Landscape and Urban Planning 134 (2015) 107–118

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Research paper

How do river dynamics and human influences affect the landscape pattern of fluvial corridors? Lessons from the Magra River, Central–Northern Italy

Simon Dufour[a,*], Massimo Rinaldi[b], Hervé Piégay[c], Amael Michalon[d]

[a] COSTEL/LETG CNRS UMR 6554, Rennes 2 University, Place recteur le Moal, 35000 Rennes, France
[b] Dipartimento di Ingegneria Civile, Firenze University, via S. Marta 3, 50139 Firenze, Italy
[c] ENS LSH/EVS CNRS UMR 5600, Lyon University, 15 Parvis René Descartes, 69007 Lyon, France
[d] CEREGE, Aix Marseille University, Europle de l'Arbois, 13100 Aix en Provence, France

HIGHLIGHTS

- Fluvial landscape dynamic along the Magra River is mainly driven by local factors.
- Landscape diversity is higher where human impact has been the greatest.
- Landscape diversity is a complex attribute difficult to use as an indicator.
- Landscape diversity should be considered with other ecological attributes (e.g. conservation status).

ARTICLE INFO

Article history:
Received 21 May 2014
Received in revised form 1 September 2014
Accepted 7 October 2014

Keywords:
Riverscape
Biodiversity
Morphological adjustment
Human impact
Indicator

ABSTRACT

Along the Magra River (Central–Northern Italy), human control at the local-scale appears to be the main driving factor of morphological changes observed since WWII. Our results, based on aerial photographs analysis and field survey, indicate that the reduction in channel width observed between the 1950s and the 1980s is probably due to local factors rather than to basin-scale factors. With regard to riparian landscape pattern, evolution from a braided pattern to a wandering/meandering pattern increases landscape diversity but some differences exist between reaches because of the different morphological trajectory and human impact. Moreover, this landscape diversity seems poorly linked to landform age, as we had expected. Evolution from a bar-braided pattern to a single-thread system generates some paradoxes from a conservation perspective: disappearance of a braided pattern but riparian woodland expansion and landscape diversity increase. This research suggests that landscape diversity is a complex attribute that should be considered with other attributes such as the specificity of habitats.

1. Introduction

Fluvial landscapes follow complex temporal trajectories because these landscapes result from the combination of physical drivers, biological interactions and human influences (Bravard, Amoros, & Pautou, 1986; Malanson, 1993; Naiman, Décamps, & McClain, 2005; Stanford et al., 1996; Ward, Tockner, Arscott, & Claret, 2002; Whited et al., 2007). These processes operate most strongly on riverine morphological pattern at the reach scale. They create a three-dimensional template with a variety of abiotic conditions linked to topographical, hydrological and sedimentological gradients (Bendix & Hupp, 2000; Poole, Stanford, Frissell, & Running, 2002; Ward, 1997). Riparian vegetation structure and composition are conditioned by this template (Dufour, Barsoum, Muller, & Piégay, 2007; Hupp & Osterkamp, 1985; Nakamura, Shin, & Inahara, 2007; Van Coller, Rogers, & Heritage, 1997) and can be radically reshaped by natural disturbance events such as large-magnitude floods, ice scour, and fire (Bendix & Cowell, 2010; Bertoldi, Zanoni, & Tubino, 2010; Friedman & Lee, 2002; Piégay & Bravard, 1997; Stromberg, Tluczek, Hazelton, & Ajami, 2010).

Because floods are the most common driver of rapid and profound change to fluvial landscapes, channel mobility is usually considered an important driver of overall corridor structure and biological diversity (Kalliola & Puhakka, 1988; Salo et al., 1986; Tabacchi, Planty-Tabacchi, Salinas, & Décamps, 1996; Ward

* Corresponding author. Tel.: +0033 299 141 846; fax: +0033 299 141 785.
E-mail addresses: simon.dufour@univ-rennes2.fr, simon.dufour@uhb.fr (S. Dufour).

http://dx.doi.org/10.1016/j.landurbplan.2014.10.007

et al., 2002). Following the Intermediate Disturbance Hypothesis, biological diversity should increase from stable (i.e. straight) to moderately dynamic systems (i.e. free meandering and island braided) and then it should decrease from moderately to highly dynamic (i.e. bar braided) (Beechie, Liermann, Pollock, Baker, & Davies, 2006; Piégay, Grant, Nakamura, & Trustrum, 2006; Tabacchi et al., 1996; Ward, 1997). Because flood frequencies and magnitudes are higher in dynamic reaches, the latter are characterised by young morphological features such as open alluvial bars (vs. heavily-vegetated floodplains) and pioneer softwood stands (vs. older, later-successional units) (Beechie et al., 2006; Miller et al., 1995; Nakamura et al., 2007). Thus the range of landform ages in a meandering system is greater than in a constantly-disturbed bar-braided system, and this greater distribution of surface ages leads to greater landscape heterogeneity.

Lastly, human activity such as flow regulation, floodplain land conversion or gravel mining modifies fluvial dynamics both directly and indirectly (Aguiar & Ferreira, 2005; Brierley, Cohen, Fryirs, & Brooks, 1999; Décamps, Fortuné, Gazelle, & Pautou, 1988; Greco & Plant, 2003; Gregory, 2006; Walter & Merritts, 2008). For example, channel narrowing can be a consequence of a reduction in bedload supply following dam construction or hillslopes afforestation (Azami, Suzuki, & Toki, 2004; Gonzalez, Gonzalez-Sanchís, Cabezas, Comín, & Muller, 2010; Grams & Schmidt, 2002; Johnson, 1994; Maekawa & Nakagoshi, 1997; Miller et al., 1995; Rollet, Piégay, Bornette, Dufour, & Persat, 2013; Takahashi & Nakamura, 2011). Locally, human pressures such as embankment, gravel mining, or livestock and forestry practices also affect the fluvial landscape pattern (Magilligan & McDowell, 1997; Sidle & Sharma, 1996; Surian & Rinaldi, 2003; Wyzga, 1993).

Because many drivers interact in space and time, in most cases, it is difficult to establish a clear link between each of them individually (i.e. local human pressure, legacy impacts, long-term climatic or channel changes) and the observed current landscape pattern or its evolution. The Magra River (Central–Northern Italy) provides a good opportunity to analyse such complex changes in landscape structure. It is a formerly braided river which has been affected by significant and spatially discrete channel modifications over the last few centuries. Following the previous understanding of the geomorphic trajectory (Rinaldi, Simoncini, & Piégay, 2009), the aim of this contribution is to evaluate and discuss changes in fluvial landscape structure which are related to the modifications in channel geometry (narrowing, degradation) and human impacts. We analyse changes of two representative reaches of the river over 70 years as a basis for a comparative approach (Brierley & Fryirs, 2009; Piégay & Schumm, 2003; Takahashi & Nakamura, 2011; Rollet et al., 2013; Villarreal, Drake, Marsh, & McCoy, 2012). The two reaches are similar in terms of hydrological regime but they contrast in terms of geomorphic and human pressure: the upstream reach is steeper and less affected by human activity than the downstream one. The objective is also to discuss the implications in terms of management of such dynamic landscape under human control. Our initial hypotheses concerning fluvial landscape structure and dynamics are the following:

(1) Channel changes differ amongst reaches because the intensity of gravel mining is different in each;
(2) This difference in geomorphic trajectory between the two reaches explains different landscape patterns (Francis, Corenblit, & Edwards, 2009): (i) in both reaches channel narrowing associated with the evolution from a bar-braided to wandering or meandering form should lead to a more heterogeneous landscape that is linked to the diversity of landform ages (Beechie et al., 2006); (ii) however a less diverse mosaic is expected in the reach where channel degradation and narrowing are the highest due to the lower rate of channel shifting and drier conditions in the floodplain generated by river bed degradation (Bravard et al., 1997).

2. Material and methods

2.1. Magra River and studied reaches

The Magra River is situated in Northern Tuscany and Liguria (Central–North Western Italy). The catchment has an area of about 1700 km^2 (Fig. 1A), with a physiographic pattern characterised by aligned ridges with a NW–SE trend, made up of Mesozoic and Tertiary units with folded structures, separated by two main basins with a similar trend: in the west, the valley of the Vara River, the main tributary of the Magra (catchment area of 572 km^2), and in the east the middle-upper Magra valley. The area falls within a temperate climatic zone with a dry summer season, and a mean annual rainfall of 1707 mm, with a maximum of approximately 3000 mm in the upper part of the catchment.

The Magra River in its downstream part is about 43 km long, alternating unconfined with semi-confined reaches as a consequence of the relevant physiographic and tectonic control of the catchment. Along the alluvial reach, channel gradient ranges from about 0.014 (upstream) to 0.0004 $m\,m^{-1}$ (near the sea) (Fig. 1B). Most of the shifting channel sections of the Magra are characterised by the occurrence of a gravel bed, with median sediment grain size ($D50$) ranging from about 17 to 90 mm, excluding the final reach close to the mouth where sand becomes predominant (Rinaldi, Teruggi, Simoncini, & Nardi, 2008). The Calamazza gauging station is located along the middle–lower portion of the river (catchment area of 932 km^2), upstream from the Vara confluence (Fig. 1A). At this location, daily average discharge is 40.8 $m^3\,s^{-1}$ (recorded over a 45-year period), while the mean of maximum annual daily discharges is 683 $m^3\,s^{-1}$ (maximum annual peak discharges are not available), and the largest recorded flood discharge is 3480 $m^3\,s^{-1}$ (instantaneous peak discharge on 15 October 1960).

For this study purposes, we focused our analysis on the time scale of seven decades along two selected unconfined reaches (Fig. 1): (a) upstream reach, consisting of the middle–upper Magra where the river flows in a relatively large alluvial valley (Piana di Filattiera); (b) downstream reach, close to the Vara confluence. These two reaches were compared in order to identify the respective importance of catchment-scale versus reach-scale controls. The two reaches have contrasting characteristics in terms of location within the network, natural morphology and human pressures, as summarised in Table 1.

