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Channel pattern medium-term changes in four rivers of Southern Italy: a summary

Abstract: Angelone F., D'Onofrio E.G., Russo F., Valente A., Magliulo P., *Channel pattern medium-term changes in four rivers of Southern Italy: a summary.* (IT ISSN 0391-9838, 2025). This study proposes a schematic and generally applicable approach in reconstructing medium-term channel pattern changes at the regional scale, with the aim to provide insights for the definition of a common morphoevolutionary trend. To this aim, the channel pattern changes experienced by four rivers of the Campania Region (Southern Italy), representative of the rivers of a much wider morphoclimatic scenario (i.e., the Mediterranean area), over a time-span of ~150 years were investigated. The studied rivers were Calore, Sele, Tammaro and Sabato Rivers, which markedly differ from the standpoints of length, flow discharge and channel mean width. A geomorphological analysis in GIS environment of historical maps, topographic maps, orthophotos and Google Earth imagery from different dates (1870, 1909, 1955, 1998 and 2023) was carried out, with a mean temporal resolution of ~38 years. The results showed a dominance (45-94% of the river length) of the sinuous channel pattern between the end of XIX century and the first decades of XX century, which was clearer in the minor rivers (i.e., Tammaro and Sabato). From 1950s to the end of XX century, sinuous channel pattern remained generally dominant (20-60%), but transitional morphologies (wandering and sinuous with alternated bars) significantly increased (22-60%). From the end of XX century onwards, sinuous channel pattern returned strikingly dominant in all the investigated rivers (43-79%). Land-use changes and, later, floods were the main controlling factors of the detected changes in channel pattern. The coherence of the obtained results was discussed in the framework of the pre-existing literature, also highlighting the central role played by the scale of the used materials for a correct analysis of channel pattern changes.

Key words: Channel adjustments, Morphoevolutionary trends, Calore River, Sabato River, Sele River, Tammaro River.

Riassunto: Angelone F., D'Onofrio E.G., Russo F., Valente A., Magliulo P., *Variazioni di medio termine della configurazione morfologica in quattro fiumi dell'Italia meridionale: una sintesi.* (IT ISSN 0391-9838, 2025). Il presente studio propone un approccio schematico e di generale applicabilità finalizzato alla ricostruzione delle variazioni di configurazione morfologica dei corsi d'acqua su scala regionale, al fine di fornire indicazioni utili alla definizione di un *trend* morfoevolutivo generale. A tal fine, sono state investigate le variazioni del *pattern* del canale attivo sperimentate, negli ultimi 150 anni circa, da quattro fiumi della Regione Campania (Italia meridionale), rappresentativi di uno scenario morfoclimatico decisamente più ampio (l'area Mediterranea). Sono stati investigati, in particolare, i fiumi Calore, Sele, Tammaro e Sabato, tra loro marcatamente differenti in termini di lunghezza, portata liquida e larghezza media dell'alveo. È stata condotta un'analisi geomorfologica in ambiente GIS di carte storiche, carte topografiche, ortofoto e immagini satellitari Google Earth di diversi anni (1870, 1909, 1955, 1998 e 2023), separate tra loro da un intervallo temporale medio di circa 38 anni. I risultati hanno evidenziato, tra la fine del XIX secolo e i primi decenni del XX secolo, una dominanza (compresa tra il 45% e il 94% delle lunghezze dei tratti analizzati) della configurazione morfologica sinuosa, particolarmente nei corsi d'acqua minori (Tammaro e Sabato). Dagli anni '50 alla fine del XX secolo, il *pattern* sinuoso rimaneva quello generalmente dominante (tra il 20% e il 60% della lunghezza dei tratti analizzati), ma si registrava, al contempo, un aumento dei *pattern* transizionali (*wandering*, sinuoso a barre alternate). Dalla fine del XX secolo in poi, il *pattern* sinuoso ritornava ad essere marcatamente dominante in tutti i fiumi investigati, caratterizzando dal 43% al 79% della lunghezza analizzata. Le variazioni di uso del suolo alla scala di bacino e, specialmente negli ultimi anni, le piene fluviali sono stati riconosciuti essere i principali fattori di controllo delle variazioni di configurazione morfologica osservate. La coerenza dei risultati ottenuti è stata verificata e discussa nel quadro della letteratura scientifica preesistente, evidenziando, al contempo, il ruolo centrale svolto dalla corretta scelta della scala dei materiali utilizzati per un'analisi attendibile delle variazioni di configurazione morfologica.

Termini chiave: Variazioni morfologiche degli alvei, *Trend* morfoevolutivi, Fiume Calore, Fiume Sabato, Fiume Sele, Fiume Tammaro

INTRODUCTION

In recent decades, rivers underwent significant adjustments, including incision and narrowing, which were widely documented both in Italy and worldwide (e.g. Rinaldi and Rodolfi, 1995; Winterbottom, 2000; Liébault

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and Piégay, 2002; Rinaldi, 2003; Hooke, 2006; Surian *et al.*, 2009; Yao *et al.*, 2012; Magliulo *et al.*, 2013; Heitmuller, 2014; Scorpio *et al.*, 2015; Mandarino *et al.*, 2020; Mandarino, 2022; and references therein).

