg of the main or the side-channel, therefore active erosion and accumulation marks can be found on these islands. The *osculating islands* drifted close to the bankline or to another island, thus sooner or later they will merge to them and as the side channel between the two forms aggrades the islands loose their independency. The *partially amalgamated islands* had already merged to the bank or another island, but still the remnants of the side-channel filled with water. *Completely amalgamated islands* are totally merged and their side-channel filled up with sediment.

The ***frequency*** of non-amalgamated islands were calculated following the method of Wyrick & Klingeman (2011), considering the spatial distribution of the islands. In case of *overlapping islands* two or more islands are in the channel at the same cross-section, thus the river is split into at least three channels. In case of the *densely located islands* two islands dissect the river at a cross-section or downstream the distance between the neighbouring islands is less than 10% of the channel width. Whilst the *infrequent islands* appear alone in the channel and the downstream distance between them greater than 10% of the width of the river.

The **elongation ratio** (L/W) of an island is the ratio of maximum length (L) and maximum width (W), referring to the energy conditions of the river in the neighbourhood of the island. Greater elongation ratio indicates greater energy, thus the island could develop dynamically. Smaller ratio refers to rounder shape, indicating sediment accumulation and decreased river energy.

4. RESULTS AND DISCUSSION

4.1. Changes in the number and territory of the islands

The real islands evolved from bars always had greater number, than of the floodplain islands, and the evolution of the two groups is also different.

4.1.1 Real islands

On the Dráva River in the studied period (1882-2007) the number of the real islands increased (from 210 to 287), whilst their area decreased (from 2381 ha to 1678 ha). Most of the islands appeared on the upper section (units 20-15.) of the river (Fig.

3A), where in average 21-25 islands/unit were characteristic. On this upper section the number of the islands slightly (3%) increased (1882: 147; 2007: 151), though their total territory decreased by 60% (from 1740 ha to 688 ha).

At the beginning of the period, in 1882 the greatest number (43) of islands appeared in units 20-19, and by 2007 it shifted downstream to the unit 18 (48 islands). The downstream drift of the islands is well represented by the decreasing island number of units 20-19, where their total area also decreased (1882: 86 islands, 1035 ha; 2007: 36 islands, 276 ha). However in units 18-15. the number of islands increased (from 61 to 115), whereas their total area was reduced (1882: 705 ha; 2007: 412 ha).

On the lower section of the Dráva (units 14-1.) the number and area of the real islands increased (by 54% and 35% respectively) during the last 130 years. Whilst the number of islands increased continuously (from 63 to 136), their total area was the greatest in 1979 (1520 ha) and by 2007 it decreased (Fig. 3B). The decreased area in 2007 could be explained by the amalgamation of the islands, as they merged into the river bank rapidly due to the decreased water level and the groins, and the new islands formed of small bars in the narrowed channel.

4.1.2. Floodplain islands

In the Dráva River there were just couple of floodplain islands during the studied period and their number decreased continuously. They had the greatest number (32) and total area (3797 ha) in 1882, when the most intensive period of river regulations was finished and this island type was created by cut-offs (Fig. 4A). Later the side channel of these islands were filled up by sediment, thus they merged to the floodplain. Therefore, in 1968 there were only 15 floodplain islands (1517 ha), and their number and area decreased further on (in 1979: 14 island, area: 1663 ha), thus in 2007 just 8 floodplain islands (976 ha) existed on the Dráva. The largest floodplain island (441 ha) appeared in 1882 in unit 11., though the smallest (18 ha) was formed in unit 7. at the same time.

The floodplain islands were the most numerous on the upper section of the Dráva (Fig. 4B). However, their number continuously decreased (from 10 to 5). The islands created by cut-off amalgamated to the banks by 1968, though some new islands were created by avulsion or by merging of smaller islands into one big form. The area of the islands increases by accumulation; for example in unit 15. the area of an island had increased by 3 ha (30 %) between 1968 and 1979. In this case, the small islands of a side-channel merged to the floodplain island, simultaneously with the sedimentation of the channel.

On the lower section floodplain islands were more abundant in 1882 (23) with significant total area (2985 ha). These islands merged to the river bank by 1968, though some new cut-offs (1968: 5, 1979: 7, 2007: 3) resulted in the development of new islands. In the 20th and 21st centuries floodplain islands occurred just in units 10-5., in the other units the islands had already amalgamated to the floodplain. The remaining islands increased their territory by merging side-bars, which became stabilised rapidly due to the dropping water stages. For example, in unit 10. the territory of a floodplain island increased from 62 ha (1968) to 95 ha (2007).

4.2. Evolution of islands

The evolution of islands is determined by their spatial relationship to the thalweg, which determines the energy conditions of the river and the erosion-accumulation processes of the islands.

The number of *islands in the thalweg* continuously reduced along the whole studied section of the Dráva (Fig. 5). In 1882 altogether 65 islands (27%) were in the thalweg, but by 2007 it decreased to 41 islands (14%). On the upper section in 1882 this island type had large number in each unit (in average 8 island/unit), but later on their number decreased to 3-5 island/unit in average (Fig. 6A).