2.2. Current landscape structure

The effects of channel shifting on current landscape structure were measured at the patch-scale from the most recent and highest quality photographs and from a field vegetation survey (Table 2). In comparison to older series, the scale of these photographs allowed us to refine the distinction between units and confirm unit type by field reconnaissance.

In the field, we determined and surveyed homogeneous vegetation units along six cross sections (three per reach) in May 2006 (Fig. 1A). Criteria of homogeneity are the physiognomy of the vegetation (e.g. grassland, forest) and the floristic composition. The cross sections are regularly spaced within the reaches (approximately every 3 km). Along each cross section, we identified homogeneous vegetation units based on floristic composition, physiognomic parameters and censed species (presence/absence) within each unit. Vegetation data were analysed by a Correspondence Analysis performed on 91 species of 11 types of vegetation units (Table 3).

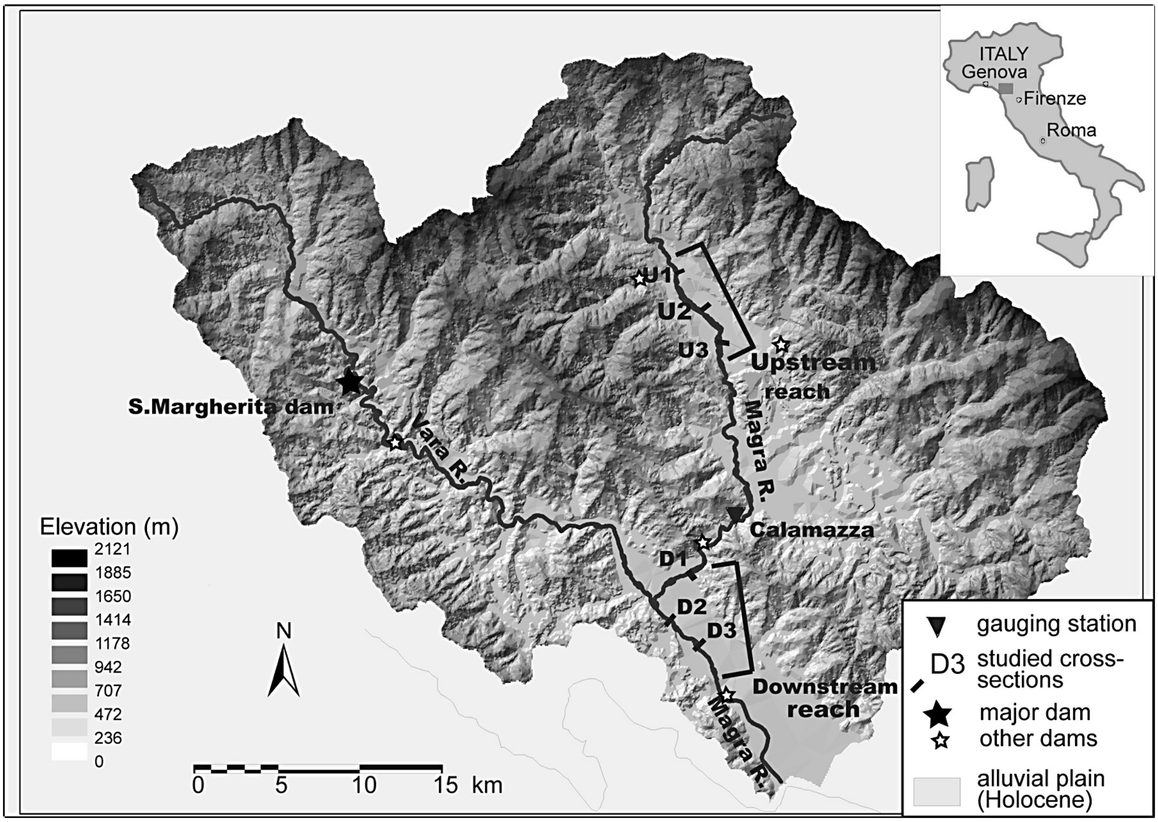

Fig. 1. Magra River catchment and study reaches.

Table 1
Characteristics of the two study reaches (see Rinaldi et al., 2009).

	Upstream reach	Downstream reach
Geomorphic characteristics		
Length (m)	9500	10,000
Elevation (m a.s.l.)	190–120	25–5
Mean slope (1989) ($m\,m^{-1}$)	0.009	0.0024
Distance to source (km)	6.5–16	33–43
Overall bed degradation (m)	2–4	5–8
Mean lateral erosion rate* (1995–2003) ($m\,y^{-1}$)	4.9	1.8
Human activity		
Catchment afforestation and steep tributary regulation by check dams	End of 19th–early 20th century	Same
Groynes	None	1920s–1930s
Dam construction	3 small dams (drainage area 19% of the drainage area of the upstream reach, and 4% of the total catchment area) (2nd half of the 20th century)	1 large dam (drainage area 43% of the Vara+ catchment area) (1930s)
In-channel sediment mining	Moderate/1960s–1980s	Intensive/1960s–1980s

* Measuring bank retreat in several section of the reach; fixed artificial banks were excluded.
+Vara River is the main tributary of the Magra River.

Table 2
Characteristics of a series of aerial photographs used for studying the decadal evolution of the fluvial corridor (active channel, riparian features), and describing the current riparian landscape structure (photographs from a given year used for particular issues are marked by x).

Date	Type*	Scale	Source+	Decadal evolution		Present structure
				Active Channel	Riparian features	Riparian features
1937	B&W	1:18 000	IGM	x	x	
1954	B&W	1:33 000	IGM–GAI	x	x	
1971	B&W	1:66 000	IGM	x	x	
1981	B&W	1:66 000	IGM	x	x	
1995	C	1:40 000	AIMA	x		
1999	C (ortho)	1:40 000	Italia 2000	x	x	
2003	B&W (ortho)	1:33 000	Regione Toscana	x		
2006	C	1:7000	CGR Parma	x		x

* B&W: black and white; C: colour.
+IGM: Istituto Geografico Militare, AIMA: Agenzia Interventi Mercato Agricolo, CGR: Compagnia Generale Riprese aeree.

Table 3
List of units mapped for the current landscape analysis at 2 levels of precision.

Level 1	Description	Level 2	Description
HUM1	Human and non vegetated units	ANT	Road, houses, villages
		ANT_BG	Bare ground (secondary paths. . .)
HUM2	Human origin and vegetated	CULT	Agriculture (crops. . .)
		VANT_T	Dominated by trees (along roads, around houses, etc.)
		VANT_S	Dominated by shrubs (along roads, between croplands, etc.)
		VANT_H	Dominated by herbaceous (football pitch, playground, etc.)
FAL	Fallow land resulting from deforestation or cropland abandonment	FAL_S	Dominated by shrubs
		FAL_H	Dominated by herbaceous plants
GRA	Grassland	WP	Wet grassland
		MP*	Mesic meadow (possible few isolated trees or shrubs)
		DP*	Dry meadow (possible few isolated trees or shrubs)
		SHR	Shrub development in DP and MP
AQU	Aquatic area	PLA	Artificial lentic water (former gravel mining)
		MC	Main channel, secondary channel connected upstream and downstream at low flow
		SC_F	Lateral channel connected upstream or downstream, active, with gravel erosion and deposition, can be temporarily dry
		SC_W	Former channel non connected, or just downstream usually located within the floodplain (e.g. surrounding by post-pioneer units)
GB	Gravel bars, sparsely vegetated	GB_1*	Vegetation cover < 5%, cobbles and pebbles
		GB_2*	Vegetation cover > 5%, presence of small sandy patches
		DSCF*	Secondary channel, dry and vegetated by pioneer species
PIO	Pioneer dominated by shrubs (manly *Salix* sp. and *Populus nigra*)	PIO_D*	Dense pioneer patch
		PIO_C*	Pioneer patch less dense with some GB_2 mixed
WOO	Woodland	FF_D*	FF degraded (e.g. lower density)
		FF_W*	FF (probably) wet
		FF_WD	FF (probably) wet and degraded (e.g. lower density)
		FF_SA*	FF dominated by *Salix alba*
		FF_SAD	FF dominated by *Salix alba*, degraded (e.g. lower density)
		FF_DD*	FF dry and degraded (e.g. lower density)

* Units have been described by a vegetation survey along the cross sections; other units have been identified in field and on photographs but not along the cross sections.

We then used object-oriented remote sensing (eCognition®) to detect patches on high resolution photos (1:7000) at corridor scale. The accuracy in patch planimetric position (2 m) has been estimated using field reference points (DPGS surveying). Units described along cross sections were used to identify the nature of all patches (Table 3). We maintained two levels of precision in unit description. At Level 1, there are eight different classes: three directly related to human activity (without vegetation, with vegetation and fallow land), grassland (natural and anthropogenic), aquatic units (including main channel, secondary channel and former channels), two types of pioneer units (dominated by herbaceous species or *Salicacea* species) and woodland units. At Level 2, each unit was divided into several sub-types based on field observation and floristic data.

The characterisation of the structure is based upon several metrics that describe units by their area (MPS = mean patch size, density = number of patches by hectare, and NP = total number of patches), form (MSI = mean shape index, MPAR = mean perimeter/area ratio, MFRACT = mean fractal dimension), edges (ED = edge density, MPE = mean patch edge), and diversity (Shannon's diversity, Shannon's evenness and dominance). Landscape indices were computed by V-LATE plug-in, which is an extension for the ArcGIS environment (Lang & Tiede, 2003).