In many cases, such adjustments led to changes in the channel pattern, defined as the shape assumed by a river when viewed from above (Leopold and Wolman, 1957). According to Rinaldi (2003), the analysis of changes in channel pattern provides useful information on the main variables controlling channel adjustments (sediment supply, grain size, bed slope, flow regime, etc.). Over time, several authors proposed classification schemes to describe and interpret river channel pattern, developing increasingly articulated approaches (Thorne, 1997). These classifications progressively evolved to support both the understanding of river behaviour and their practical application in management application (Rinaldi *et al.*, 2016).

Leopold and Wolman (1957) proposed a quantitative approach to distinguish the planimetric configurations of channels – straight, meandering and braided – based on the relationship between channel slope and bankfull discharge. This initial classification was later extended to include other configurations such as anastomosing channels (Brice, 1975; Rust, 1978), wandering channels (Henderson, 1963; Osterkamp, 1978; Desloges and Church, 1989; Knighton and Nanson, 1993; Church, 2002) and, more generally, anabranching rivers (Nanson and Knighton, 1996; Makaske, 2001; Nanson, 2013; Fuller *et al.*, 2013). Schumm (1963, 1977) classified alluvial rivers on the basis of whether their beds were stable, eroding or aggrading and further differentiated them through the dominance of suspended load, mixed load or bedload sediment transport (Kondolf, 2016).

The classification proposed by Rosgen (1994) was probably the most comprehensive morphological classification of natural watercourses, based on a number of key parameters such as slope, confinement, section width/depth ratio, sinuosity and grain size, and also included confined riverbeds that are usually classified by other criteria. Based on the concepts of Mollard (1973) and Schumm (1985), Church (1992, 2006) summarised channel patterns based on sediment supply, sediment calibre and channel gradient. In particular, Church (2006) related the morphology of alluvial channels to sediment transport and deposition processes, developing a comprehensive classification of alluvial channels based on the Shield's number, clarifying how channel characteristics and shapes reflected transport processes (Kondolf, 2016).

More recently, a channel pattern classification scheme (modified from Rinaldi, 2003) was developed for the assessment of river morphological conditions through the Morphological Quality Index (MQI), within a broader methodological framework known as IDRAIM (Stream Hydromorphological Evaluation, Analysis and Monitoring System; Rinaldi *et al.*, 2016). The classification included configurations such as Straight, Sinuous, and Meandering channels (single-thread), Sinuous with Alternate Bars and Wandering channels (transitional), and Braided and Anastomosed channels (multi-thread). These configurations are defined based on quantitative parameters such as sinuosity, braiding and anastomosing index, in some cases complemented by additional qualitative features. Rinaldi *et al.* (2016) highlight that the changes in channel pattern, together with those in channel width and riverbed elevation, provide useful data to reconstruct the morphoevolutionary trajectory of a given river. The latter, in turn, represent a key starting point to assess the morphological quality of the river, which can be efficiently used to plan river management measures.

In this framework, the relevance of the river channel patterns and its variations over time in the analysis of medium-term channel adjustments is evident. Although scientific literature extensively addresses channel adjustments in various rivers (Rinaldi, 2003; Surian and Rinaldi, 2003; Scorpio *et al.*, 2015), it has never specifically focused on channel patterns variations alone.

This study aims introducing a relatively simple, schematic and rapid approach based on the analysis of maps and orthophotographs within a Geographic Information System (GIS) environment for identifying potential morpho-evolutionary trends among rivers at a regional scale. To date, no other study has exclusively and systematically compared medium-term changes in channel patterns across multiple river systems, interpreting these changes in light of current scientific knowledge. Focusing exclusively on morphological configuration meets a methodological need for synthesis and comparability. This approach enables essential, spatially coherent information to be extracted across different river reaches, facilitating a synoptic understanding of the observed changes.

Specifically, the study focused on four rivers in the Campania Region (Southern Italy) which differ in length, discharge and mean channel width (i.e., Calore, Sele, Tammaro and Sabato) over a period of ~150 years. The selected rivers are representative of the those of a much wider morphoclimatic scenario, i.e. the Mediterranean area, as confirmed by a vast pre-existing literature (i.e. Hooke, 2006; Scorpio and Rosskopf, 2016; and references therein). Thus, the obtained data represent a useful support to reconstruct and interpret the morphoevolutionary phases of other rivers of the Mediterranean area, and to the understanding of the role played by the controlling factors.

This study, in addition to enhance the understanding of river morpho-evolutionary phases, also pursues a significant operational objective, as the data produced will be a key starting point for future researches aimed at supporting management applications. In fact, many papers (e.g.,

