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CHARACTERISTICS OF FLUVIAL ISLANDS ALONG THREE GRAVEL-BED RIVERS OF NORTH-EASTERN ITALY

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ABSTRACT. *River islands are defined as discrete areas of woodland vegetation located in the riverbed and surrounded by either water-filled channels or exposed gravels, exhibiting some stability and remaining exposed during bank-full flows. Islands are very important from both morphological and ecological points of view, representing the most natural condition of a fluvial system and are strongly influenced by human impacts. This study aims at analyzing the morphological and vegetation characteristics of three different types of islands (pioneer, building and established) in three distinct rivers in the NE of Italy, affected by different intensities of human pressure. The study was conducted on several sub-reaches of the Piave, Brenta and Tagliamento rivers. The first is a gravel-bed river, which suffered intense and multiple human impacts, especially due to dam building and in-channel gravel mining. The same alterations can also be observed in the Brenta River, which also presents bank protections, hydropower schemes and water diversions. On the other hand, the Tagliamento River is a gravel-bed river characterized by a high level of naturality and very low human pressures. The analyses were conducted using aerial photographs and LiDAR data acquired in 2010 in order to define and distinguish the three different island types and to obtain a characterization of ground and vegetation features. The results suggest that the fluvial islands lie at different elevations and this fact implies a different resistance capacity during flood events. Pioneer islands and building islands lie at lower elevations than established islands causing a lower capacity to survive during considerable flood events, in fact in most cases those islands types were removed by ordinary floods. Established islands lie at higher elevations and only intense and infrequent flood events (Reccurence Interval> 10-15 years) are able to determine considerable erosions. Regarding the characteristics of vegetation, we can observe a strong distinction between the three types. Established islands always exhibit the greatest vegetation height and the presence of these plants, sometimes higher than 30 m, contributes to increase the resistance and the stability of these components of fluvial systems.*

Características de las islas fluviales en tres ríos de gravas del noreste de Italia

RESUMEN. *Las islas fluviales se pueden definir como acumulaciones de sedimento colonizadas por la vegetación, situadas en el interior de un curso fluvial (río* *o arroyo). Delimitadas por el canal activo, presentan cierto grado de estabilidad a pesar de que en condiciones de crecida a nivel de cauce lleno (*bankfull discharge*) quedan expuestas al flujo de la corriente. Las islas fluviales resultan de gran importancia tanto desde el punto de vista morfológico como ecológico, pues representan el estado natural de los sistemas fluviales y presentan por ello un alto grado de alteración ante la acción antrópica. Este estudio analiza las caracteristicas morfológicas y de vegetación de tres tipologías de islas diferentes (pioneras, en desarrollo y estables), en tres ríos del Noreste de Italia afectados por diferentes grados de presión antrópica. Concretamente, la investigación se ha llevado a cabo en varios subtramos de los ríos Piave, Brenta y Tagliamento. El primero de ellos, el Piave, es un río con lecho de gravas, prevalentemente "wandering", que sufre una intensa presión antrópica relacionada con la construcción de grandes diques y con la extracción de áridos a lo largo del cauce. El mismo tipo de alteraciones pueden observarse en el río Brenta, el cual presenta también obras laterales de protección de márgenes, instalaciones hidroeléctricas y obras hidráulicas de desviación lateral. Por otro lado, el Tagliamento es un río con lecho de gravas de canales entrelazados que se caracteriza por un alto grado de naturalidad y reducida presión antrópica. Se han realizado analisis utilizando fotografías aéreas y datos LiDAR, relevados en el año 2010, con el objetivo de determinar y definir las tres diferentes tipologías de islas fluviales y lograr una caracterización de la topografía del terreno, así como de la estructura de la vegetación. Los resultados han evidenciado que las islas fluviales se hallan a diferentes cotas y elevaciones del terreno, lo que implica una diferente capacidad de resistencia a la erosión durante los eventos de crecida. Las islas pioneras y las islas en desarrollo se encuentran a cotas inferiores respecto a las islas estables, lo que implica una limitada capacidad de sobrevivir a crecidas notables: eventos de crecida ordinarios (periodo de retorno >7-10 años) desplazan o eliminan este tipo de islas en la mayoría de los casos. Las islas estables se situan en cotas más elevadas, y solo fuertes crecidas (periodo de retorno > 10-15 años) poseen la capacidad de provocar en ellas procesos erosivos considerables. Estas islas presentan una mayor diversidad, y su vegetación muestra una altura más elevada, con árboles que pueden superar los 30 metros, lo cual contribuye a incrementar la estabilidad y la resistencia a la erosión de estos componentes fluviales.*

Key words: fluvial island, gravel bed river, Piave River, Tagliamento River, Brenta River.
Palabras clave: islas fluviales, ríos de gravas, ríos Piave, Brenta y Tagliamento, Noreste Italia.