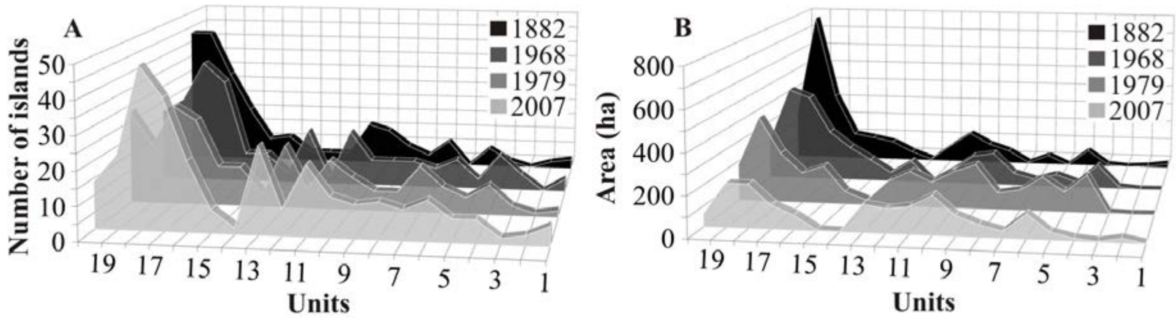

Figure 3. Spatial and temporal changes in the number (A) and the total area (B) of real islands in the different units between 1882 and 2007.

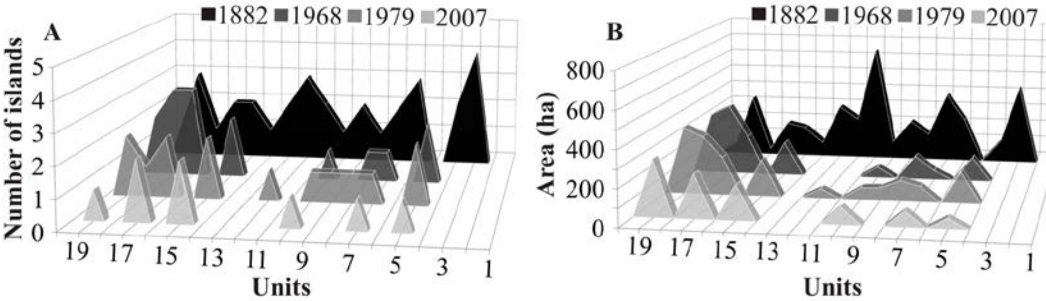

Figure 4. Spatial and temporal changes in the number (A) and the total area (B) of floodplain islands in the different units between 1882 and 2007.

Most of these (17) islands in 1882 were in unit 19., but later their number was reduced drastically, thus in the 20th-21st centuries there were only 4-5 islands in the thalweg, though most of them (6-13) was still in the units 18-17. On the lower section of the Dráva islands in the thalweg were less numerous. In 1882 there were just 2 island/unit in average, because the channel was straightened by cut-offs and it was quite narrow. Later as the channel became wider, mid-channel bars were formed in it which developed into islands. Therefore, in this lower section in 1968 there were 46 islands in the thalweg (5 island/unit). But due to the overall decline of islands their number decreased continuously, thus in 2007 there were only 15 islands in the thalweg (in average 2 island/unit).

The dominance of *osculating islands* characterized the Dráva between 1882 and 2007. The number of this island type increased continuously from 118 to 173, though their proportion among other islands has not changed significantly (1878: 49%; 2007: 59%). Osculating islands mostly characterize the upper section of the Dráva (Fig. 6B), though the units, where this type was the most common shifted downstream. Thus, in 1882 the greatest number (28) of osculating islands was in unit 20., but in 2007 it was in unit 17 (28). On the lower section the number of osculating islands doubled (1882: 34; 2007: 75), becoming the dominant (45%) island type of the section.

The number of *partially amalgamated islands* increased during the studied period from 30 to 52, thus 12.4-17.6% of the islands belonged to this class. It means, that gradually more and more islands lost their identity and by drifting close to other forms they connected to them. The process also relates to the decreasing water levels, as more side-channels lost their water-transport function. The process became obvious by 2007, when the greatest number and proportion of islands belonged to the class of partially amalgamated islands. Most of them appeared on the upper section of the Dráva, where by 2007 their number increased to 4-26 island/unit in average.

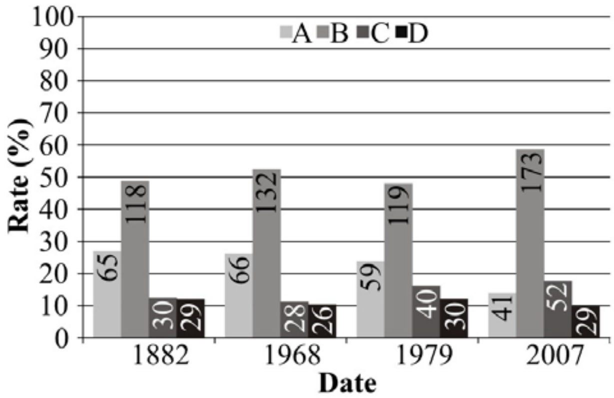

Figure 5. Frequency of evolutionary island types. A: island in the thalweg; B: osculating island; C: partially amalgamated island; D: completely amalgamated island; the numbers indicate the total number of islands within a certain type.