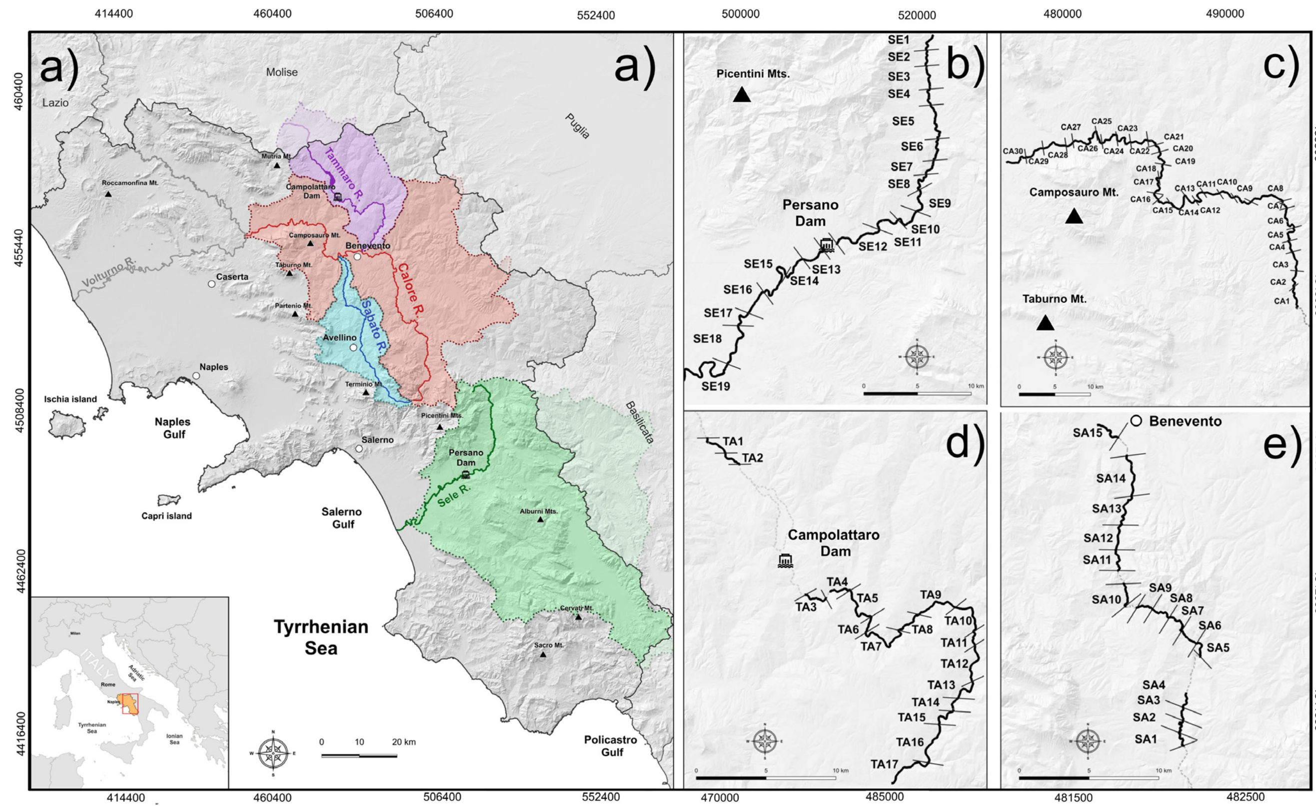

Figure 1 - (a) Location map of the investigated rivers (thick, continuous lines) and basins (hatched, thin lines) in the framework of the Campania Region. (b-d) Subdivisions into reaches of the investigated rivers, according to Rinaldi *et al.* (2015; 2016): b) Sele R.; c) Calore R.; d) Tammaro R.; e) Sabato R.

Table 1 - Main features of the investigated rivers. ARL: analysed river length.

River	Range of last 150 years channel mean width (m)	Current mean annual flow discharge (m^3/s)	Current length (km)	ARL (%)
Sele	173-59	69.4	68	89
Calore	158-33	30.0	110	74
Tammaro	75-24	5.0	68	59
Sabato	59-16	4.2	61	43

Sear *et al.*, 1995; Gilvear, 1999; Kondolf *et al.*, 2003; Downs & Gregory, 2004; Brierley & Fryirs, 2005, 2008; Meitzen *et al.*, 2013; Tadaki *et al.*, 2014) demonstrated that the reconstruction of channel pattern changes, together with channel width and riverbed elevation changes, are fundamental in reconstructing rivers morphoevolutionary trajectories. These latter, in turn, are a key starting point to assess the hydromorphological state of a river and to correctly plan proper river management measures.

STUDY AREA

This study focused on the Calore, Sele, Tammaro and Sabato Rivers, all of them located in the Campania region (fig. 1). Table 1 shows the main characteristics of the studied rivers.

The Campania region is located in the north-western sector of Southern Italy, between 40.0° N and 41.5° N and 13.5° E and 16.0° E and has an area of ~14,000 km^2. The area has a complex orography and can be subdivided into three main physiographic units (sensu Rinaldi *et al.*, 2015), namely: (i) the Apennine mountain range, with altitudes ranging between ~1000 m and over 2000 m a.s.l. accounting for 30% of the total area; (ii) low-altitude hills and alluvial valleys for a further 52%; and (iii) coastal plains accounting for the remaining 18% (De Vita *et al.*, 2012). The climate of the Campania region is of a Mediterranean type, with hot and dry summers and moderately cool and rainy winters (Diodato, 2005; Diodato *et al.*, 2011). Average annual temperatures in the area vary between 10°C and 12°C in the inner areas and between 13°C and 15°C along the coast (Diodato, 2005). The rainfall regime is characterised by a marked seasonal variability, with a principal maximum during the autumn–winter months and a minimum in summer. Precipitation ranges from approximately 700-900 mm along the coast during the dry summer period to 1700-2000 mm in the central Apennine ridge during the wet season (Bandini, 1931). Historical rainfall trends and their seasonal variability were described by Longobardi and Villani (2010) and Longobardi *et al.* (2016). During the period 1818-1999, the area experienced a moderately negative rainfall trend, especially in the north-east and south-west areas, where the rivers investigated in this study flow. The main wet periods occurred between the mid-1930s and mid-1940s and between the early 1960s and late 1970s, while the main dry periods occurred between the mid-1940s and early 1960s and between the late 1970s and the first decade of the XXI century (Longobardi and Villani, 2010; De Vita *et al.*, 2012). At the same time, the seasonal variability also appeared to be characterised by a negative trend, with a transition of the rainfall regime from seasonal to more uniform. The rivers investigated flow into two main basins (i.e., Calore River and Sele River), as the Tammaro and Sabato Rivers are the main tributaries of the Calore River. The main characteristics of the studied basins are shown in table 2. The Sele R. flows through all the above mentioned physiographic units (i.e., Apennine mountains range, hills/alluvial plains and coastal plain) and finally flows into the Tyrrhenian Sea. The Calore R. basin, on the other hand, is an inner basin, being the Calore R. the main left tributary of the Volturno R. It is different from the Sele basin, in that it only crosses the physiographic units of the mountain range and hills/alluvial plains without reaching the coastal plain.