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1. Introduction

Gravel bed rivers are typically localized into or close to areas characterized by large amount of coarse sediment supply and frequent variations of flow discharge. Typically localized in the piedmont areas, braided rivers are defined as streams which flow in multiple and migrating channels across an alluvial gravel bed, containing numerous and changing bars, ponds and islands (Gray and Harding, 2007). River islands are usually defined as areas of woodland vegetation that exhibit different levels of stability and remain exposed, partially or totally, during flood events (Osterkamp 1998; Ward *et al.,* 1999). These vegetated patches are normally completely surrounded by exposed gravel and or water channels, flowing or no-flowing. Fluvial islands are very important by an ecological point of view increasing the biodiversity within the river corridor. In fact, the island, are characterized by a mosaic of habitats of different ages (Picco *et al.*, 2014), and present different levels of disturbance and geomorphology aspects that are uncommon along the managed riverbanks. Due to the separation of the islands from the floodplain, these can be important for the migratory flow andfurthermore them can offer safe refuge for wildlife from many predators. Consequently the river management strategies need to take into account these aspects, because an excessive reduction in the total island area could have negative ecological implications. Along the Tagliamento River, Arscott *et al.* (2000) found that the aquatic habitat complexity was greater in the island-braided section than in the island-devoid section, and Van der Nat *et al.* (2003) showed that aquatic habitats were more established in areas of vegetated islands even as compared to bar-braided areas.

Many different authors (Hooke, 1986; Church and Rice, 2009; Hooke and York, 2011; Kiss *et al.,* 2011) are inclined to define fluvial islands as vegetated bars due to the fact that the dynamics of islands are closely comparable to gravel bar dynamics. Leopold *et al.* (1964) implicitly incorporates island development in an early classification of straight, braided and meandering channel patterns. These authors consider two different processes: a) the evolution of relatively stable medial bars on which vegetation can establish itself within braided channels; b) the isolation of a section of vegetated floodplain through avulsion and cut-off along meandering channels. Kellerhals *et al.* (1976) further discriminated between occasional, frequent, split and braided island patterns. The various aspects and characteristics of fluvial islands can also help to describe the river processes that happend in the past, some plant species require specific growth conditions, such as inundation duration, gradient, and particle size (Picco *et al.*, 2012b) and that can help to determine the flow conditions in the area.

Fluvial island development and its stability can be strongly conditioned by flow regulations, as reported by several authors (Kondolf, 1997; Braatne *et al.,* 2003; Picco *et al.* 2014), during the last decades dams constructions along all large European rivers reduced flood peaks, increased base flow, and stored sediments. Reduced flow peaks downstream dams eliminate most processes of channel erosion, overbank deposition, and sediment replenishment; moreover the sediment transported downstream of dams can be only a fraction of the potential sediment load. Poff *et al.* (2007) demonstrated as the sum of these changes generally reduces the biologic habitat, diversity, and interactions between biotic and hydrologic processes. Osterkamp (1998) describes several scenarios in which islands could disappear. Perimeter sediment deposition could eliminate an island by several processes: a) by preferential in-filling of one of the side channels that effectively raises the bed level in one anabranch but not in the other, and thereby shifts the flow into a single path; b) by sedimentation around the whole perimeter of the island until it eventually coalesces with other nearby islands or the floodplain, again forcing the flow into a single path; c) by incision, by the flow, of one channels side and drop out of the other leaving it 'high and dry'. This is common downstream dams after that peak flows have been reduced. If a low flow regime persists for long enough, vegetation may accumulate between an island and its floodplain (Picco *et al.,* 2014). Floods can eliminate an island by two processes. The first one is by simply increasing the flow to levels high enough that the entire island is eroded away. The second one is by changing the main direction of the flow during a flood, thereby altering the angle of attack from the water and gradually wearing away the island by abrasion (Wyrick, 2005).