Whilst in 1882 this island type was the most common in unit 20. (5 islands), then in the 20th-21st centuries the islands shifted downstream and partially amalgamated islands became the most common (10 islands) in unit 18. (Fig. 6C). On the lower section of the Dráva River the number of partially amalgamated islands doubled (1882: 13 islands; 2007: 26 islands), thus their average density became 2 island/unit. They became more frequent on the lower section in 1979 and 2007, owing to in-stream river regulations (groins and revetments), as these engineering structures supported the merging of islands into the banks or each other.

The *completely amalgamated islands* had almost the same number (26-30) throughout the study period, probably because on the maps they were not properly illustrated. This type of islands in contrary to the other islands, were located mostly on the lower section of the Dráva (Fig. 6D). It could be explained by (1) their origin, as most of these islands were floodplain islands created by cut-offs, and there was enough time for the sedimentation of their side-channels, and (2) on some places the rapid sedimentation of the side-channels was supported by groins which close the side-channels.

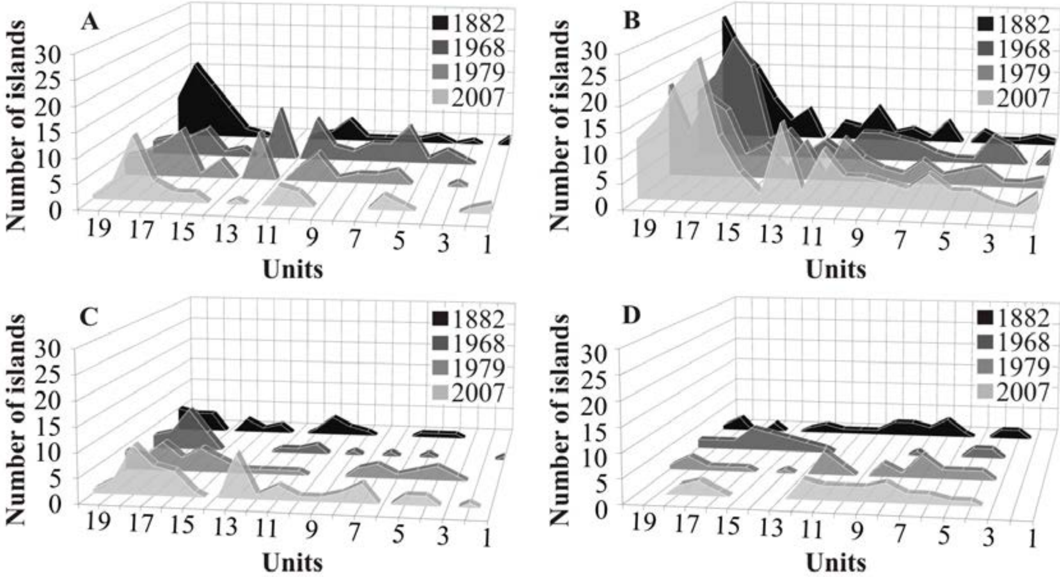

Figure 6. Spatial and temporal variations in the evolution classes of islands in the 10 km-long units. A: island in the thalweg; B: osculating island; C: partially amalgamated island; D: completely amalgamated island.

4.3. The frequency of the islands

The frequency of the islands decreased between 1882 and 2007, as the proportion of overlapping islands decreased from 52% to 30%, and the frequency of densely located islands increased (from 45% to 66 %; Fig. 7). The spatial pattern of the frequency distribution of islands is also characteristic. Downstream their frequency decreased, thus the distance between them increased (Fig. 8).

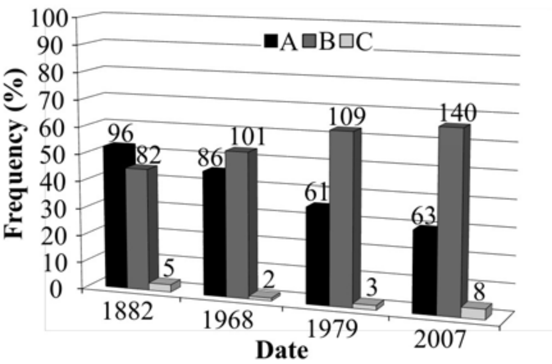

Figure 7. The frequency of islands reflects that how densely they are located to each other. A: overlapping; B: densely located; C: infrequent.

The upper section of the Dráva was characterized by *overlapping islands* during the whole study period. In 1882 there were altogether 90 overlapping islands here (in average 18 island/unit) and they were the most abundant (34) in unit 19. However their number decreased to 49 by 2007, and most of them (16) were in unit 17. On the lower section in 1882 there were only 6 overlapping islands (just in units 13. and 11.), and later their number increased (in 1968: 25; 1979; 19; 2007: 14) and they appeared in other units as well.

The *densely located islands* had different temporal and spatial variation (Fig. 8), as they became more abundant on the whole Dráva. On the upper section their number increased from 41 (1882) to 70 (2007), in average 12 densely located islands appeared in each unit. In 1882 they were the most numerous (13) in unit. 17., but by 2007 their peak shifted upstream, thus 23 densely located islands appeared in unit 18. On the lower section the number of densely located islands also increased (1882: 41; 2007: 70), thus they became the most abundant island type of the section.