From a geological-structural standpoint, the investigated rivers flow within intra-Apennine morphostructural depressions presenting terraced Quaternary deposits of mainly alluvial and volcanic origin (Brancaccio *et al.*, 1987; Magliulo *et al.*, 2007; Cartojan *et al.*, 2014). In some areas (e.g. the lower Sele R. valley and the middle-lower Calore R. valley), Quaternary alluvial deposits form very thick sedimentary successions (Cinque *et al.*, 1988; Magliulo, 2005). The Quaternary deposits, in turn, unconformably rest on both terrigenous deposits of Mio-Pliocene age, which form predominantly hilly reliefs subject to intense erosive phenomena, and on carbonate deposits, often karstified, of Mesozoic age that form the substrate of the main mountain massifs (Mostardini and Merlini, 1986).

From a geomorphological point of view, steep slopes, locally deeply dissected by gorges, characterize the sectors of the basins shaped in limestone deposits. At the top of these slopes, there are karstified remnants of ancient erosive landscapes (paleosurfaces or Paleosuperfici Auct.) (Brancaccio *et al.*, 1987; Magliulo *et al.*, 2005). In contrast, hills shaped into terrigenous deposits present gently-rolling morphologies and low-angle slopes, and are subject to intense water erosion and mass movements. Thick sequences of alluvial and scree-talus deposits connect the slopes to the floodplains. These deposits often form coalescent or telescopically-arranged alluvial fans. In turn, the alluvial fans deposits are in heteropic contact, downslope, with fluvial or fluvio-lacustrine deposits that are arranged into several orders of river terraces. Locally, structural terraces developed on pyroclastic deposits (e.g., Campanian Ignimbrite) and travertines are also present (Magliulo, 2005; Cartojan *et al.*, 2014; Magliulo *et al.*, 2021b Martucci *et al.*, 2025).

In terms of land use, the Campania Region has undergone significant changes over the last 150 years. Between the mid-1800s and the 1930s, deforestation was widespread, with peaks between 1870-1890 and 1900-1930 (Ellis *et al.*, 2010; Scorpio and Piégay, 2021). On the contrary, since the 1930s, Southern Italy has experienced forest expansion due to both natural reforestation and reforestation measures implemented from the 1950s onwards (Tichy, 1962; D' Ippolito *et al.*, 2013; Scorpio *et al.*, 2015). According to Bevilacqua (2005), this process also reflects the natural re-expansion of forests following agricultural abandonment and the shift of agricultural activities to valley bottoms and alluvial coastal plains (Mazzoleni *et al.*, 2004; Migliozzi *et al.*, 2010). In particular, in the Sele R. basin, forest cover increased, at the basin scale, by 18% between 1960 and 1990 and by 14% from 1990 to 2012 (Magliulo *et al.*, 2021b), while in the Calore R. basin (which includes the F. Sabato and F. Tammaro basins), forest cover increased by 12% between 1960 and 1990 and remained almost unchanged in the following 30 years (Magliulo *et al.*, 2022). Most of the human interventions along the river channels occurred mainly between the 1960s and the 1990s, a period in which in-channel sediment mining, now prohibited by law, was particularly intense (Scorpio *et al.*, 2015; Magliulo *et al.*, 2021a).

Finally, the Sele and Tammaro are dammed rivers. In particular, the Sele R. was dammed by the Persano Dam, which was closed in 1934. Such dam is open for ten months out-of-twelve in a year. Differently, the Tammaro R. is dammed by the Campolattaro Dam, which was closed in 2006, forming the Campolattaro Reservoir. Generally speaking, dams reduce both sediment and flow discharge downstream, and contribute significantly to channel adjustments (Grant, 2012). Unfortunately, no sediment discharge data were available for the Persano and Campolattaro Dams.

MATERIALS AND METHODS

The multi-temporal analysis of channel pattern changes along the Sele, Calore, Tammaro, and Sabato Rivers was conducted within a GIS-based framework, using QGIS (version 3.34; QGIS Development Team, 2023) and ArcGIS Desktop (version 10.3; ESRI, 2014). The analysis was based on cartographic sources and orthorectified aerial imagery from five reference years (i.e., 1870, 1909, 1955, 1998, and 2023).

All data were georeferenced using the UTM-WGS84 coordinate system (EPSG:32633). A first order and second order polynomial transformation were used for georeferentiation of historical topographic maps and more recent topographic maps, respectively.