The aim of the present study is to analyze the characteristics of fluvial islands along three gravel-bed rivers affected by different levels of human pressure, as well as to better comprehend the different response to floods, in order to obtain more information to define more effective flood management programs, precautionary actions and to predict hydraulic hazards.

2. Study area

The study was conducted along three different sub-reaches of the Brenta, Piave and Tagliamento Rivers (Fig. 1). These rivers are comparable in terms of size, climate and geological setting, but they differ for the presence of human structures and interventions.

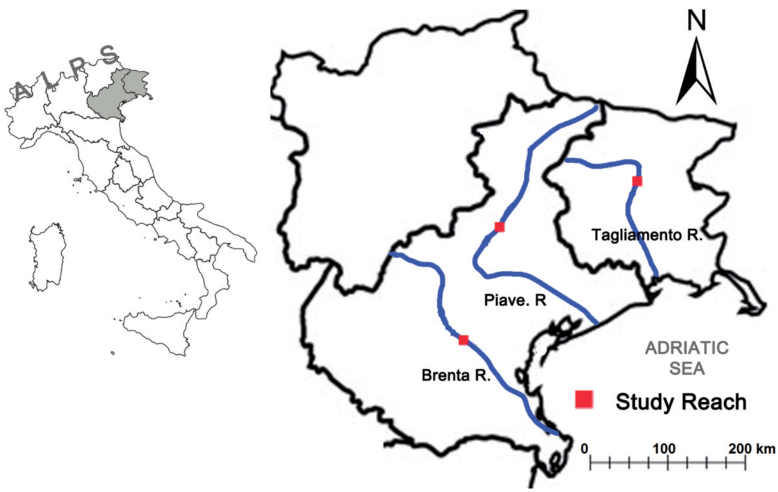

Figure 1. The study areas are located in the North-Eastern Italy, from west to east it is possible to see the Brenta River, the Piave River and the Tagliamento River.

2.1. Brenta River

The Brenta River basin is located in the eastern Italian Alps (Italy) and its course interests Trentino-Alto Adige and Veneto Region (Fig. 2). The study reach, called Fontaniva, features a length of around 3 km and it is located downstream in respect to the mountain hydrological basin (1567 km^2) between Bassano del Grappa and Carturo. Featuring an average annual precipitation of 1100 mm (spring and autumn are the rainiest seasons), the area presents an intermediate position between the piedmont and the floodplain. The dominant morphology of the reach is braided; the width is around 678 m and the average slope is 0.003 m m^{-1}, it flows being divided in several channels that contribute to form many fluvial islands. The Brenta River is characterized by the presence, all over its basin, of dams, hydrological derivations and embankments.

It is possible to define the Brenta as a river affected by strong human pressure. In this sense the Fontaniva reach is strongly influenced by longitudinal embankments and bridges (Moretto *et al*., 2013).

Figure 2. The Fontaniva study reach, flow direction is from left to right.

2.2. Piave River

The Piave River rises at an elevation of 2037 m a.s.l., and has a length of 222 km. It flows from its source in the Dolomites to the Adriatic Sea. The drainage basin is composed mainly of sedimentary rocks (predominantly limestone and dolomite) and has an area of 4500 km^2. The study reach (Fig. 3) is around 3 km long and is located along the middle course of the Piave River, within the mountain district. The average valley gradient is about 0.004 m m^{-1} and the channel width ranges from 100 m to 1000 m. The study reach may be described as transitional between wandering and braided morphology. The median grain size varies between 20 and 50 mm. The Piave River features a complex pattern of vegetation distribution along the analysed study reach (Picco *et al*. 2012a, 2012b, 2014), which is far more composite than those identified in less disturbed river systems (Hupp and Osterkamp, 1996; Gurnell and Petts, 2002; Tabacchi *et al*., 1998; Bendix and Hupp, 2000).