2.3. Assessment of channel and corridor planimetric changes

In order to assess channel and landscape evolution along the Magra River, a diachronic approach was performed on a set of eight aerial photographs referenced under ArcGIS software (Freeman, Stanley, & Turner, 2003; Greco & Plant, 2003) (Table 2). According to previous similar analyses using the same methodologies (e.g. Hughes, MacDowel, & Marcus, 2006; Surian et al., 2009a; Winterbottom, 2000), a maximum error of approximately 5–6 m was estimated for our measurements on aerial photographs.

First, for all of the photos, we digitalised the active channel including the wetted channel and the unvegetated bars. Second, in order to study fluvial landscape changes, we defined the corridor analysed along each reach. To do this, we used the corridor resulting from the overlay of all active channels since 1937 to map the area which has been occupied by the active channel at least once over the studied period, and that represents a floodplain corridor younger than 1937. Due to differences in aerial photograph resolution and quality, we distinguished only six different units within this corridor: the active channel (wetted channel and unvegetated bars), pioneer vegetation (sparse vegetation on gravel bar), units dominated by shrub species, woodland, meadow, agriculture, and human activity (roads, gravel mining, houses). Digitisation of these units was limited to five series of photographs according to their date and quality (Table 2). Lastly, we divided each reach into 250 m subreaches in order to obtain some replicates at a finer scale and assess the variability of changes along the continuum.

From the overlay of all active channel shapes, we determined the age of formation for all surfaces within the corridor (Greco, Fremier, Larsen, & Plant, 2007).

2.4. Assessment of channel vertical evolution

Data to assess vertical evolution of the Magra River is very sparse. From Rinaldi et al. (2009) we used longitudinal profiles surveyed since 1914. In particular, a time series of channel-bed longitudinal profiles (from 1914 to 2000) was available only for the downstream reach, while for the upstream one, field surveys (conducted in the period from 2003 to 2006) allowed for classification of the overall vertical changes (Rinaldi et al., 2008, 2009).

To compare long-term evolution of the two reaches, we also evaluated bed degradation along the three cross sections per reach, by comparing current and past elevation of the active bed. For this purpose, along each cross section, we surveyed superficial topography and, in riverine units, overbank sediment thickness over the former active channel. Bed degradation is given by the relative elevation difference between the current bed and the former gravel layer, whose age is given by the GIS analysis (see below) (Piégay, Joly, Foussadier, Mourier, & Pautou, 1997).

3. Results

3.1. Active channel dynamics in space and time

As a result of the various human impacts and pressures within the system, the two study reaches differ in terms of amounts and rates of channel adjustment (Table 1). Since WWII, bed degradation has always been higher along the downstream reach (Fig. 2A). This degradation is associated with a much greater rate of sediment mining along this reach, estimated at about 1600,000 m^3 $year^{-1}$ between 1958 and 1973, that is one or two orders of magnitude higher than annual bedload transport (Cavazza & Pregliasco, 1981; Rinaldi et al., 2009).

Considerable channel narrowing occurred between 1954 and 2006 (Fig. 2B). Within the 1937–2006 shifting corridor, the proportion of main channel and unvegetated bars dropped from 60–75% to 20–30%. The magnitude of narrowing is higher downstream, and channel adjustments stopped later than upstream (1990s vs. 1980s). Lastly, there is no upstream to downstream progression of channel narrowing, at least between 1954 and 1981, during which both reaches underwent narrowing with the same temporal pattern.

A noticeable increase in the width (5 to 10%) occurred in both reaches in the period between 1937 and 1954, during which the large floods of 1940 and 1951 occurred (respective discharge: 1440 $m^3\,s^{-1}$ and greater than the 1.5 year return period discharge (i.e. $Q_{1.5}$) for 2 days and 1000 $m^3\,s^{-1}$, greater than $Q_{1.5}$ for 7 days) (Fig. 3). Thus between 1937 and 1954 the area of eroded land was higher than stabilized land (Fig. 2C). Neither of the hydrological indicators (maximum annual daily discharge nor the number of days exceeding the $Q_{1.5}$) seem to be clearly related to the very considerable narrowing observed after 1954 (Fig. 3) with more stabilised than eroded areas (Fig. 2C). Since 1981, the active channel width has been decreasing in the downstream reach, whereas it has remained quite constant in the upstream reach, where eroded and stabilised areas are closer in value. In both reaches, a small, but significant, widening occurred (in 1999 upstream; and in 2003 downstream), followed by a new slight decrease until 2006. However, the magnitude is relatively low compared to the last few decades' narrowing rate: less than 10% widening versus 55% and 30% (respectively) narrowing downstream and upstream.

3.2. Land cover and landscape structure changes

Over the past seven decades, the proportion of the corridor occupied by agriculture and grazing areas has remained quite steady, except for the lower values observed in 1954, with higher values downstream (20 vs. 10%) (Fig. 4). Other human activity mainly increased from 0 to 10% between 1954 and 1971 in the downstream reach. New woodland areas proliferated in the landscape in both reaches, appearing primarily on 1971 photographs and becoming increasingly prevalent (almost 30%) by 1999. Thus, we clearly observed a progressive shift in landscape composition of the corridor, from open units to closed, wooded units.

Moreover, the nature of land cover that "replaced" active channel indicates a difference between the two reaches. Most of the new vegetation in the upstream reach is unmanaged vegetation (e.g. woodland). Downstream, unmanaged vegetation was the main land cover that replaced active channel during the earliest period (1937–1954) and the most recent period (1981–1999) but artificial land-covers (e.g. cropland, planted trees and garden) dominated between 1954 and 1981.

Between 1954 and 1971, changes in the proportion of landscape units increased the landscape diversity index because of a decrease in the dominance of the active channel (Fig. 5). In the upstream reach, the maximum was observed in 1981, whereas in the downstream reach, diversity was still increasing between 1981 and 1999.

The median value of the diversity index calculated without the anthropogenic units shows lower values (because of fewer units overall), but the increasing trend over the seven decade period is the same. In the downstream reach, the increase observed between 1954 and 1971 is higher when all units are considered together, and so partially interpreted as a "human-induced" increase. On the other hand, the increase observed between 1981 and 1999 is greater when natural units are considered alone and is thus mainly due to changes in the relative proportions of those units. In the upstream reach, we observed the same range between the median values (calculated for all or natural units alone) at each date, therefore the trend of increasing landscape diversity is most likely related to differences in the proportion of natural units in the reaches over time.

3.3. Current corridor structure

The corridor landscape in the upstream reach exhibits a different overall configuration from that observed in the downstream reach. In the upstream reach patches are smaller (MPS = 2429 vs. 3240 m^2) and are present in higher density (4.12 vs. 3.09 patch ha^{-1}) than in the downstream reach for an equivalent form (Table 4). Moreover the overall edge density is greater in the upstream reach than in the downstream reach (+25%).

Landscape metrics calculated upon the current corridor structure confirm that landscape diversity is higher downstream than upstream. This result is consistent at both levels of precision within the unit description (Table 4). At level 1, the exclusion of human units (i.e. the natural corridor) decreases diversity downstream more than upstream, but the values remain different between the two reaches. The reason for such a difference is that no units are particularly dominant downstream, whereas two units are dominant upstream: gravel bars (33.0 vs. 13.6% downstream) and woodland (35.4 vs. 22.5%) (Table 5).

While gravel bars and woodland prevail in the corridor upstream (>33% each), grasslands and anthropogenic units are frequent in the downstream corridor, but not significantly dominant (ca. 20% each). The downstream reach exhibits higher proportion of fallow lands and grasslands, two anthropogenic units, which results from the presence of both bigger and more numerous patches (Table 5). Patches of gravel bars, pioneer units and woodlands do not show any difference in mean size and shape between the two reaches, but their density is higher upstream. This difference is also highlighted by the correspondence analysis (Fig. 6). The first axis (F1) highlighted young units (gravel bars, pioneer vegetation) characterised by pioneer and ruderal species (*Salix* sp., *Melilotus alba*, *Phalaris arundinacea*) opposed to more mature/stable units. The second axis (F2) opposed grasslands from riparian humid forest, with dry and degraded forest at an intermediate position. Both reaches are clearly distinguished along the first axis: the upstream reach is dominated by pioneer units and the downstream one by post-pioneer floodplain forests and associated species (*Crataegus monogyna*, *Ligustrum vulgare*, *Hedera helix*). The downstream reach is also characterised by degraded forest (e.g. lower density due to wood cutting) and some non-native (e.g. *Bamboo* sp., *Robinia pseudo-acacia*) and invasive species (*Arundo donax*) usually favoured by human disturbance. Along the second axis, three groups can be observed: (i) dry and mesic grasslands, (ii) dry