Historical topographic maps provided by the Italian Geographical Military Institute (IGMI) dated back to 1870 and 1909, both at 1: 50,000 scale, were scanned at 300 and 600 dpi resolution, imported into ArcGIS® 10.3 and georeferenced. Large scale (i.e., 1:5000) topographic maps (i.e. Carta Tecnica Regionale, provided by the Regione Campania Authority) were used as the basis for georeferencing and approximately 30 ground control points (GCPs) were selected, generally located near the active channel. The analysis was also carried out on IGMI 1:25,000 scale topographic maps from 1955, scanned at 1200 dpi and already georeferenced by the map producer.

For 1998, 1: 13,000 scale colour orthophotos provided by the Campania Region and already georeferenced by the data provider were used. For 2023, the images were acquired from Google Earth, which provides georeferenced data compatible with the adopted coordinate system. The main characteristics of the materials used are summarised in table 3.

For each year considered, the active river channels were manually digitised in a GIS environment. We considered as part of the "active channel", according to IDRAIM manual (Rinaldi *et al.*, 2016), both the fluvial bars and the low-flow channel (or channels, in case of multi-thread channel patterns). Stable vegetated islands were excluded. The boundaries of the active channel were defined based on the modern floodplain or, if absent, on the lowest terrace in contact with the channel. On the topographic maps, the active channels were identified on the basis of distinctive morphological elements represented by proper cartographic symbols. On orthophotos and satellite images, the channels were identified visually. Digitisation was carried out at a working scale of 1:4000 or greater to ensure an adequate level of detail. Only river segments with sufficient width and/or visibility to provide reliable results were analysed, while channel segments that were too narrow and/or hidden by overhanging riparian arboreal vegetation were excluded from the analysis, as it was not possible to digitise them correctly. The analysed river length will be hereinafter referred to as ARL. Detailed geomorphological field surveys were carried to verify, where possible, the accuracy of the data obtained from the topographic map analysis and to look for geomorphological evidence of abandoned riverbeds and embankments. The riverbed centerline was derived from the active channel polygon through a semi-automated GIS-based procedure involving Voronoi polygons. The active channel polygon was first converted into lines and then into points distributed at regular intervals along both riverbanks. Using the "v.voronoi.skeleton" function within the GRASS environment, Voronoi polygons were generated. The internal edges of these polygons, which represent lines equidistant from the banks, were extract-

Table 2 - Main features of the investigated rivers basins. Latitude and longitude refer to the extreme North-Western and South-Eastern vertexes of the rectangle that enclose the basin. Data about percent of forests are from Magliulo *et al.* (2021a, b; 2022).

Basin	Latitude	Longitude	Area (km^2)	Minimum altitude (m a.s.l)	Maximum altitude (m a.s.l.)	Mean annual rainfall (mm)	Main land use	% of forests (2012)
Sele	40°51' N 40°09'N	14°56' E 15°50' E	3245	0	1886	1071	Forests	52.6
Calore	41°30' N 40°46' N	14°27' E 15°20' E	3037	35	1810	1100	Arable lands	22.1
Tammaro	41°30' N 41°09' N	14°34' E 14°59' E	671	127	1468	1015	Arable lands	18.0
Sabato	41°08' N 40°46' N	14°41' E 15°00' E	401	112	1801	1193	Forests	39.6

Table 3 - Main characteristics of the used materials. Legend – HM: historical topographic maps; RM: more recent topographic map; O: orthophoto; IGMI: Italian Geographic Military Institute; GE: Google Earth; CRA: Campania Region Authority. The scale values marked with * indicate the scale range of data visualization. Positional errors were calculated according to Slama *et al.* (1980) and Taylor (1982).

Year	Type	Producer	Scale	Scanning Resolution (dpi)	Positional Error (m)
1870	HM	IGMI	1:50,000	300	33
1909	HM	IGMI	1:50,000	600	29
1955	RM	IGMI	1:25,000	1200	15
1998	O	CRA	1:13,000	-	2
2023	O	GE	1:1000-1:2500*	-	-

ed to obtain the channel centerline for each active channel considered.

The subdivision of the studied rivers into homogeneous reaches (fig. 1b-e) was carried out according to the method proposed by Rinaldi *et al.* (2015, 2016), which considers not only channel pattern, but also confinement conditions (both longitudinal and transversal), the presence of anthropogenic infrastructures, and hydrological discontinuities, such as confluences with the main tributaries and dams. This reach-scale segmentation allowed us to better analyse the spatial variations in channel pattern over the investigated time span.

Channel pattern were determined based on the criteria and thresholds listed by Rinaldi *et al.* (2015, 2016). The following channel pattern were observed: straight, sinuous, meandering, sinuous with alternated bars, wandering, braided. The classification was based on quantitative parameters such as the sinuosity index (for single-tread channels) and the braiding index (for multi-thread channels). Straight channels were identified by a braiding index of approximately 1 and a sinuosity index of less than 1.05 (Brice, 1975; Malavoi and Bravard, 2010). To distinguish between sinuous and meandering channels, a sinuosity index threshold of 1.5 was used (Leopold & Wolman, 1957), considering sinuous channels those with sinuosity < 1.5 and meandering channels those with sinuosity > 1.5. We considered braided patterns those displaying a braiding index higher than 1.5.

For transitional morphologies, such as sinuous with alternated bars and wandering, it was not possible to define univocal numerical thresholds (ISPRA, 2016); in these cases, classification was based on qualitative observations and the length of lateral bars, generally exceeding 80% of the channel reach.