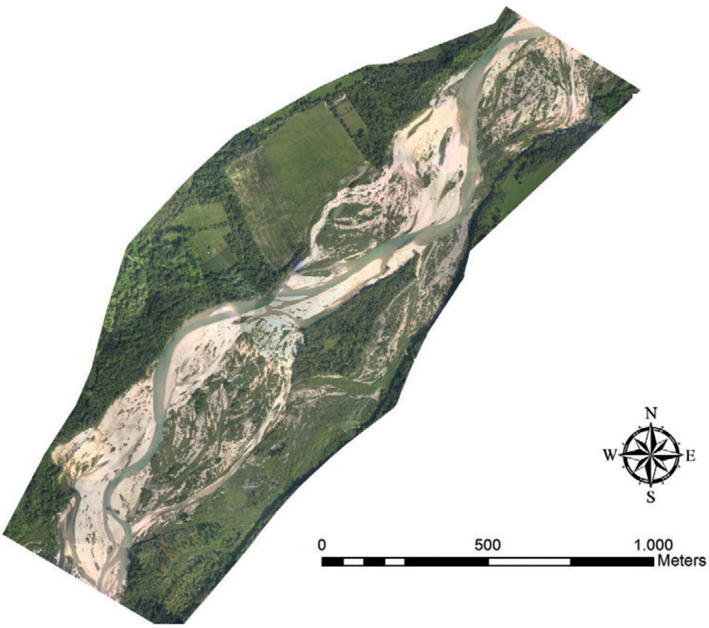

Figure 3. The Belluno study reach, flow direction is from top to the bottom.

2.3. Tagliamento River

The Tagliamento River is located in the Southern Alps of North-Eastern Italy. It originates at 1195 m a.s.l., and flows for 178 km to the northern Adriatic Sea, thereby forming a link corridor between the Alpine and the Mediterranean zones. Its drainage basin covers 2871 km^2. The river has a straight course in the upper part, while most of its course is braided shifting to meandering in the lower part where dykes have constrained the lower 30 km, thus it is now little more than an artificial channel about 175 m wide. However, the upper reaches are more or less intact, thus the basic river processes, such as flooding and the erosion and accumulation of sediment, take place under near natural conditions. The hydraulic regime of the Tagliamento River is characterized by irregular discharges, high sedimentation load and high dynamism (Picco *et al.,* 2013), due to the climatic and geological conditions of the upstream portion of the basin. The flood peak moves downstream very fast and can reach the village of Latisana (on the regulated lower part) in just 12 hours. The river is considered as the last morphologically intact river in the Alps, and therefore constitutes an invaluable resource. In fact the extensive vegetated islands and gravel bars are key indicators of its natural conditions, while engineering works for flood control or navigation have eliminated such features in most of the European water courses. The study reach (Fig. 4) is around 3 km long and is located between the villages of Osoppo and Forgaria nel Friuli, in the piedmont area. The average valley gradient is about 0.003 m m^{-1} and the channel width is around 1000 m. The study reach may be described as a braided reach.

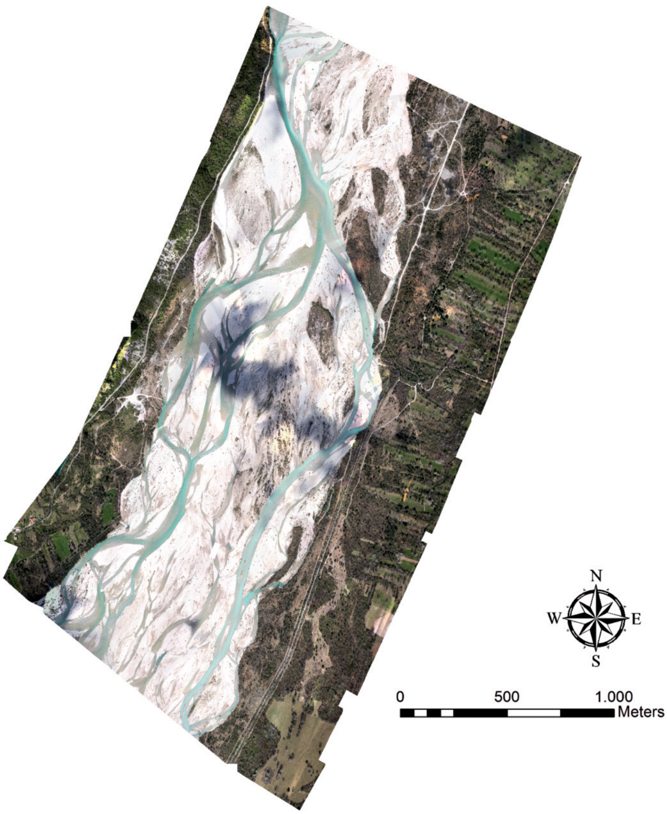

Figure 4. The Cornino study reach, flow direction is from top to the bottom.