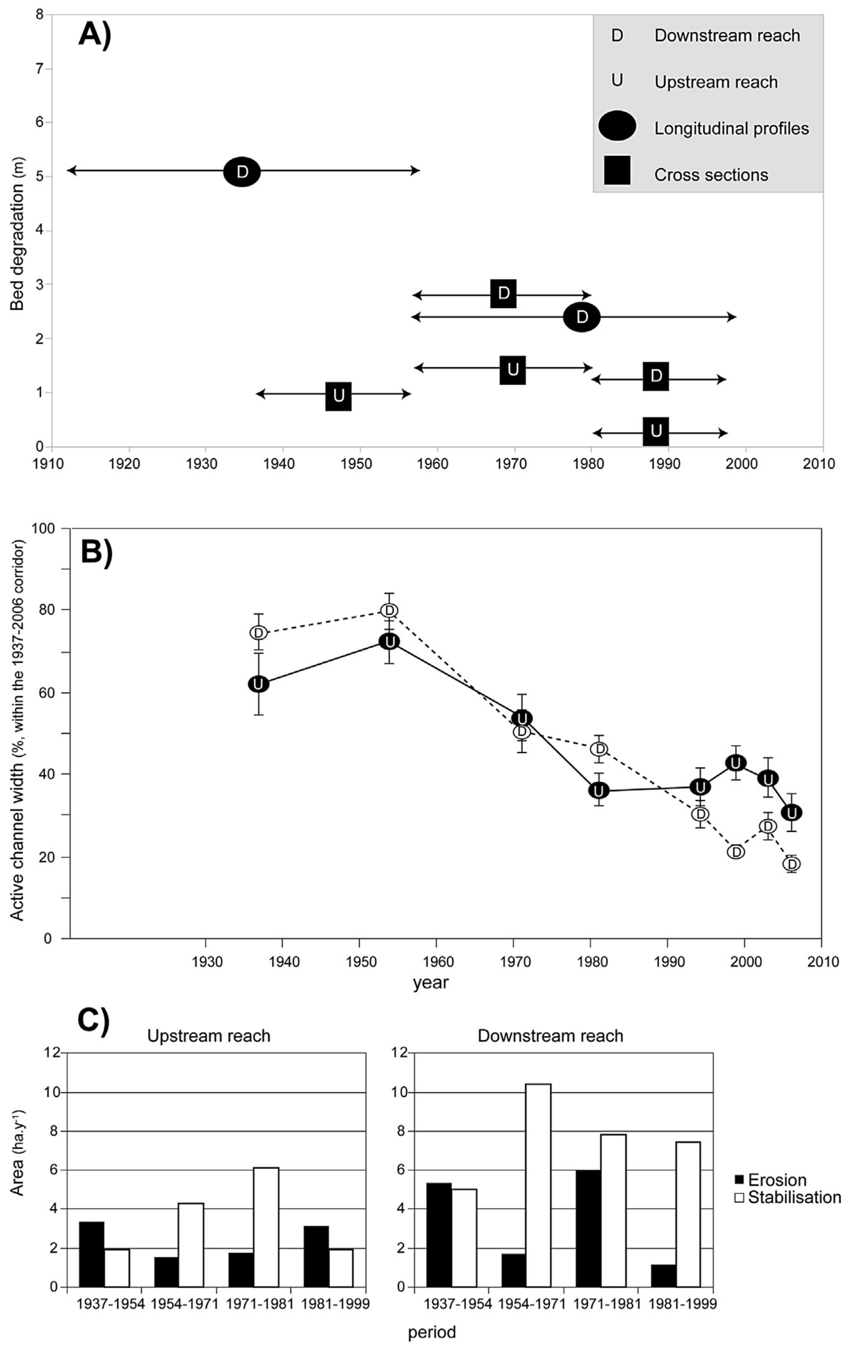

Fig. 2. Evolution of the channel. (A) Bed degradation over the last century, evaluated by long profile comparison (circles) or cross section analysis (squares), arrows indicate the extension of the period of measurement; (B) Planimetric evolution since 1937, proportion of active channel within the shifting corridor slitted by 250 m subreaches, mean and 95% confidence interval, $n = 40$ downstream (white circles) and 38 upstream (black circles); (C) eroded and stabilised areas by period (i.e. respectively total area of the floodplain eroded by the active channel between the 2 dates and total area of active channel at the first date that becomes another type of unit).

floodplain forests, and (iii) wet floodplain forests. Some species indicated some differences in ecological condition between these three groups (e.g. *Bromus erectus* for dry open units, *Rosa canina* and *Robinia pseudo-acacia* for dry forests, *Alnus glutinosa* and *Salix alba* for wet forests). However, there is no clear opposition between reaches concerning dry and wet forests, as was expected.

3.4. Corridor surface age distribution

The mean age of the corridor surfaces is similar in both reaches (43 and 41 years), but the distribution is different (Table 4). The upstream reach presents a higher proportion of surfaces that are younger than 25 years (28.9 vs. 10.7%) and surfaces that are older than 69 years (12.2 vs. 4.1%). This can be linked to the relative lower narrowing intensity over the last seven decades.

The vegetation patch diversity seems moderately correlated to landforms age diversity (Fig. 7), and the strength of the relationship is slightly higher downstream than upstream. This result indicates that various land covers can result from a given age of landform stabilisation, due to other drivers that generate within-form variability (e.g. conditions of water availability, sediment grain size); these drivers play a greater role upstream than downstream.

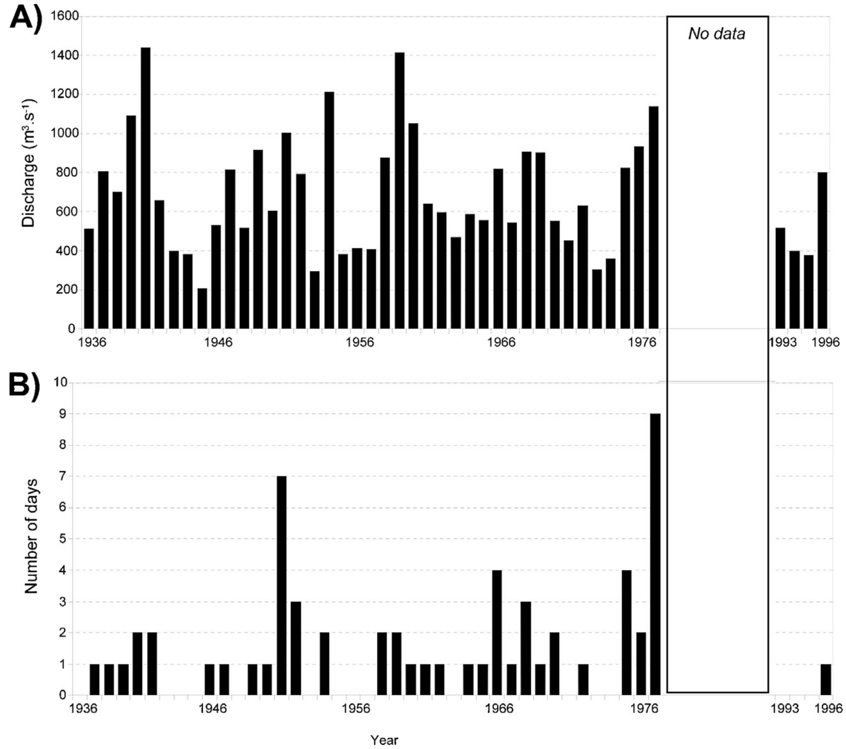

Fig. 3. Discharge at the Calamazza gauging station (location shown in Fig. 1) over the last few decades. (A) Annual maximum daily discharge; (B) number of days with exceeded discharge of 1.5-year return period. Units for discharge: ($m^3\ s^{-1}$). The dashed line represents the linear trend over the narrowing period (1954–1977).

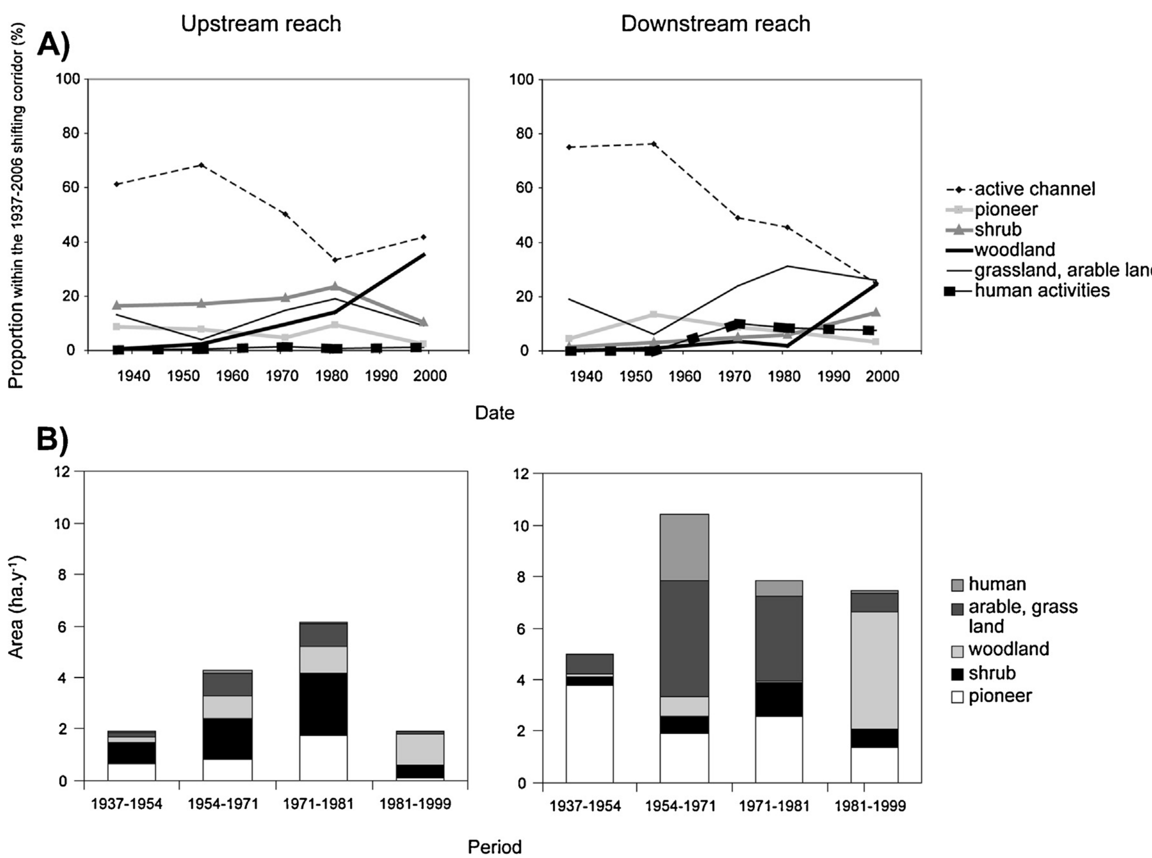

Fig. 4. Evolution of Magra River corridor. (A) Changes in the proportion of each landscape unit within the 1937–2006 shifting corridor between 1937 and 1999; (B) Area of former active channel occupied by the landscape units (i.e. active channel at the first date that becomes another land cover).