In multitemporal analysis, the changes in channel pattern in each considered reach were classified, according to Rinaldi *et al.* (2016), into three classes, i.e. (i) no changes in channel morphology, (ii) changes to a similar morphology, and (iii) changes to a markedly different morphology. By calculating the percent of each reach length compared to the total ARL, the percent of ARL with changes in channel morphology belonging to the three above listed classes of channel morphology changes was calculated for each river at all the considered dates.

RESULTS

Channel pattern analysis at the river scale

The subdivision of the analysed river centrelines according to channel pattern is shown in fig. 2, which reports the spatial distribution of the identified patterns, and is quantified in fig. 3. Fig. 4 shows some selected cases of channel pattern changes in reaches representative of the general trend of the whole river.

Fig. 3 clearly shows that in all the investigated rivers, the sinuous pattern was dominant, with the only exception of the Calore R. in 1955, in which transitional morphologies (i.e., wandering and sinuous with alternated bars) prevailed, accounting for 31% and 29% of the ARL, respectively (figs 3b; 4f). Sinuous pattern ranged from 94% of the ARL in the Sabato R. in 1870 (figs 3d; 4o) to 20% in the Calore R. in 1955 (fig. 3b).

Fig. 3 also shows that between 1909 and 1955, transitional morphologies became more frequent in all the investigated rivers (figs 4i-l; 4o-p). Such increase was particularly clear in the Calore R., in which such morphologies increased from 32% to 60% of the ARL (fig. 3b). It can also be observed that, in the same time-span, among transitional morphologies, wandering pattern prevailed over sinuous with alternated bars pattern in the major rivers (i.e., Sele and Calore), while the opposite occurred in the minor ones (i.e. Sabato and Tammaro). Conversely, transitional morphologies drastically decreased in the following time-span, i.e. 1955-1998, in all the analysed rivers (fig. 3). Finally, a new slight increase of transitional morphologies was noted from 1998 to 2023 in three rivers out-of-four (i.e., Sele and, subordinately, Calore, and Sabato), while a further decrease of such morphologies characterized the Tammaro R., only.

Braided morphologies were observed in the Sele R. only (figs 3a; 4a) and decreased with time, ranging from 17% of the ARL in 1870 to 2% in 2023 (fig. 3a). Differently, straight morphologies were detected in all the considered rivers in almost all the considered years, but the percent of the ARL was generally low (i.e., from 2% in the Calore R. in 1870 to 12% in the Sabato R. in 2023).

Finally, meandering morphologies were observed in all the investigated rivers at all the considered dates (fig. 3). Such pattern was more frequent in the two major rivers, i.e. Calore and Sele, accounting for a percent of the ARL ranging from 15% to 21% (fig. 3a-b). Differently, such percent was lower, ranging from 2% to 13%, in the minor rivers (i.e., Sabato and Tammaro; fig. 3c-d). For each river, the percent of ARL that showed meandering pattern did not undergo significant changes throughout the entire considered period, except for the Sabato R. This is coherent with what is shown by fig. 2, in which the spatial distribution of the detected morphologies for each river is reported. Fig. 2, in fact, shows that locations of reaches displaying meandering morphologies remained substantially unchanged through time. Fig. 2 also highlights an increase in spatial variability of the channel pattern between 1909 and 1955 for all the considered rivers. Such an increase is marked by the major fragmentation into segments of different colour in fig. 2. Conversely, fig. 2 highlights a significant homogenization of the channel pattern between 1955 and 1998 towards a dominant sinuous pattern, which was coherent with fig. 3, and lasted until 2023, except for the Sele R. (fig. 3a)