3. Material and Methods

The analyses were conducted on a single dataset relating to 2010 for each river reach under consideration. Aerial photographs and LiDAR data were used. Aerial photographs were rectified and co-registered to a common mapping base at 1:5000 by a GIS software (Esri ArcGIS 9.2). Approximately 30 ground-control points were used to rectify each single frame and a second order polynomial transformation was then applied. The active channel extension was defined as the area delimited by water and/or not vegetated sediments.

As proposed by Picco *et al*. (2014), in order to distinguish the difference between vegetated patches, from aerial photo interpretation, a relationship between the age (tree ring measurements) and height of the plants was developed using field data. Referring to the island evolution model proposed by Edwards *et al*. (1999), pioneer islands and vegetated bars were identified as distinct morphological units, the first class with vegetation higher than 3 m. The vegetation is generally defined as good indicator of stability (Kollman *et al*., 1999), consequently pioneer, building and established islands were distinguished based on the maturity and size of the vegetation. The classification, using aerial photos, was made by estimating vegetation height based on canopy texture, shape and shadows. Pioneer islands, defined as an initial stage of development of vegetated patches in rivers (Mikus *et al*., 2012), were described as surfaces on bars with patchy vegetation 3-5 m high. Building islands are an intermediate stage of development, characterized by an increasing stage and extent (Mikus *et al.,* 2012). Finally, established islands are defined as surfaces existing also after high flow events (Wyrick and Klingeman, 2011) and characterized by areas with a tall dense vegetation cover (Gurnell and Petts, 2002). In a natural braided gravel-bed river, these landforms rarely survive more than 20 or 25 years (Gurnell *et al*., 2001).

Canopy height derived from LiDAR data was used to complement the aerial photographs (Zanoni *et al.,* 2008). For each river a LiDAR flight was carried out in August 2010. The availability of these data allowed us to analyze the vertical characteristics of the ground and the features concerning the vegetation of the islands point density of 2-3 m^{-2} was reached after filtration. Digital Terrain Model (DTM) and Digital Surface Model (DSM) were created at 0.5 m resolution for each river reach. Based on the 0.5 m LiDAR resolution, the subtraction of the original DTM layer from the DSM layer, generated the Canopy Height Model (CHM) raster, which was used to obtain the maximum elevation of island ground and the maximum height of the island vegetation (Picco, 2010).

4. Analysis

In Fig. 5 are reported the characteristics concerning the total area covered by the different island types along the three different study reaches related to the active channel extension. It is possible to observe as the Brenta reach and the Tagliamento reach show similar differences, with much greater established island sizes than the other two types, while along the Piave reach there is a less clear distinction between the sizes of the three different island kinds. It is rather interesting to see as, regarding the ratio island area vs. active channel area, there is a stronger difference along the Brenta reach than the other two rivers. In fact, the median value for the established islands is around 0.025 along the Brenta River and around 0.001 and 0.005 along the Piave River and Tagliamento River, respectively.

In Fig. 6 are reported the characteristics of the ground elevation and the vegetation height of the Brenta River sub-reach islands. It is clear the distinction in both the analysed characteristics, with a significant distinction of the median values reported.