The number of *infrequent islands* was very low on the whole Dráva reach (Fig. 8), thus on the upper section they appeared just in one unit (No. 15) in 1882. On the lower section this class of islands appeared more frequently, though just in very low number (1882: 4, 1968: 2, 1979: 3, 2007: 8 islands). Infrequent islands characterize the straight and regulated channel sections, because these sections are getting narrower and in the high energy conditions the development of new islands is difficult.

4.4. The shape of islands – elongation ratio

In this part of the analysis just those islands were evaluated which are in the thalweg or osculate to the bank or another island. The shape of the islands (elongation ratio: L/W) refers to the energy conditions of the river around the island, thus floodplain islands usually has smaller elongation ratio, whilst those in the thalweg have higher ratios.

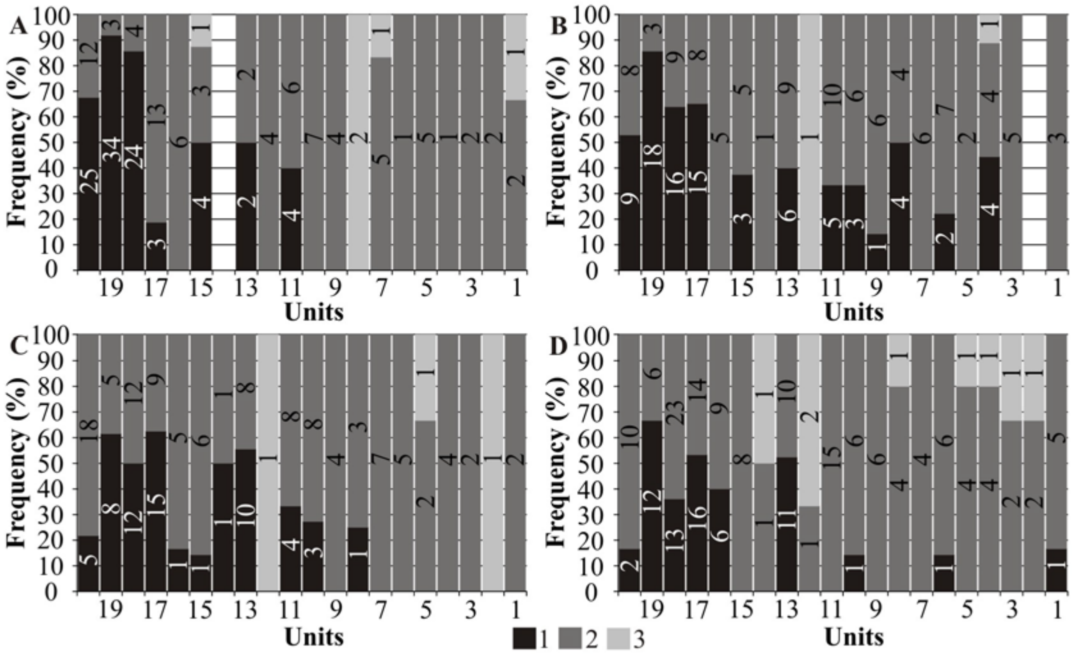

Figure 8. The frequency of islands in the different times (A: 1882; B: 1968; C: 1979; D: 2007). 1: overlapping; 2: densely located; 3: infrequent.

However, due to the merge of islands it also could happen that the newly developed floodplain island has greater elongation ratio than the islands it was formed of. An example for this is given in unit 6. (Fig 9), where 5 islands existed in the channel in 1968 (L/W: 1.63-8.44), but by 1979 they merged and a long island formed (L/W = 7.93).

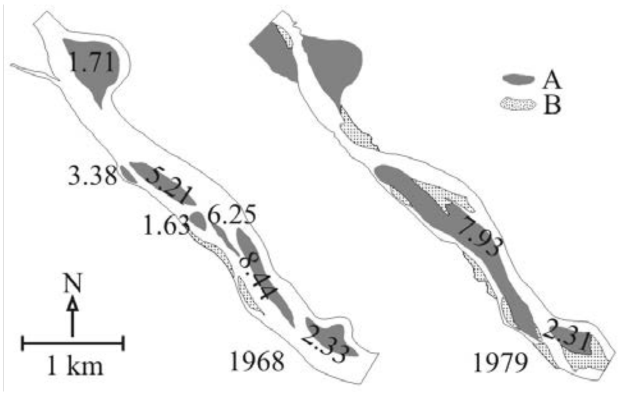

Figure 9. The elongation ratio of the islands in unit 6, and the development of the forms between 1968 and 1979. A: island; B: gravel-bar, the numbers indicate the elongation ratio of a form.

The islands of the Dráva were classified based on their elongation ratio (Fig. 10). On the whole Dráva section 11-26% of the islands have quite round shape (L/W≤2), whilst most of them (41-58%) is round (2<L/W≤4). As the erosion and accumulation are more intensive, the elongation ratio increases (4<L/W≤6), which is characteristic for 16-32% of the islands. Only 5-18% belongs to the class of strongly elongated islands (L/W>6), and they mostly appeared in 1968 and 2007.