Table 4
Current landscape pattern characteristics.

	Index	Upstream reach	Downstream reach
Area analysis	Mean patch size (MPS) (m^2)	2429	3240
	Density (number of patch ha^{-1})	4.1	3.1
	Total patches (NP)	1069	1677
Form analysis	Mean shape index (MSI)	3.8	3.7
	Mean perimeter/area ratio (MPAR)	0.7	0.5
	Mean fractal dimension (MFRACT)	1.9	1.8
Edge analysis	Edge density (ED) (m ha^{-1})	2424	2037
	Mean patch edge (MPE) (m)	589.0	660.0
Diversity analysis Level 1	Shannon's diversity	1.5	2.0
	Shannon's evenness	0.7	0.9
	Dominance	0.5	0.1
Diversity analysis level 2	Shannon's diversity	2.4	3.0
	Shannon's evenness	0.8	0.9
	Dominance	0.7	0.4
Diversity analysis without anthropogenic units	Shannon's diversity	1.4	1.7
	Shannon's evenness	0.8	0.9
	Dominance	0.4	0.1
Age surfaces distribution	0 to 25 years	28.9%	10.7%
	25 to 69 years	58.9%	85.2%
	More than 69 years	12.2%	4.1%
	Mean (years)	41	43

Table 5
Current landscape characteristics, for unit acronym see Table 3 MPAR: mean perimeter/area ratio; MPS: mean patch size; ED: edge density.

Unit	Number of patch		Area (ha)		Proportion (%)		MPAR		MPS (m^2)		ED (m ha^{-1})	
	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down
HUM1	79	201	3.0	44.2	1.1	8.1	1.2	0.8	377	2212	0.3	0.4
HUM2	77	270	5.8	70.2	2.2	12.9	1.0	0.6	749	2599	0.3	0.5
FAL	5	134	0.9	40.7	0.3	7.5	0.8	0.4	1712	3036	0.0	0.2
GRA	148	337	20.2	107.0	7.8	19.7	0.7	0.5	1368	3176	0.6	0.6
AQU	61	86	23.1	59.3	8.9	10.9	0.7	0.6	3794	6899	0.2	0.2
GB	232	192	85.7	73.9	33.0	13.6	0.5	0.5	3693	3849	0.9	0.3
PIO	281	216	29.1	25.4	11.2	4.7	0.7	0.5	1035	1178	1.1	0.4
WOO	186	242	91.9	122.5	35.4	22.5	0.6	0.3	4941	5062	0.7	0.4

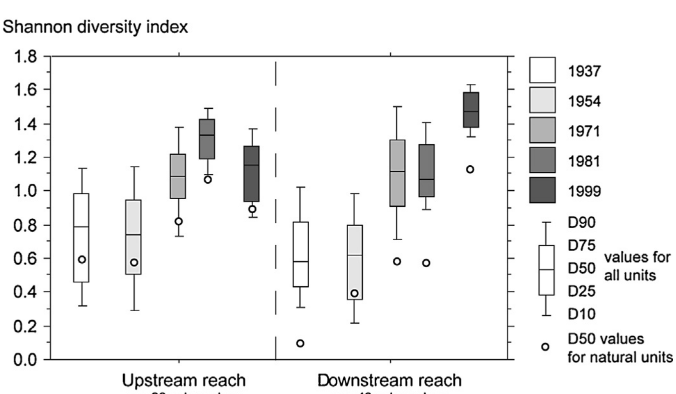

Fig. 5. Change in landscape diversity within the two studied reaches of the Magra River between 1937 and 1999. Shannon index is calculated for each of the 250 m sub-reaches for 5 years integrating the humanised patches. Variability between sub-reaches is given by the interval between *D*90 and *D*10 or *D*75 and *D*25 values (i.e. 90th, 10th, 75th and 25th percentiles of the diversity indices for all of the sub-reaches in each reach). A *D*50 value calculated for natural units only is also provided to see if the trend is the same with and without the humanised patches and thus we can find out if the evolution is generated by changes in all the units or just by one category.

4. Discussions

4.1. Channel narrowing and vegetation expansion: Causes and current dynamics

The strong impact of human activity upon European gravel-bed rivers has been indicated in numerous studies over the last few decades (Bravard et al., 1997; Brooks, 1988; Petts, Möller, & Roux, 1989). Among rivers in Central–Northern Italy, channel degradation and narrowing can be interpreted as result of a complex superimposition of basin-scale and local factors (Surian, Ziliani, Cibien, Cisotto, & Baruffi, 2008; Surian et al., 2009a; Surian, Ziliani, Comiti, Lenzi, & Mao, 2009b). Our results for the Magra River indicate that an important reduction in channel width, and metamorphosis from a bar-braided to a wandering/meandering pattern, observed between the 1950s and the 1980s, are probably caused by local factors. Reach-wide or regional changes are not expressed in the patterns observed. For example, there is not a clear upstream to downstream progression of the narrowing process (Fig. 2), and hydrologic data do not clearly explain the narrowing between 1954 and 1981 (Fig. 3). If long-term changes in watershed land use and the flood regime can explain the general trend in channel evolution over the last two centuries, local factors appear to be dominant in explaining the acceleration recorded in channel narrowing since the 1950s. This result is consistent in terms of magnitude and timing with other observations made in France

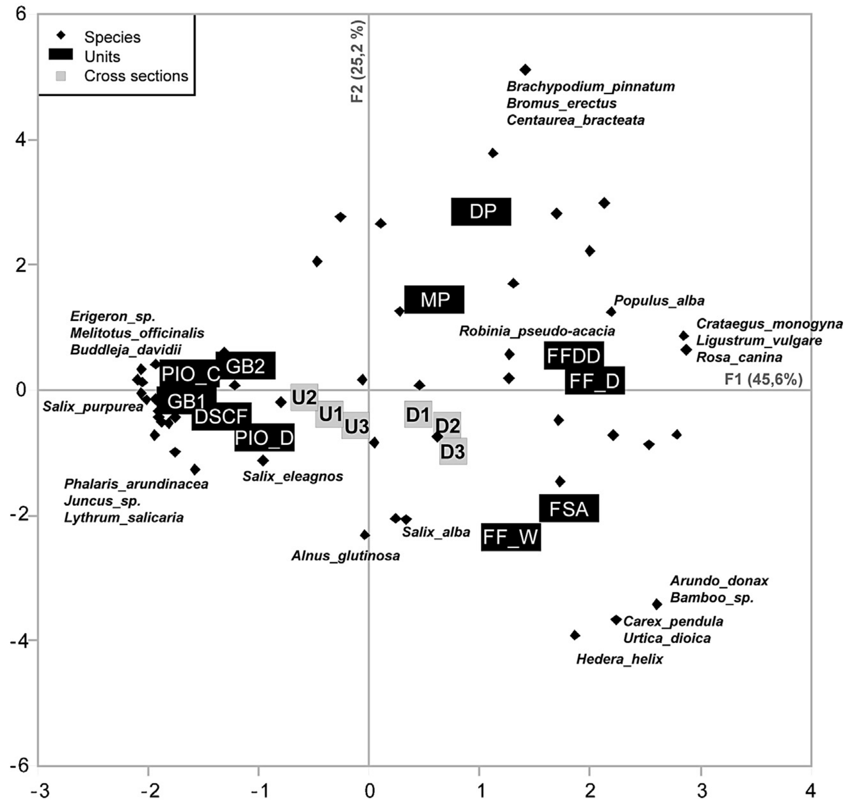

Fig. 6. Results of the correspondence Analysis performed on 91 species and 11 types of vegetation unit surveyed along 6 cross sections (3 for each reach). Axis F1 and F2 captured respectively 45.6 and 25.2% of the total inertia. Relevant species are named and for unit names see Table 3. The position of the cross sections on the factorial map is given by the weighted mean based on the relative proportion of units along each cross-section.

(Liébault & Piégay, 2002) or in Italy (Surian & Rinaldi, 2003). At reach-scale, two factors can explain the narrowing process: river bed degradation, usually linked to intensive gravel mining, as well as vegetation development due to the abandonment of traditional agricultural, grazing and forestry practices. It is difficult to know which of these two causes most affects the narrowing process, because, between the 1950s and the 1970s they often occurred concurrently. In Italy, bed degradation has been traditionally

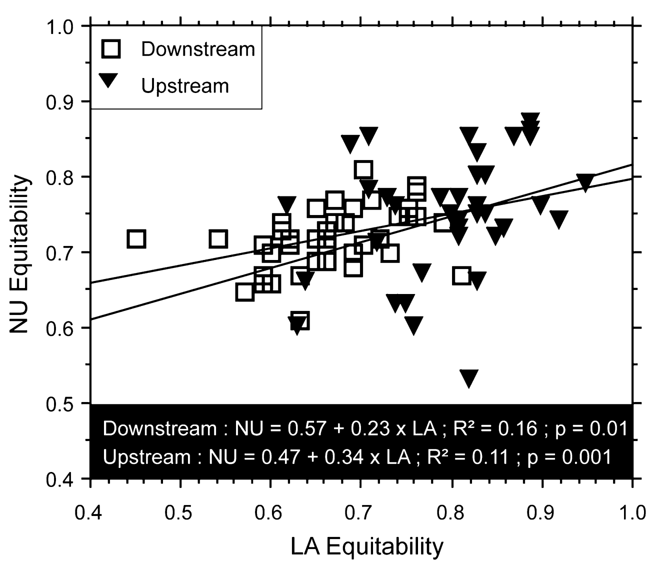

Fig. 7. Landscape diversity vs. landform age diversity (NU = natural units, LA = landforms age; equitability is normalised index for diversity calculated for each of the 250 m subreaches with $n = 40$ downstream and 38 upstream; see Hammer et al., 2004).

considered as the main cause, for the following reasons: (1) channel narrowing has been mainly studied by geomorphologists who focused on morphological parameters and not on biological ones; (2) little quantitative data is accessible to evaluate changes in rural societies' practices; and, (3) the role of vegetation as a driver for channel geometry changes emerged relatively late. Along the Magra, channel narrowing in the downstream reach is higher than in the upstream reach, because, in the former, more intensive sediment mining occurred along with higher degradation (first hypothesis). This higher channel narrowing downstream is also due to the superimposition of more factors: general bedload decrease at basin level, presence of groynes, and the reduced bedload of the Vara due to the existence of a dam (even if the drainage area at the dam is less than 15% of the drainage area in the lower Magra reach). Groynes may have played a significant role on the channel narrowing and incision (Zawiejska & Wyżga, 2010) but they cannot be considered as the only cause of changes as these adjustments also occurred in the upstream reach where groynes were absent. The role played by the evolution in agricultural practices, for example from traditional pasture and firewood cutting to arable lands in France, such as the Eygues River (Kondolf, Piégay, & Landon, 2007) or the Ain River (Liébault & Piégay, 2002), is not demonstrated for the Magra basin.