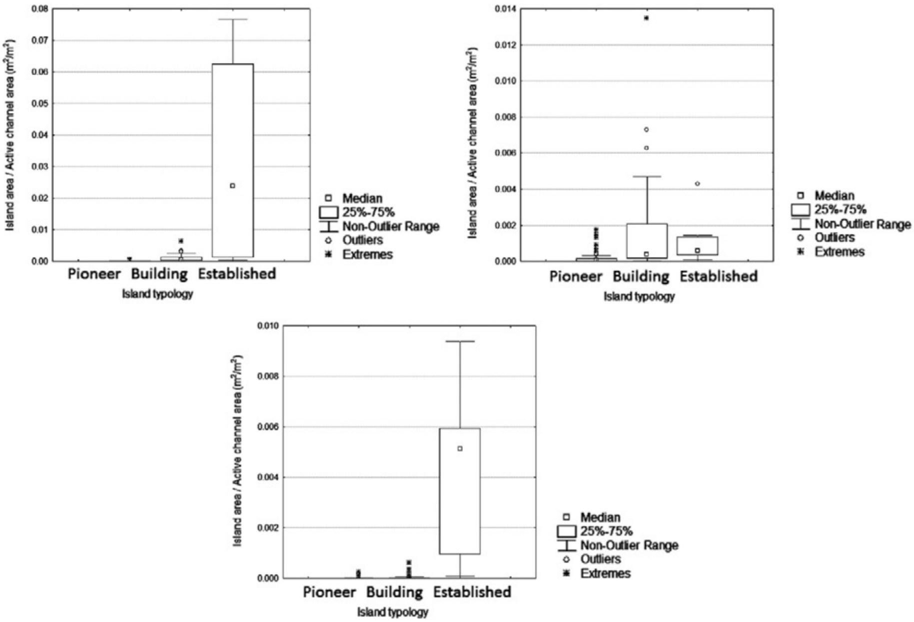

Figure 5. Variation in island size related to the active channel area along the Brenta River (on the left), the Piave River (on the right) and the Tagliamento River (on the bottom).

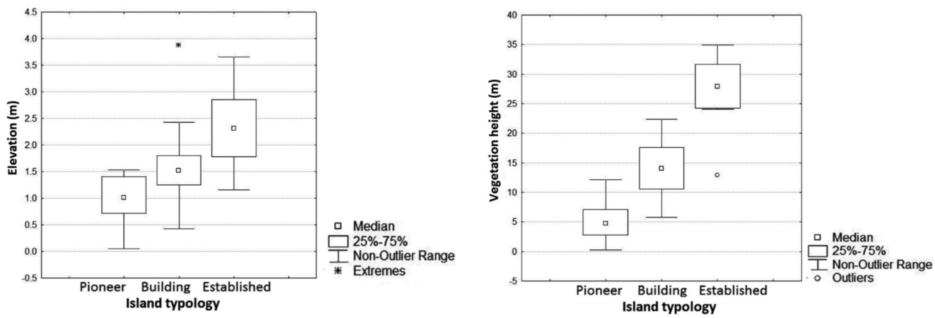

Figure 6. Maximum ground elevation of the Fontaniva sub-reach islands (on the left) and maximum vegetation height (on the right).

In Fig. 7 are reported the characteristics of the ground elevation and the vegetation height on the Piave reach islands. A lower difference, in respect to the Brenta River reach, between the ground elevation of the three different fluvial island types can be highlighted. In fact, there is only a difference between the median values of about 0.5 m, while in the Fontaniva reach that value rises until around 1.3 m. Looking at the vegetation height, it is possible to observe a clear distinction between the Brenta and the Piavestudy reaches, with a consistent decrease ofthe median values all over the three island types under consideration.

Finally, looking at the Cornino reach (Fig. 8), also in this case, there is a lower difference between the ground values in respect with those registered along the Brenta River. It is also interesting to see as, along the Tagliamento River, some vegetated patches that could be classified as islands can rise into some hollows.

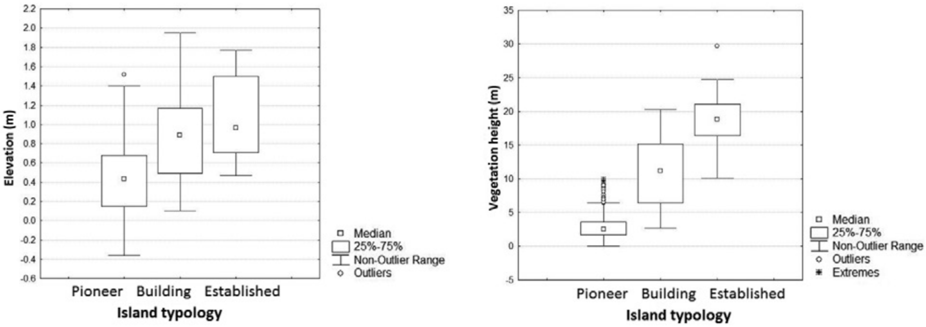

Figure 7. Maximum ground elevation of the Belluno sub-reach islands (on the left) and maximum vegetation height (on the right).