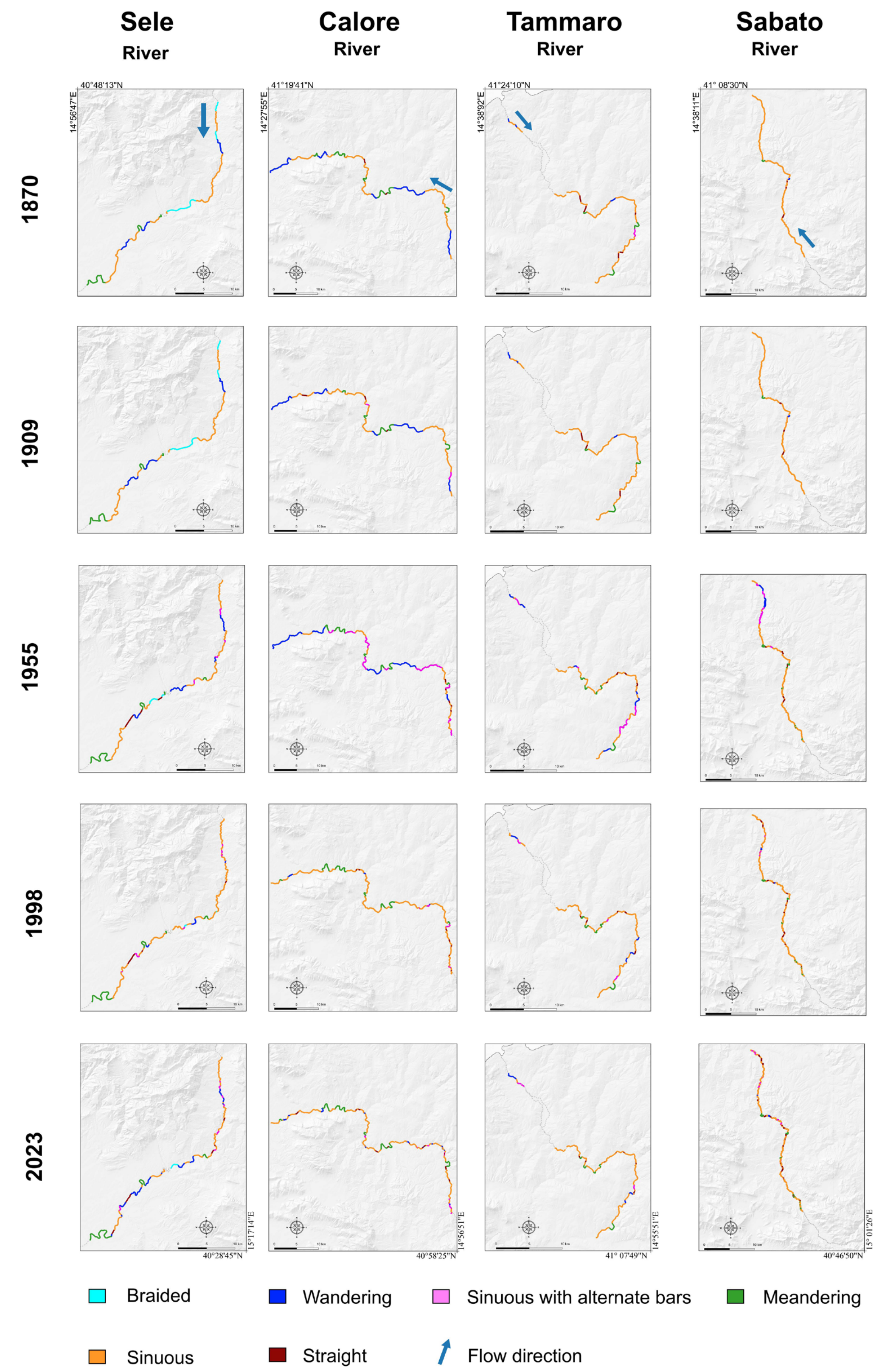

Figure 2 - Spatial distribution of the detected channel morphologies in the investigated rivers from 1870 to 2023. A) Sele R.; B) Calore R.; C) Tammaro R.; D) Sabato R.

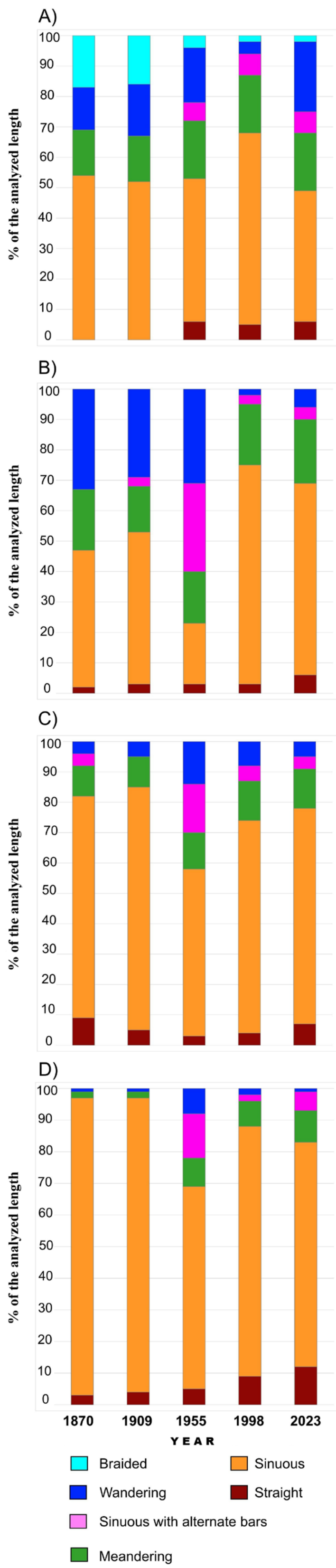

Figure 3 - Channel morphologies, expressed as percent of the ARL, of the investigated rivers at the considered dates. A) Sele R.; B) Calore R.; C) Tammaro R.; D) Sabato R.

Channel pattern analysis at the reach scale

For each reach, the dominant pattern was assessed and the results are reported in tables 4, 5, 6 and 7. The tables substantially confirmed what was reported in the previous sub-section, i.e. a dominance of sinuous morphologies and an increase in spatial variability between 1909 and 1955, followed by a decrease in such variability in the following years.

According to Rinaldi *et al.* (2016), the detected channel morphology changes in the obtained reaches were subdivided into three classes: (i) no changes in channel morphology; (ii) changes to a similar morphology (Class B); and (iii) changes to a markedly different morphology (Class C). The results were reported in fig. 5.

For the period 1870-1909, a difference is evident between the major (i.e., Sele and Calore) and minor rivers (i.e., Sabato and Tammaro). The reaches of the minor rivers seemed not experiencing any changes in channel pattern in this time-span, as confirmed by table 6 and table 7. Differently, the major rivers experienced morphological changes in a percent of their ARL ranging from 14% (for the Calore) to 26% (for the Sele). In particular, Class C changes were more frequent in the Sele R., accounting for 14% of the ARL, compared with 5% of the Calore R.