4.2. Corridor structure and evolution relating to river dynamics

Over a seven decade period, we have observed a progressive change from a bar-braided to a wandering/meandering river channel pattern. Quantitatively, this evolution resembles the trend observed by Piégay, Alber, Slater, and Bourdin (2009) on several other braided rivers. Channel evolution generates a decrease in channel and bar habitats and the expansion of woodland units (Fig. 4) (Perona et al., 2009). Concerning landscape pattern, channel narrowing explains most of this evolution, as diversity indices increase for both reaches, as expected (second hypothesis). This is mainly due to a reduction in the relative dominance of the active channel within the corridor to the benefit of woodland and other riparian features. The proportion of the increase in landscape diversity due to human activity appears to be relatively low (Fig. 5). Lastly, landscape diversity has not increased over the last 25 years in the upstream reach as the narrowing process seems to have ended in the 1980s. In conclusion, the evolution of riparian landscape diversity seems primarily linked to channel processes and secondarily to human activity occurring on floodplains and hillslope areas adjacent to the active channel. These recent morphological dynamics will likely maintain the landscape diversity at a high level unless and until the relative influence of strong system drivers shifts (e.g., accelerating hydrologic regime trends from climate change). The current landscape could thus be considered as a new metastable biomorphological state (at management time-scales) partially self-maintained by fluvial dynamic and riparian vegetation interactions (Tabacchi, Steiger, Corenblit, Monaghan, & Planty-Tabacchi, 2009).

Currently, the two reaches have slightly different geomorphic patterns, with a sinuous, more meandering and less mobile channel downstream (Table 1, Rinaldi et al., 2009). Thus the structure of the fluvial corridor is also different (Beechie et al., 2006; Nakamura et al., 2007). Landscape diversity is higher downstream, even if human-influenced units are excluded from the analysis, because of a more regular distribution in the areal proportion amongst units. The current higher channel mobility upstream does not generate a higher diversity of habitats, as expected (second hypothesis) and observed for aquatic habitats by Arscott, Tockner, and Ward (2000). This is due to a higher proportion of bar units dominating the landscape in the upstream reach, with fewer vegetation units represented than downstream. In both reaches, landscape diversity is poorly linked to the diversity of landform age distributions (Fig. 7), probably because the variability of landform conditions in a given age category is high enough to generate diverse habitats.

Concerning the species present in both reaches, we hypothesised that channel degradation downstream favours species adapted to drier conditions. It is true, in a sense, that dry units are more frequently present downstream than upstream (see contribution to the first axis in Fig. 6). But humid forests are also created by channel shifting in the downstream reach. The higher overbank sediment thickness in the downstream reach (0.5 to 2 m vs. 0.3 to 0.5 m) could partially limit the differentiation between reaches due to the vertical evolution of the channels.

5. Conclusions

Evolution from a bar-braided pattern to a single-thread system, such as in the Magra River, generates some paradoxes from a conservation perspective. From a historical point of view, we observed the disappearance of a braided pattern, which was formerly well developed in the Alpine rivers (Bravard & Peiry, 1993; Gurnell & Petts, 2002) and thus could be considered as an important heritage to maintain (Arscott et al., 2000; Gurnell & Petts, 2002; Tockner et al., 2006). But, on the other hand, the new channel morphology provides some ecological benefits that can compensate the loss: riparian woodland expansion (Hughes et al., 2001; Takahashi & Nakamura, 2011) as well as increasing species and landscape diversity (Hupp & Rinaldi, 2007; Mikuś, Wyzga, Kaczka, Walusiak, & Zawiejska, 2013; Ward et al., 2002). From a management point of view, this raises the question of which attributes to preserve or promote among competing options within a given reach (Woolsey et al., 2007). These management targets should not focus on a single attribute, but multiple and complementary ones (DiBari, 2007; Gregel, Turner, Miller, Melack, & Stanley, 2002; Steel et al., 2010; Tabacchi et al., 2009; Woolsey et al., 2007). Indeed, our results suggest that landscape diversity should not be the only attribute to be analysed as an indicator of the ecological status of a riparian corridor (Dufour & Piégay, 2009; Steel et al., 2010). For example, in the upstream reach, which was less affected by human impacts, the landscape is mainly dominated by two habitats that result from a high rate of lateral channel mobility: gravel bars and woodland. As a result, it currently has a lower landscape diversity than the downstream reach. However, it exhibits some ecological habitats, such as pioneer units, which are valuable at the network scale for maintaining a diversity of ages and species within riparian forests, supporting wildlife communities, and providing geomorphic functions such as bank stability and large woody debris supply as they age (Hughes et al., 2001). In addition to these biophysical functions of riparian landscapes, there are social, cultural, and aesthetic values of the fluvial landscape, which are typically poorly represented among management and restoration objectives and which should be included. Thinking of landscape diversity within a conceptual framework such as the notion of ecosystem services should help to enhance the definition of objectives in restoration projects and management practices going forward (Bullock, Aronson, Newton, Pywell, & Rey-Benayas, 2011; Dufour, Rollet, Oszwald, & Arnauld De Sartre, 2011; Wainger, King, Mack, Price, & Maslin, 2010).

Acknowledgments

The staff and the Ph.D. students of the hydrosystem research group of the University of Lyon/UMR 5600, V. Gaertner, L. Grospretre, A. Honegger, J. Lejot, Y. Le Lay, and A.J. Rollet, of the Department of Civil and Environmental Engineering, University of Florence, C. Simoncini, L. Coppi, G. Doretti, S. Lamagna, L. Luppi, L. Bellacci, A. Vergaro, and of the Department of Land and Agroforest Environments, University of Padova, F. Comiti, L. Mao, E. Pecorari, are particularly thanked for their contribution during an intense week of research and field measurements during the spring 2006 investigation. We thank J. Stella and external reviewers whose comments significantly improved the paper.

References

Aguiar, F. C., & Ferreira, M. T. (2005). Human-disturbed landscapes: Effects on composition and integrity of riparian woody vegetation in the Tagus River basin. *Portugal. Environmental Conservation*, *32*, 30–41. http://dx.doi.org/10.1017/S0376892905001992

Arscott, D. B., Tockner, K., & Ward, J. V. (2000). Aquatic habitat diversity along the corridor of an alpine floodplain river (Fiume Tagliamento Italy). *Archiv fur Hydrobiologie*, *149*, 679–704.

Azami, K., Suzuki, H., & Toki, S. (2004). Changes in riparian vegetation communities below a large dam in a monsoonal region: Futase dam Japan. *River Research and Applications*, *20*, 549–563. http://dx.doi.org/10.1002/rra.763

Beechie, T. J., Liermann, M., Pollock, M. M., Baker, S., & Davies, J. (2006). Channel pattern and river-floodplain dynamics in forested mountain river systems. *Geomorphology*, *78*, 124–141. http://dx.doi.org/10.1016/j.geomorph.2006.01.030

Bendix, J., & Hupp, C. R. (2000). Hydrological and geomorphological impacts on riparian plant communities. *Hydrological Processes*, *14*, 2977–2990. http://dx.doi.org/10.1002/1099-1085(200011/12)14:16/17<2977::AID-HYP130>3.0.CO;2-4

Bendix, J., & Cowell, C. M. (2010). Fire, floods and woody debris: Interactions between biotic and geomorphic processes. *Geomorphology*, *116*, 297–304. http://dx.doi.org/10.1016/j.geomorph.2009.09.043

Bertoldi, W., Zanoni, L., & Tubino, M. (2010). Assessment of morphological changes induced by flow and flood pulses in a gravel bed braided river: The Tagliamento River (Italy). *Geomorphology*, *114*, 348–360. http://dx.doi.org/10.1016/j.geomorph.2009.07.017

Bravard, J. P., Amoros, C., & Pautou, G. (1986). Impacts of civil engineering works on the successions of communities in a fluvial system. A methodological and predictive approach applied to a section of the Upper Rhône River, France. *Oikos*, *47*, 92–111.

Bravard, J. P., Amoros, C., Pautou, G., Bornette, G., Bournaud, M., Creuzé des Châtelliers, M., et al. (1997). Stream incision in Southeast France: Morphological phenomena and ecological effects. *Regulated Rivers: Research and*

Management, *13*, 1–16. http://dx.doi.org/10.1002/(SICI)1099-1646(199701)13:1<75::AID-RRR444>3.0.CO;2-6

Bravard, J. P., & Peiry, J. L. (1993). La disparition du tressage dans les Alpes françaises sous l'effet de l'aménagement des cours d'eau (19ème-20ème siècles) [Braided pattern disappearance in French Alps over the 19th and 20th century]. *Zeitschrift für Geomorphologie*, *88*, 67–79 [in French].