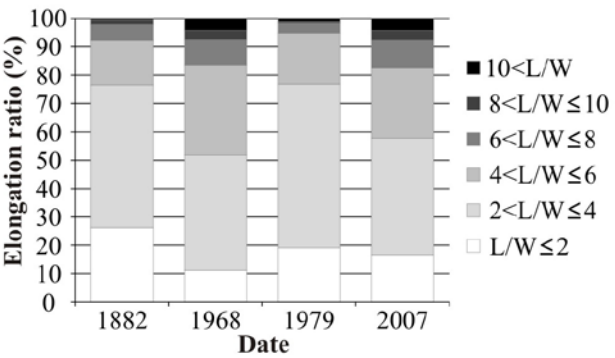

Figure 10. The elongation ratio (L/W) distribution of the islands during the period of 1882-2007.

Considering the spatial distribution of the elongation ratio it seems, that in 1882 on the upper section the average elongation ratio was 3.02 and most of the islands had quite rounded (L/W≤2: 28%) and rounded shape (2<L/W≤4: 53%). On the lower section the average elongation ratio was higher (3.74), though quite rounded (21%) and rounded islands (43%) dominated (Fig. 11A). By 1968 the islands became more elongated (in average: 4.3) on the whole section. On the upper section the average elongation ratio increased to 3.85. It could be explained by the decreasing proportion of islands with low elongation ratio (L/W≤2: 17%; 2<L/W≤4: 43%), and the increasing frequency of elongated islands (4<L/W≤6: 28%; L/W>6: 12%). On the lower section the highest average elongation ratio (4.79) of the whole studied period was measured in 1968, when elongated (4<L/W≤6: 34%) and the strongly elongated (L/W>6: 21%) islands became typical (Fig. 11B). In 1979 the average elongation ratio of the whole Dráva decreased to 3.31 (Fig. 11C), and this decrease was typical both on the upper (average elongation ratio: 3.04) and the lower sections (3.65). The islands became again more elongated (4.2) by 2007, with the same tendencies as earlier, but the variation of the ratio was smaller than before, thus the islands became more uniform along the whole Dráva (Fig. 11D).

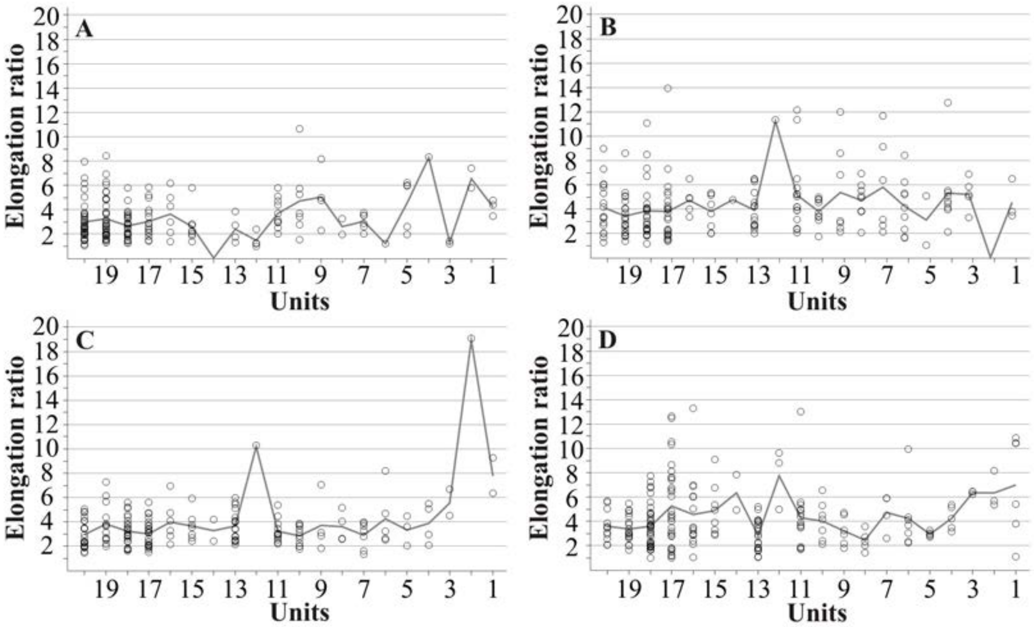

Figure 11. The elongation ratio of the individual islands (circles) and the average elongation ratio each unit (line). A: 1882, B: 1968, C: 1979, D: 2007.

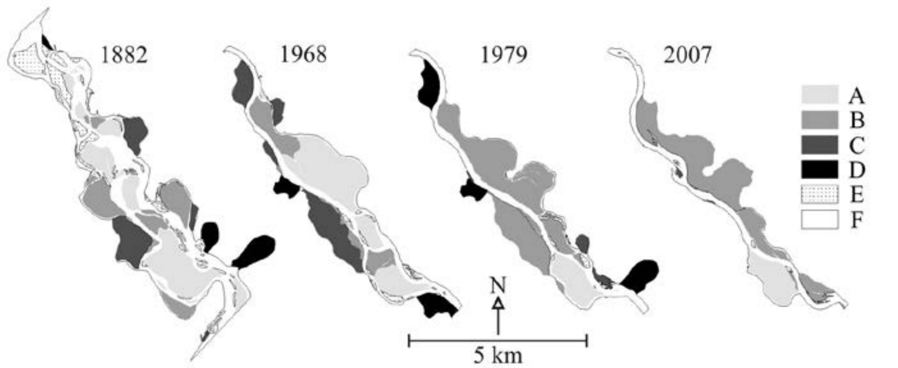

Figure 12. The different evolutionary types of islands in unit 19. between 1878 and 2007. A: island in the thalweg; B: island osculating to the bank or another island; C: partially amalgamated island; D: completely amalgamated island; E: gravel-bar; F: water surface.