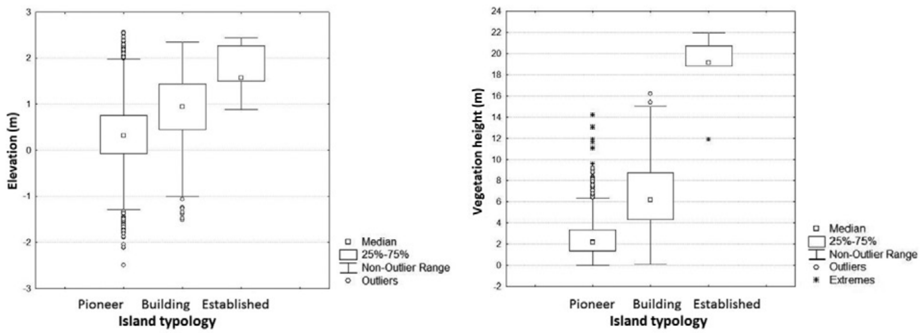

Figure 8. Maximum ground elevation of the Cornino sub-reach islands (on the left) and maximum vegetation height (on the right).

5. Discussion and Conclusions

The analysis here presented allowed us to better understand how and how much the islands can be affected by the surrounded environment. The results, in fact, show consistent differences between the three analyzed river systems. Taking into account the different human impact intensity all over the basins and along the fluvial corridor it is possible to connect the differences in size, cover, ground elevation and vegetation height of the fluvial islands with the human activities overall. In fact, the systems under consideration are theoretically comparable by the morphological, biogeographical and hydrological point of view, but these systems are affected in very different manners by human activities.

Looking at the higher cover of fluvial islands along the Brenta reach, this phenomenon is probably due to the high level of embankments that do not permit constant sediment recruitment from the banks with consequent channel narrowing. This process allows easier vegetation stabilization over the higher bars that are not disturbed periodically by the floods. On the other hand, along the Tagliamento river there is a higher difference between the sizes of the stable islands and the other two kinds, this is probably due to the fact that only the more established islands are able to resist to the very common flood events that could happen different times per year moving huge volumes of sediments (Picco *et al*., 2013). These observations matched with those made by different authors (Bertoldi *et al*., 2009; Comiti *et al.,* 2011; Picco *et al.,* 2012a) wherein the island dynamics were found to be strictly associated to the occurrence of major floods (RI > 10-15 years), which are the only ones able to generate substantial island erosions.

Thanks to the LiDAR data, was possible to analyze important morphometric characteristics of the different kinds of islands. As expected, the established ones lie at higher elevation. This is due to the fact that older vegetation growing on established islands allows the deposition of fine sediments which, in turns, enhances the conditions for vegetation growth, providing even better circumstances for the vegetation to establish on stable islands (Picco *et al.,* 2012a). The flood control (by dams) and the sediment recruitment control (by embankments), can be the factors that trigger the higher difference in the ground elevation between the three island types along the strongly affected Brenta river. In fact, a more active environment, as in this case the Talgiamento reach, permits a mixed distribution of channels, bars and islands that, ultimately, maintain similar morphological characteristics all over the active channel do not allowing the narrowing processes seen along the Brenta river. This explains also the lower difference in the ground elevation along the Cornino reach islands.

This higher stability of the established islands along the Fontaniva reach is, also, reflected by the very high vegetation that composes this island typology, in respect of the lower maximum height observed along the two more natural rivers under consideration.

This important analysis can be carried out with the simple detection starting from aerial photographs. This kind of analysis can be helpful also to predict the hydraulic hazard linked to the morphological changes and to formulate more effective flood management programs. Analyzing the island characteristics it is possible to observe how the fluvial system is stable, permitting to predict the potential increase in hydraulic hazards depending on the conditions and expansion of perifluvial vegetation and fluvial islands. Using LiDAR data it is possible to predict the Large Wood (LW) characteristics, dimensions and volumes that could be moved downstream during floods in case of island erosion processes, permitting to localize areas of storage or areas that can be affected by the direct impact of LW (eg. bridges, check dams, bank protections); on the other hand it is possible to define the potential volume of sediment that can be released during island erosion. All this important information can be really useful to better define flood management programs and precautionary action such as, for example, the removal of the biggest trees from the islands located close to critical sections.

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