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# Islands in a European mountain river: Linkages with large wood deposition, flood flows and plant diversity

Paweł Mikuś [a], Bartłomiej Wyżga [a,*], Ryszard J. Kaczka [b], Edward Walusiak [a], Joanna Zawiejska [c]

[a] Institute of Nature Conservation, Polish Academy of Sciences, al. Mickiewicza 33, 31-120 Kraków, Poland
[b] Faculty of Earth Sciences, University of Silesia, ul. Będzińska 60, 41-200 Sosnowiec, Poland
[c] Institute of Geography, Pedagogical University, ul. Podchorążych 2, 30-084 Kraków, Poland

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ABSTRACT

Vegetated islands are characteristic landforms of braided mountain rivers. Long-term observations and recent morphological and botanical surveys conducted in the gravel-bed Czarny Dunajec, Polish Carpathians, were used to determine the processes and patterns governing initiation and development of islands and their floristic complexity. Moreover, dendrochronologically estimated years of island inception were compared with the timing and magnitude of flood flows in the period 1970–2011 to infer about controls on the formation and persistence of islands in the river. In the high-energy, braided river, islands originate as a result of deposition of large vegetative particles, mostly large wood, on gravel bars and the associated vegetative regeneration of living wood or the growth of seedlings and saplings in the shelter of wood accumulations. Tree-ring dating of the largest trees growing in particular zones of building and established islands indicated a predominant upstream island growth in the river. It results from repeated accumulation of living wood on the head of islands and its subsequent regeneration and contrasts with the progressive downstream growth of islands in the rivers supplied with large, stable logs of the tree species without the capability to re-sprout. The lack of islands from the years 1982–1996 most likely reflects the removal of relatively young islands by two major floods in the 1990s which were, however, unable to destroy older and larger islands. After 1997 the occurrence of low to moderate floods facilitated the formation and persistence of islands. The plant inventory demonstrated that species richness increased non-linearly with the increasing age, area and shoreline length of islands. Islands supported more plant species than the riparian forest and attained comparable species richness at an early stage of development. Fast developing, dynamic and supporting rich plant communities, islands contribute highly to the overall floristic complexity of the river corridor and their re-establishment should be viewed as an important factor in the restoration of hydromorphologically degraded mountain rivers.



## 1. Introduction

River islands are discrete areas of vegetation within active river zones, surrounded by either low-flow channels or exposed sediment surfaces. They are formed by two distinct but often overlapping processes: (i) vegetation encroachment and development on bars separating interconnecting low-flow channels; or (ii) fragmentation of vegetated floodplain by channel avulsions. The first process is typical of high-energy, braided rivers draining mountain areas, while the second one mostly occurs in low-energy, anastomosing rivers that normally develop toward the lower reaches of river networks (Rinaldi et al., in press). This paper focuses on the islands originating in a mountain river as a result of the operation of the first process.

Once common in European rivers, in the late historical times islands were almost completely eliminated from the rivers (Gurnell and Petts, 2002) as a result of: (i) increased flow and sediment dynamics and the rate of turnover of the active zone of the rivers draining intensively managed catchments (e.g. Kondolf et al., 2002), and (ii) simplification of the channel pattern in the course of river-control works (Gurnell et al., 2009). Today they occur in rivers that have avoided major human impact (Tockner et al., 2003) or where islands developed during the 20th century in response to a reduction in flow and sediment dynamics (Wyżga et al., 2012). Re-establishing of islands may be a relatively fast and cost-effective means of the restoration of hydromorphologically degraded mountain rivers but its effective use in the restoration requires highlighting several aspects related to island inception, development and persistence as well as environmental significance.

Hitherto existing concepts of vegetation succession within river floodplains (e.g. Hupp and Osterkamp, 1985; Müller, 1995, 1998) emphasize the role of pioneering herbaceous plants in vegetation encroachment onto exposed riverine sediments. However, a large body of evidence has been collected, showing that island inception in mountain rivers is rather related to the deposition of large wood in their channels. While American researchers emphasize the role of large, stable pieces of dead wood in island development (e.g. Fetherston et al., 1995; Abbe and Montgomery,

* Corresponding author.
*E-mail address:* wyzga@iop.krakow.pl (B. Wyżga).

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1996), European scientists point to the significance in this respect of living wood of Salicaceae deposited on gravel bars (e.g. Gurnell et al., 2001, 2005; Moggridge and Gurnell, 2009).

Flood disturbances are a key control on vegetation establishment and survival in rivers (Moggridge and Gurnell, 2009). On one hand, floods recruit to rivers and deposit on channel bars large vegetative particles (Gurnell, 2007; Bertoldi et al., 2011) that can initiate the formation of islands. On the other hand, they can topple growing plants (Tanaka and Yagisawa, 2009) and laterally erode islands (Edwards et al., 1999). Moreover, where the energy of flood flows is too high, it can either prevent island development (Gurnell and Petts, 2006) or lessen island size (Dufour et al., 2007).

Island-braided river reaches support rich fauna, with high species richness in such reaches shown for fish, benthic macroinvertebrate, amphibian and ground beetle communities (Gurnell et al., 2005; Wyżga et al., 2009, 2011). This can be attributed to the high heterogeneity of habitats coupled with their relative stability. Investigations in the Tagliamento River, Italy, demonstrated that the rate of habitat turnover in an island-braided reach was slower in comparison with that typifying a bar-braided reach (Arscott et al., 2002; Van der Nat et al., 2003). Francis et al. (2009) indicated that the presence of abundant and heterogeneous island landforms almost certainly translates into higher diversity of plant species in river reaches containing islands, though this effect has never been quantified.