Brierley, G., & Fryirs, K. (2009). Don't fight the site: Three geomorphic considerations in catchment-scale river rehabilitation planning. *Environmental Management*, *43*, 1201–1218. http://dx.doi.org/10.1007/s00267-008-9266-4

Brierley, G. J., Cohen, T., Fryirs, K., & Brooks, A. (1999). Post-European changes to the fluvial geomorphology of Bega catchment, Australia: Implications for river ecology. *Freshwater Biology*, *41*, 839–848. http://dx.doi.org/10.1046/j. 1365-2427.1999.00397.x

Brooks, A. (1988). *Channelized rivers: Perspectives for environmental management*. UK: John Wiley & Sons., 326 p.

Bullock, J. M., Aronson, J., Newton, A. C., Pywell, R. F., & Rey-Benayas, J. M. (2011). Restoration of ecosystem services and biodiversity: Conflicts and opportunities. *Trends in Ecology and Evolution*, *26*, 541–549. http://dx.doi.org/10.1016/j.tree.2011.06.011

Cavazza, S., & Pregliasco, P. (1981). Sulle modificazioni dell'apporto terrigeno alla foce del Fiume Magra causate dall'uomo. In A. Antonelli, S. Cavazza, G. C. Cortemiglia, F. Egori, M. Martinelli, N. Pellegrini, P. Pregliasco, & G. Raggi (Eds.), *Tra fiumi, mare e terraferma* (pp. 57–128). Sarzana: Tipografia Zappa [in Italian].

Décamps, H., Fortuné, M., Gazelle, F., & Pautou, G. (1988). Historical influence of man on the riparian dynamics of a fluvial landscape. *Landscape Ecology*, *1*, 163–173. http://dx.doi.org/10.1007/BF00162742

DiBari, J. N. (2007). Evaluation of five landscape-level metrics for measuring the effects of urbanization on landscape structure: The case of Tucson, Arizona, USA. *Landscape and Urban Planning*, *79*, 308–313. http://dx.doi.org/10.1016/j.landurbplan.2006.04.004

Dufour, S., Barsoum, N., Muller, E., & Piégay, H. (2007). Effects of channel confinement on pioneer woody plant community structure, composition and diversity along the River Drôme (SE, France). *Earth Surfaces Processes and Landforms*, *32*, 1244–1256. http://dx.doi.org/10.1002/esp.1556

Dufour, S., Rollet, A. J., Oszwald, J., & Arnauld De Sartre, X. (2011). Ecosystem services, an opportunity to improve restoration practices in river corridors? In *Research note*. Available on ⟨http://hal.archives-ouvertes.fr/hal-00587959/fr/⟩.

Dufour, S., & PiégayF H. (2009). From the myth of a lost paradise to targeted river restoration: Forget natural references and focus on human benefits. *River Research and Applications*, *25*, 568–581. http://dx.doi.org/10.1002/rra.1239

Francis, R. A., Corenblit, D., & Edwards, P. J. (2009). Perspectives on biogeomorphology, ecosystem engineering and self-organisation in island-braided fluvial ecosystems. *Aquatic Sciences*, *71*, 290–304. http://dx.doi.org/10.1007/s00027-009-9182-6

Freeman, R. E., Stanley, E. H., & Turner, M. G. (2003). Analysis and conservation implications of landscape change in the Wisconsin River floodplain, USA. *Ecological Applications*, *13*, 416–431.

Friedman, J. M., & Lee, V. J. (2002). Extreme floods, channel change, and riparian forests along ephemeral streams. *Ecological Monographs*, *72*, 409–425.

Gonzalez, E., Gonzalez-Sanchís, M., Cabezas, A., Comín, F. A., & Muller, E. (2010). Recent changes in the riparian forest of a large regulated Mediterranean river: Implications for management. *Environmental Management*, *45*, 669–681. http://dx.doi.org/10.1007/s00267-010-9441-2

Grams, P. E., & Schmidt, J. C. (2002). Streamflow regulation and multi-level flood plain formation: Channel narrowing on the aggrading Green River in the eastern Uinta Mountains, Colorado and Utah. *Geomorphology*, *44*, 337–360. http://dx.doi.org/10.1016/S0169-555X(01)00182-9

Greco, S. E., Fremier, A. K., Larsen, E. W., & Plant, R. E. (2007). A tool for tracking floodplain age land surface patterns on a large meandering river with applications for ecological planning and restoration design. *Landscape and Urban Planning*, *81*, 354–373. http://dx.doi.org/10.1016/j.landurbplan.2007.01.002

Greco, S. E., & Plant, R. E. (2003). Temporal mapping of riparian landscape change on the Sacramento River, miles 196–218, California, USA. *Landscape Research*, *28*, 405–426.

Gregel, S. E., Turner, M. G., Miller, J. R., Melack, J. M., & Stanley, E. H. (2002). Landscape indicators of human impacts to riverine systems. *Aquatic Sciences*, *64*, 118–128.

Gregory, K. J. (2006). The human role in changing river channels. *Geomorphology*, *79*, 172–191. http://dx.doi.org/10.1016/j.geomorph.2006.06.018

Gurnell, A. M., & Petts, G. E. (2002). Island-dominated landscapes of large floodplain rivers, a European perspective. *Freshwater Biology*, *47*, 581–600.

Hammer, Ø., Harper, D. A. T., & Ryan, P. D. (2004). *PAST—PAlaeontological STatistics. Version 2.07*. Available on ⟨norgues.uio.no/past/download.html⟩ (February 2011).

Hughes, F. M. R., Adams, W. M., Muller, E., Nilsson, C., Richards, K. S. R., Barsoum, N., et al. (2001). The importance of different scale processes for the restoration of floodplain woodlands. *Regulated Rivers: Research and Management*, *17*, 325–345. http://dx.doi.org/10.1002/rrr.656

Hughes, M. L., MacDowel, P. F., & Marcus, W. A. (2006). Accuracy assessment of georectified aerial photographs: Implications for measuring lateral channel movement in a GIS. *Geomorphology*, *74*, 1–16. http://dx.doi.org/10.1016/j.geomorph.2005.07.001

Hupp, C. R., & Osterkamp, W. R. (1985). Bottomland vegetation distribution along Passage Creek, Virginia, in relation to fluvial landforms. *Ecology*, *66*, 670–681.

Hupp, C. R., & Rinaldi, M. (2007). Riparian vegetation patterns in relation to fluvial landforms and channel evolution along selected rivers of Tuscany (Central Italy). *Annals of the Association of American Geographers*, *97*, 12–30. http://dx.doi.org/10.1111/j.1467-8306.2007.00521.x

Johnson, W. C. (1994). Woodland expansion in the Platte River, Nebraska. *Ecological Monographs*, *64*, 45–84.

Kalliola, R., & Puhakka, M. (1988). River dynamics and vegetation mosaicism: A case study of the River Kamajohka, northernmost Finland. *Journal of Biogeography*, *15*, 703–719.

Kondolf, G. M., Piégay, H., & Landon, N. (2007). *Changes since 1830 in the riparian zone of the lower Eygues River* (22) France: Landscape Ecology. http://dx.doi.org/10.1007/s10980-006-9033-y

Lang, S., & Tiede, D. (2003). (*vector based tool for quantitative landscape analysis*) vLATE Extension für ArcGIS—vektorbasiertes Tool zur quantitativen Landschaftsstrukturanalyse. In *ESRI Anwenderkonferenz 2003*. Innsbruck: CDROM. Available on ⟨https://sites.google.com/site/largvlate/home⟩ (June 2012) [In German].

Liébault, F., & Piégay, H. (2002). Causes of 20th century channel narrowing in mountain and piedmont rivers and streams of Southeastern France. *Earth Surface Processes and Landforms*, *27*, 425–444. http://dx.doi.org/10.1002/esp.328

Maekawa, M., & Nakagoshi, N. (1997). Riparian landscape changes over a period of 46 years, on the Azusa River in central Japan. *Landscape and Urban Planning*, *37*, 37–43.

Magilligan, F. J., & McDowell, P. F. (1997). Stream channel adjustments following elimination of cattle grazing. *Journal of the American Water Resources Association*, *33*, 867–878. http://dx.doi.org/10.1111/j.1752-1688.1997.tb04111.x

Malanson, G. P. (1993). *Riparian landscapes*. Cambridge, UK: Cambridge University Press.

Mikuś, P., Wyzga, B., Kaczka, R. J., Walusiak, E., & Zawiejska, J. (2013). Islands in a European mountain river: Linkages with large wood deposition, floodflows and plant diversity. *Geomorphology*, *202*, 115–127. http://dx.doi.org/10.1016/j.geomorph.2012.09.016

Miller, J. R., Schulz, T. T., Hobbs, N. T., Wilson, K. R., Schrupp, D. L., & Baker, W. L. (1995). Changes in the landscape structure of a southeastern Wyoming riparian zone following shifts in stream dynamics. *Biological Conservation*, *72*, 371–379. http://dx.doi.org/10.1016/0006-3207(94)00049-V

Naiman, R. J., Décamps, H., & McCLain, M. (2005). *Riparia, ecology, conservation and management of streamside communities*. San Diego, CA: Academic Press, Elsevier.

Nakamura, F., Shin, N., & Inahara, S. (2007). Shifting mosaic in maintaining diversity of floodplain tree species in the northern temperate zone of Japan. *Forest Ecology and Management*, *241*, 28–38. http://dx.doi.org/10.1016/j.foreco.2006.12.022

Perona, P., Camporeale, C., Perucca, E., Savina, M., Molnar, P., Burlando, P., et al. (2009). Modelling river and riparian vegetation interactions and related importance for sustainable ecosystem management. *Aquatic Sciences*, *71*, 266–278. http://dx.doi.org/10.1007/s00027-009-9215-1

Petts, G. E., Möller, H., & Roux, A. L. (1989). *Historical change of large alluvial rivers: Western Europe*. Chichester: John Wiley & Sons.