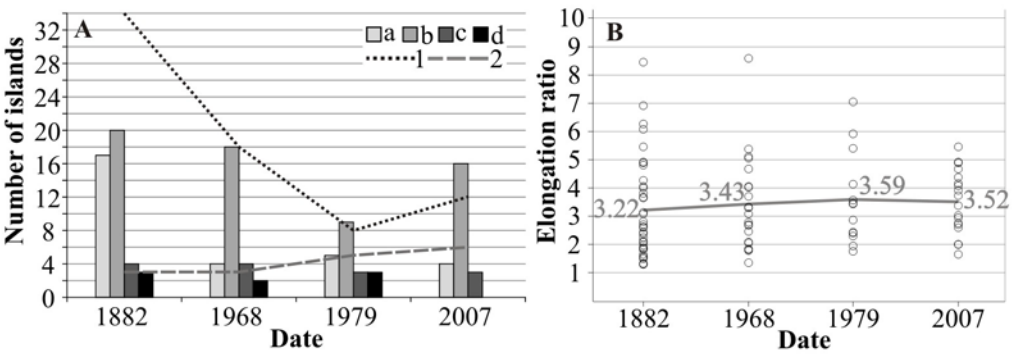

Figure 13. The evolutionary stages and spatial frequency of the islands (A) in unit 19. and the elongation ratio (B) of the islands (circles) and the mean elongation ratio of each survey (line and number); a: island in the thalweg; b: island osculating to the bank or another island; c: partially amalgamated island; d: completely amalgamated island; 1: overlapping island, 2: densely located island.

4.5. Connection between the different classifications – cases studies on two units

To present the relationship between the different island classifications and to reveal the triggering forces of the morphological changes two characteristic units were selected. Unit 19. (215.4-202.2 fkm) represents the upper section of the Dráva, which is almost unregulated (Fig. 12), where only some groins were built, but the effect of the lowest HPP is quite strong. The unit 13. (149.1-138.9 fkm) is located on the lower section of the Dráva, where intensive channel regulations influence the morphology (Fig. 14), as here the channel was straightened by two cut-offs, and in the 20^{th} century several revetments and groins were built to unify the channel.

In unit 19. large number of islands split the channel into several branches in 1882 (Fig. 12-13). At that time real islands were characteristic (43) with huge area (in total: 786 ha), and only one floodplain island (61 ha) appeared on the downstream section of the unit which was created by a cut-off. This floodplain island was already completely merged to the floodplain in 1882. Large proportion (39%) of the islands was in the thalweg, though osculating ones were the most abundant (45%). The unit was so densely inhabited by islands, that 92% of them was in overlapping situation with the others. The average elongation ratio was only 3.22, as most of the islands were quite rounded (L/W≤2: 32%) and rounded (2<L/W≤4: 41%). Only 27% of the islands were elongated or strongly elongated. These characteristics of the unit refer to medium energy conditions, where the island probably developed very slowly in the anastomosing channel.

Between 1882 and 1968 the number (26) of real islands decreased significantly, as well as their area (by 312 ha). By 1968 two large floodplain islands (340 ha) were formed of smaller amalgamating islands. As the former side-channels were filled up by sediment, a more uniform channel developed. In this narrower channel only 14% of the real islands were represented in the thalweg, and the proportion of osculating (64%) and partially amalgamated islands (21%) increased simultaneously. The islands became less frequent along the Dráva, as the ratio of the overlapping islands reduced to 86% and the ratio of the dense islands increased to 14%. Most of the islands became rounded (2<L/W≤4: 47%) and elongated (4<L/W≤6: 29%), and the number of quite round (12%) and very elongated islands decreased (5%). These changes suggest that as the channel became narrower the outer islands merged to the banks or into other islands. In the narrower channel the energy of the Dráva increased and therefore the low number of remaining islands was formed more dynamically. However, the complex anastomosing pattern became simpler, and the Dráva was going to develop a single channel.

Between 1968 and 1979 the number of real islands became even less (18) and their area decreased further on (by 50 ha). The two former floodplain islands merged into each other, though a side-channel still separated them from the floodplain. However, new islands appeared in the thalweg, thus their proportion (25%) was almost doubled. The frequency of the islands became lower in the unit, as the proportion of overlapping islands reduced to 62%. Compared to 1968, the average elongation ratio increased to 3.59, though the extremities decreased. These changes are probably in relation with the construction of HPPs and the resulted annual mean and lowest water-level decrease. The channel became narrower and the remaining side channel gradually lost its function. Therefore the former islands merged to each other or the banks, as the water-stages dropped. The remaining islands formed dynamically, but overall the Dráva became simpler and poorer morphologically and ecologically as well, as the islands as habitats declined.