Using observations from island- to heavily island-braided reach of the Czarny Dunajec River, Polish Carpathians, this paper aims to answer the following questions:

1) What are the roles of diffuse seed germination and large vegetative particles in the initiation of islands in mountain rivers?
2) How and why does island development in European braided rivers differ from that typical of American rivers draining pristine and old-growth forests?
3) What is the impact of floods of different magnitude and timing on the initiation and survival of islands in a mountain river?
4) How does species richness of plant communities change through the sequence of island development stages and how do the islands contribute to the overall complexity of terrestrial plant communities in the river corridor?

## 2. Field setting

The Czarny Dunajec (Fig. 1) is one of two headwater watercourses of the Dunajec, the second largest river of the Polish Carpathians. The Czarny Dunajec originates at about 1500 m a.s.l. in the high-mountain Tatra massif (with elevations in the catchment up to 2176 m a.s.l.), and in the Tatra Mountains foreland it flows for about 38 km, joining with the Biały Dunajec River at an altitude of 578 m (Fig. 1). The Tatra part of the catchment has cool to moderately cold climate with annual precipitation totals ranging from 1200 to 1700 mm (Niedźwiedź and Obrębska-Starklowa, 1991). It determines the hydrological regime of the river, with low winter flows and floods occurring between May and August. In the Tatra Mountains foreland, the climate is moderately cool and annual precipitation totals range from 800 to 900 mm within the Orawa-Nowy Targ Basin to 900–1200 mm within the Gubałówka Hills (Niedźwiedź and Obrębska-Starklowa, 1991).

Supplied with coarse material in the Tatras, the river formed a non-cohesive alluvial plain in the Tatra Mountains foreland. In the 20th century, and especially in its second half, the foreland river reach experienced considerable channel changes. With decreased flood flows and catchment sediment supply and the resultant reduction in dynamics of the Czarny Dunajec (Zawiejska and Wyżga, 2010), numerous islands developed within the previously bare river channel and bar-braided morphology of the river changed to island-braided one in unmanaged channel sections (Wyżga et al., 2012). At the same time, channelization works and in-channel gravel mining resulted in considerable narrowing and incision of the channel coupled with the replacement of the former multi-thread channel pattern by a single-thread one along a majority of the river course (Zawiejska and Krzemień, 2004; Zawiejska and Wyżga, 2010).

These channel changes were accompanied by the expansion of riparian forest along the Czarny Dunajec (Wyżga et al., 2012). This process was stimulated by a reduction in pastoral and agricultural pressure on the riparian areas and either artificial (in channelized river sections) or spontaneous (in unmanaged sections) narrowing of the channel/active zone of the river, that has left the abandoned portion of the channel bed for the forest development. Currently the riparian forest occurs along almost the whole river length, delivering wood debris to the Czarny Dunajec, especially due to bank erosion during floods. As a result of periodic turnover of the riparian zone by the river in unmanaged channel sections, the harvest of trees in the riparian forest and the removal of larger fallen trees from the river for firewood, the debris has relatively small size and exhibits high mobility. Wood inventory performed after a 7-year flood in 2001 indicated the average estimated mass of individual wood accumulations in the river amounting to 233 kg, equivalent to about 0.5 $m^3$ of wood (Wyżga and Zawiejska, 2010). The wood debris is preferentially retained in wide, multi-thread river sections that are typified by intense delivery of fallen shrubs/trees from the local riparian forest, low unit stream power of flood flows and the abundance of retention features such as bars or islands (Wyżga and Zawiejska, 2005, 2010).

Islands were surveyed in a 4 km long, unmanaged channel section in the middle course of the Czarny Dunajec (Fig. 1). Here, the river still maintains a geomorphic dynamic equilibrium and a multi-thread channel pattern (Wyżga et al., 2010, 2012), and the width of its active zone varies from about 60 m at both ends of the section to 180 m in its middle part. In the middle part of the section, the river exhibits heavily island-braided morphology, with islands constituting 55% of the total area of the emerged surface within its active zone (Fig. 2). At the upstream and downstream ends of the section, the river has island-braided morphology and islands represent about 28% of the emerged area. The plant inventory of riparian forest was performed along the unmanaged section and the upstream, channelized section of the Czarny Dunajec. Islands and the riparian forest in the middle river course host a variety of plant communities from pioneering herbal communities, through tamarisk (*Myricaria germanica* L.) and willow shrubs to mature alder and willow forest. Hydrological characteristics of the middle river course were determined by records from the Koniówka gauging station (catchment area of 134 $km^2$; Fig. 1) where mean annual discharge amounts to 4.4 $m^3\ s^{-1}$ and the average for the highest annual discharges to 56 $m^3\ s^{-1}$. As the Czarny Dunajec in its middle course flows on a large, fluvioglacial–alluvial fan, the increase in the catchment area between the station and the study reach is negligible (Fig. 1) and the hydrological characteristics obtained for the station can be considered representative of the study reach.

## 3. Study methods

Because of differences in terminology used in the literature, we first define particular development stages of vegetated islands considered in the paper. Pioneer islands represent an initial stage of development of vegetative patches in rivers. Islands with the age of 1 to 4 years were classified in this group. Building islands are at an intermediate stage of development, still increasing their elevation due to fine sediment accretion as well as the extent on gravel bars. Islands with the age between 5 and 15 years were linked with this group. Established islands were older than 15 years; they usually attained the height comparable with floodplain elevation and occupied the whole area between neighbouring low-flow channels.

This paper compiles information on the island development in mountain rivers gathered during three research periods/campaigns.