Piégay, H., Alber, A., Slater, L., & Bourdin, L. (2009). Census and typology of braided rivers in the French Alps. *Aquatic Sciences*, *71*, 371–388. http://dx.doi.org/10.1007/s00027-009-9220-4

Piégay, H., & Bravard, J. P. (1997). Response of a Mediterranean riparian forest to a 1 in 400 year flood, Ouvèze River, Drôme-Vaucluse, France. *Earth Surface Processes and Landforms*, *22*, 31–43, 10.1002/(SICI)1096-9837(199701)22:1<31::AID-ESP677>3.0.CO;2-#.

Piégay, H., Grant, G., Nakamura, F., & Trustrum, N. (2006). Braided river management: From assessment of river behaviour to improved sustainable development. In G. H. Sambrook-Smith, J. L. Best, C. S. Bristow, & G. E. Petts (Eds.), *Braided rivers: Process, deposits, ecology and management* (pp. 257–275). Oxford: International Association of Sedimentologists (Special publication 36 of the International Association of Sedimentologists).

Piégay, H., Joly, P., Foussadier, R., Mourier, V., & Pautou, G. (1997). Principes de réhabilitation des marges du Rhône à partir d'indicateurs géomorphologiques, phytoécologiques et batrachologiques (cas du RCC de Pierre Bénite) [Rehabilitation of the Rhone river margins, lessons from various indicators]. *Revue de Géographie de Lyon*, *72*, 7–22 [in French].

Piégay, H., & Schumm, S. A. (2003). System approach in fluvial geomorphology. In M. G. Kondolf, & H. Piégay (Eds.), *Tools in fluvial geomorphology* (pp. 105–134). Chichester, UK: J. Wiley and Sons.

Poole, G. C., Stanford, J. A., Frissell, C. A., & Running, S. W. (2002). Three-dimensional mapping of geomorphic controls on flood-plain hydrology and connectivity from aerial photos. *Geomorphology*, *48*, 329–347. http://dx.doi.org/10.1016/S0169-555X(02)00078-8

Rinaldi, M., Simoncini, C., & Piégay, H. (2009). Scientific design strategy for promoting sustainable sediment management: The case of the Magra river (Central–Northern Italy). *River Research and Applications*, *25*, 607–625. http://dx.doi.org/10.1002/rra.1243

Rinaldi, M., Teruggi, L. B., Simoncini, C., & Nardi, L. (2008). Dinamica recente ed attuale di alvei fluviali: alcuni casi di studio appenninici (Italia Centro-Settentrionale) [Recent and current river dynamic in Apennine Mountain Italy]. *Il Quaternario Italian Journal of Quaternary Sciences*, *21*, 291–302 [in Italian].

Rollet, A. J., Piégay, H., Bornette, G., Dufour, S., & Persat, H. (2013). Assessment of consequences of sediment deficit on a gravel river-bed downstream of dams in restoration perspectives: Application of a multicriteria, hierarchical, and spatially explicit diagnosis. *River Research and Applications*, http://dx.doi.org/10.1002/rra.2689

Salo, J., Kalliola, R., Hakkinen, I., Makinen, Y., Niemela, P., Puhakka, M., et al. (1986). River dynamics and the diversity of Amazon lowland forest. *Nature*, *332*, 254–258. http://dx.doi.org/10.1038/322254a0

Sidle, R. C., & Sharma, A. (1996). Stream channel changes associated with mining and grazing in the Great Basin. *Journal of Environmental Quality*, *25*, 1111–1121.

Stanford, J. A., Ward, J. V., Liss, W. J., Frissell, C. A., Williams, R. N., Lichatowich, J. A., et al. (1996). A general protocol for restoration of regulated rivers. *Regulated Rivers: Research and Management*, *12*, 391–413.

Steel, E. A., Hughes, R. M., Fullerton, A. H., Schmutz, S., Young, J. A., & Fukushima, M. (2010). Are we meeting the challenges of landscape-scale riverine research? A review. *Living Review Landscape Research*, *4*, 1. Available on ⟨www.livingreviews.org/lrlr-2010-1⟩ (April 2011).

Stromberg, J. C., Tluczek, M. G. F., Hazelton, A. F., & Ajami, H. (2010). A century of riparian forest expansion following extreme disturbance: Spatio-temporal change in Populus/Salix forests along the Upper San Pedro River. *Arizona. Forest Ecology and Management*, *259*, 1181–1189. http://dx.doi.org/10.1016/j.foreco.2010.01.005

Surian, N., & Rinaldi, M. (2003). Morphological response to river engineering and management in alluvial channels in Italy. *Geomorphology*, *50*, 307–326. http://dx.doi.org/10.1016/S0169-555X(02)00219-2

Surian, N., Rinaldi, M., Pellegrini, L., Audisio, C., Maraga, F., Teruggi, L. B., et al. (2009). Channel adjustments in Italian rivers: Evolutionary trends, causes and management implications. In L. A. James, S. L. Rathburn, & G. R. Whittecar (Eds.), *Management and restoration of fluvial systems with broad historical changes and human impacts* (451) (pp. 83–95). Boulder, Colorado, USA: Geological Society of America Special Paper.

Surian, N., Ziliani, L., Cibien, L., Cisotto, A., & Baruffi, F. (2008). Variazioni morfologiche degli alvei dei principali corsi d'acqua veneto-friulani negli ultimi 200 anni [Morphological changes of Fruili–Venetian region rivers since 200 years]. *Il Quaternario, Italian Journal of Quaternary Sciences*, *21*, 279–290 [in Italian].

Surian, N., Ziliani, L., Comiti, F., Lenzi, M. A., & Mao, L. (2009). Channel adjustments and alteration of sediment fluxes in gravel-bed rivers of north-eastern Italy: Potentials and limitations for channel recovery. *River Research and Applications*, *25*, 551–567. http://dx.doi.org/10.1002/rra.1231

Tabacchi, E., Planty-Tabacchi, A. M., Salinas, J., & Décamps, H. (1996). Landscape structure and diversity in riparian plant communities: a longitudinal comparative study. *Regulated River: Research and Management*, *12*, 367–390, 10.1002/(SICI)1099-1646(199607)12:4/5<367::AID-RRR424>3.0.CO;2-X.

Tabacchi, E., Steiger, J., Corenblit, D., Monaghan, M. T., & Planty-Tabacchi, A. M. (2009). Implications of biological and physical diversity for resilience and resistance patterns within Highly Dynamic River Systems. *Aquatic Sciences*, *71*, 279–289. http://dx.doi.org/10.1007/s00027-009-9195-1

Takahashi, M., & Nakamura, F. (2011). Impacts of dam-regulated flows on channel morphology and riparian vegetation: A longitudinal analysis of Satsunai River, Japan. *Landscape and Ecological Engineering*, *7*, 65–77. http://dx.doi.org/10.1007/s11355-010-0114-3

Tockner, K., Karaus, U., Paetzold, A., Claret, C., & Zettel, J. (2006). Ecology of braided rivers. In G. Sambrook Smith, J. Best, C. Bristow, & G. E. Petts (Eds.), *Braided rivers. IAS special publication* (pp. 339–368). Oxford: Blackwell Publisher.

Van Coller, A. L., Rogers, K. H., & Heritage, J. L. (1997). Linking riparian vegetation types and fluvial geomorphology along the Sabie River within the Kruger National Park, South Africa. *African Journal of Ecology*, *35*, 94–212. http://dx.doi.org/10.1111/j.1365-2028.1997.090-89090.x

Villarreal, M. L., Drake, S., Marsh, S. E., & McCoy, A. L. (2012). The influence of wastewater subsidy, flood disturbance and neighbouring land use on current and historical patterns of riparian vegetation in a semi-arid watershed. *River Research and Applications*, *28*, 1230–1245. http://dx.doi.org/10.1002/rra.1510

Wainger, L. A., King, D. M., Mack, R. N., Price, E. W., & Maslin, T. (2010). Can the concept of ecosystem services be practically applied to improve natural resource management decisions? *Ecological Economics*, *69*, 978–987. http://dx.doi.org/10.1016/j.ecolecon.2009.12.011

Walter, R. C., & Merrits, D. J. (2008). Natural streams and the legacy of water-powered mills. *Science*, *319*, 299–304.

Ward, J. V. (1997). Riverine landscapes: Biodiversity patterns, disturbance regimes, and aquatic conservation. *Biological Conservation*, *83*, 269–278. http://dx.doi.org/10.1016/S0006-3207(97)00083-9

Ward, J. V., Tockner, K., Arscott, B. D., & Claret, C. (2002). Riverine landscape diversity. *Freshwater Biology*, *47*, 517–539. http://dx.doi.org/10.1046/j.1365-2427.2002.00893.x

Whited, D. C., Lorang, M. S., Harner, M. J., Hauer, F. R., Kimball, J. S., & Stanford, J. A. (2007). Climate, hydrologic disturbance, and succession: Drivers of floodplain pattern. *Ecology*, *88*, 940–953.

Winterbottom, S. J. (2000). Medium and short-term channel planform changes on the Rivers Tay and Tummel, Scotland. *Geomorphology*, *34*, 195–208.

Woolsey, S., Capelli, F., Gonser, T., Hoehn, E., Hostman, M., Junker, B., et al. (2007). A strategy to assess river restoration success. *Freshwater Biology*, *52*, 752–769.

Wyzga, B. (1993). River response to channel regulation: Case study of the Raba river, Carpathians, Poland. *Earth Surface Processes and Landforms*, *18*, 541–556. http://dx.doi.org/10.1002/esp.3290180607

Zawiejska, J., & Wyżga, B. (2010). Twentieth-century channel change on the Dunajec River, southern Poland: Patterns, causes and controls. *Geomorphology*, *117*, 234–246. http://dx.doi.org/10.1016/j.geomorph.2009.01.014