During the last period (1979-2007) the number (22) of real islands started to grow, though it is still just the quarter of the value of 1882 (786 ha). The floodplain island which dominated the unit got closer to the bank and its area was reduced to 309 ha (by 17%) due to lateral erosion. However, the islands slowly lost their identity, as the ratio of islands in the thalweg reduced (17%) and as much as 70% of the islands osculated to the bank or another island. The islands appeared close to each other (overlapping islands: 67%), however these "nodes" became separated by longer island-free sections. Significant changes were observed considering the elongation ratio of the islands: the ratio of quite rounded islands (L/W≤2) reduced to 5%, but the rounded (2<L/W≤4) islands became dominant (67%). These changes probably in connection with the completion of HPPs, which capture the bedload, decrease the water stages and create daily small flood-waves. As the result of dropping stages the surface of the former bars became vegetated, thus the number of islands increased. However, these are small ones, and their round shape suggest that the accumulation plays important role in their development and therefore they will loose their identity soon or later by merging. As islands are mostly osculating, the channel becomes even more uniform, tending to have a sinuous channel pattern.

In unit 13. the development of islands was different than in the unit 19 presented above. In 1882 only three real islands existed in the channel (total area: 7 ha) and two large floodplain islands (area: 193 ha and 115 ha) which were created by cut-offs (Fig. 14). One of the floodplain islands was already completely amalgamated to the floodplain and the other was osculated to the riverbank. As the small islands were at the aggrading side-channel of the downstream floodplain island, they overlapped each other, though along the main channel no islands developed. The mean elongation ratio of the islands was 1.32, thus the islands were rounded shaped. Thus this survey represents the channel metamorphosis of the originally meandering channel into a straight one at the end of the 19th century.

Between 1882 and 1968 the straightened channel became wider (its average width of main channel increased from 318 m to 442 m) due to the increased slope created by cut-offs. In the widened channel 17 real islands appeared (total area 110 ha) dissecting the main-channel and creating a braided channel pattern. The former floodplain islands totally merged to the floodplain and they were not visible anymore. Most of the real islands (65%) were in the thalweg, the others osculated to the banks or other islands. Almost 60 % of the newly developed islands became densely spaced, the rest were overlapping with each other. The mean elongation ratio of the unit increased to 3.95. Though 53% of the islands were rounded (2<L/W≤4), the proportion of islands with high higher elongation ratio increased (4<L/W≤6: 27%; L/W>6: 20%). These changes reflect the morphological consequences of cut-offs. The slope of the artificially straightened channel increased (Varga, 2002), but simultaneously the Dráva had a great bed-load discharge. Therefore, the channel became braided with bars, which developed into islands. The dynamic evolution of the forms is reflected by their elongation ratio (Fig. 15).

In the next period (1968-1979) the number and the total area of the real islands almost remained the same (2 more islands and 16 ha area increase). However, their location in the channel changed, as the number of islands in the thalweg decreased (53%) and more and more islands (42%) osculated to the bank. More islands (56%) became overlapped, the rest were just densely spaced. The average elongation ratio decreased (3.42), and the most rounded category (L/W≤2) of islands also appeared (5%).

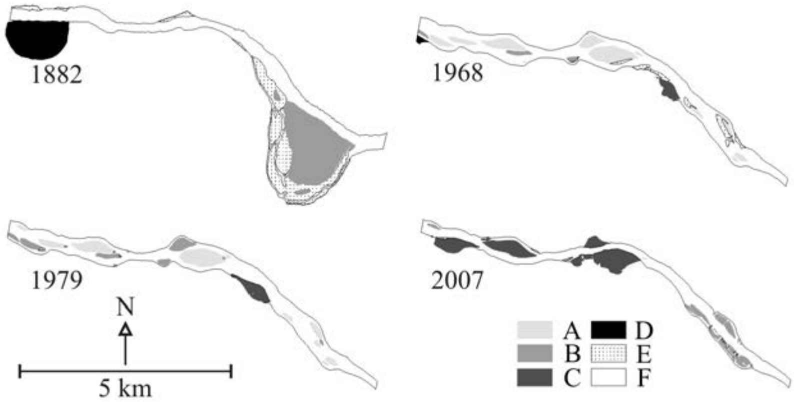

Figure 14. The different evolutionary types of islands in unit 13. during the period of 1878 and 2007. A: island in the thalweg; B: island osculating to the bank or another island; C: partially amalgamated island; D: completely amalgamated island; E: gravel-bar; F: water surface.

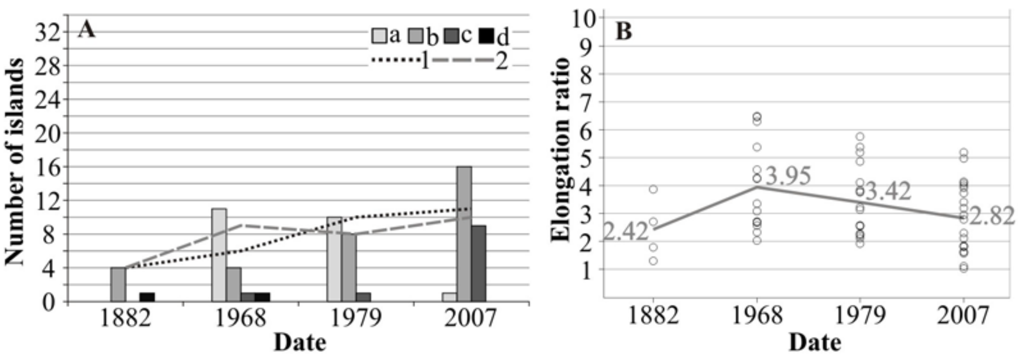

Figure. 15. The evolutionary stages and spatial frequency of the islands (A) in unit 13. and the elongation ratio (B) of the islands (circles) and the mean elongation ratio of each survey (line and number); a: island in the thalweg; b: island osculating to the bank or another island; c: partially amalgamated island; d: completely amalgamated island; 1: overlapping island, 2: densely located island.

It is in connection with the increase of osculating islands, as they drift closer to each other the side-channel between them will be narrower and side-bars could join to the islands making them rounder. The decreasing energy conditions are reflected by the disappearance of strongly elongated islands (L/W>6).

Finally, between 1979 and 2007 the number of real islands (26) was the greatest throughout the study period, however their total area almost remained the same (126-138 ha).

Most of the islands (62%) osculated to other forms or partially amalgamated (35%), and they became much rounder (mean L/W: 2.82). The main channel became narrower and uniform (only one island was in the thalweg).

Most of the islands (53%) overlapped each other or they were densely spaced (48%). These changes reflect the effect of groins, as behind them large number of small new islands were developed of gravel-bars. However the islands rapidly merge to each other or the banks. These facts reflect the decline of islands and the disappearance of this kind habitat from the lowland section of the Dráva.

5. CONCLUSIONS

During the studied period (1882-2007) the different river engineering works considerable altered the evolution of islands. On the examined 236 km-long Dráva section during the last almost 130 years the number of all island types increased by ca. 18% (1882: 242 island; 2007: 295 island) and their total area reduced by 57 % (1882: 6178 ha, 2007: 2654 ha), reflecting considerable changes in the dynamism of islands. These changes were triggered by human influence: until the 1968 survey mostly the effects of cut-offs (increased slope and sediment discharge) prevailed, therefore the Dráva widened and braided pattern became dominant on several units. However, in the second half of the 20^{th} century reservoirs were constructed upstream of the studied section and revetments and groins were created, which resulted in narrowing and unifying of the channel.

The greatest changes happened in case floodplain islands, as their number decreased by 75 % (from 32 to 8) and their total area by 92% (from 3797 ha to 976 ha). Most of them were created by cut-offs, therefore they appeared in larger number on the upper section, than on the lower one. Since the cut-offs were made in the 19^{th} century, the elapsed time was enough for the sedimentation of their side-channels, therefore these islands amalgamated into the banks. Only some new floodplain islands developed by merge of smaller gravel-bars or the rejuvenation of former side-channels. However, they all will amalgamate to the bank soon or later, as the side-channels loose their water- and sediment-supply due to the water-level drop caused by reservoir constructions.

The real islands formed of bars show different evolutionary way, as their number increased by 36 % (from 210 to 287), though their total area decreased by 30% (from 2381 ha to 1676 ha). It means that their size decreased from 11.3 ha to 5.8 ha in average. On the upper section of the Dráva real islands appeared in greater number, than on the lower section, as on the upper section the greater slope and flow energy support their development. Nowadays real islands especially develop near groins where the flow-field of the Dráva was modified.

Despite of the new islands behind groins the multiple-channel pattern of the Dráva is declining, thus the islands as riparian habitats are disappearing. At the same time the islands become more endangered and vulnerable, partly due to their decreasing size and partly due to the increasing number of osculating (1878: 118 islands and 2007: 173 islands) or partially amalgamated islands (1878: 30 islands and 2007: 52 islands). As the islands migrate close to the banks they will soon or later completely merge into the banks, thus they will disappear. The process is also supported by the shape of the islands, as they have more rounded shape as they osculate and side-bars connect to the islands. At the meantime the thalweg of the main channel will be more pronounced predicting the development of a sinuous single channel. The disappearance of islands is more rapid on the upper section of the Dráva, because this section is affected the most by the hydro-power plants, and because originally it had large number of islands in the natural state of the Dráva.

The islands act as important elements of the riparian ecological system, as they could serve as “stepping stones” for the species (Gilpin, 1980; Osterkamp, 1998; Gurnell & Petts, 2002). This ecological function of the islands could be described by their spatial frequency. It seems that the islands spaced less and less frequently, thus greater and greater distances separate them from each other. It is reflected by the continuously decreasing number of the overlapping islands (1882: 52% and 2007: 30%) and the increasing number of densely located islands (1882: 45% and 2007: 66%). The process is especially pronounced on the upper section, where the great slope of the Dráva River makes the upstream migration of riparian species even more difficult.

It could be concluded, that floodplain islands almost disappeared and the channel became narrower and more uniform in the last 130 years. The originally anastomosing channel became straightened by cut-offs, therefore on the sediment-rich and steep-sloped Dráva intensive island formation started and its pattern became braided in the 20^{th} c. However, due to the water-level drop caused by reservoir constructions and the blocking of side-channels by groins most of the islands osculated or merged to the banks in the late 20^{th} century. Thus, nowadays just small islands develop behind the groins, but the main channel lost its diverse morphology and the habitats on the islands are declining and getting more vulnerable.

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