Most of the morphological changes detected at the reach scale occurred between 1909 and 1998 in all the investigated rivers (figs 4a-b-c; 4e-f-g; 4i-l-m; 4o-p-q; 5). In the minor rivers (i.e., Tammaro and Sabato), they mainly occurred between 1909 and 1955 (figs 4i-l; 4o-p), affecting percentages of the ARL ranging between 20% (Sabato R.) and 31% (Tammaro R.; fig. 5c-d). Among the minor rivers, while the Sabato R. reaches did not experience changes to markedly different morphologies (Class C) in this time-span (fig. 5d), Class C changes were dominant over those of Class B in the Tammaro R. (figs 4i-l; 5c). Conversely, in the major rivers (Calore and Sele), changes in channel pattern mainly occurred between 1955 and 1998 (fig. 4f-g) and were more severe, affecting percentages of the ARL ranging from 33% in the Sele R. to 63% in the Calore R. (fig. 5a-b). In these rivers, changes to markedly different morphologies dominated over those to similar morphologies, as they affected 24% of the ARL in the Sele R. and 38% in the Calore R. (fig. 5a-b). Channel pattern changes were detected, in these time-span, also in the smallest rivers (figs 4l-m; 4p-q; 5c-d), as they affected 18% of the Tammaro R. and 26% of the Sabato ARL, even if, similarly to the previous period, Sabato R. reaches never experienced changes between markedly different morphologies (Class C).

In the last investigated time-span (i.e., 1998-2023), the percent of the ARL affected by channel changes decreased compared with the previous period (1955-1998), as it ranged from 29% in the case of the Sele R. to 6% in the Calore R. (fig. 5). It is interesting to note that the Calore R. was the one affected by the more severe channel changes in the

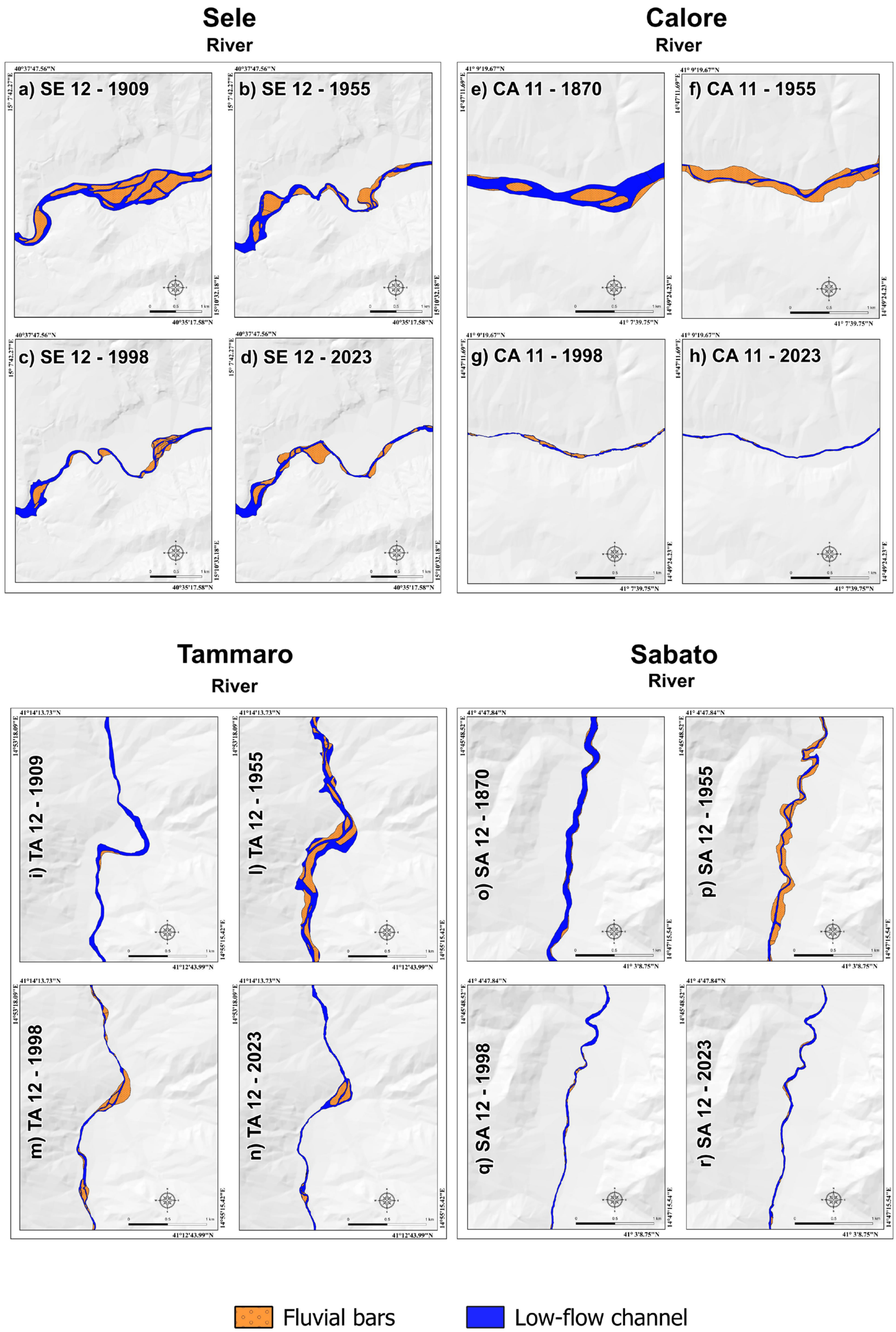

Figure 4 - Geomorphological sketches of some selected river reaches representative of the main trends in channel pattern evolution of the investigated rivers. a-d) Sele R.; e-h) Calore R.; i-n) Tammaro R.; o-r) Sabato R.

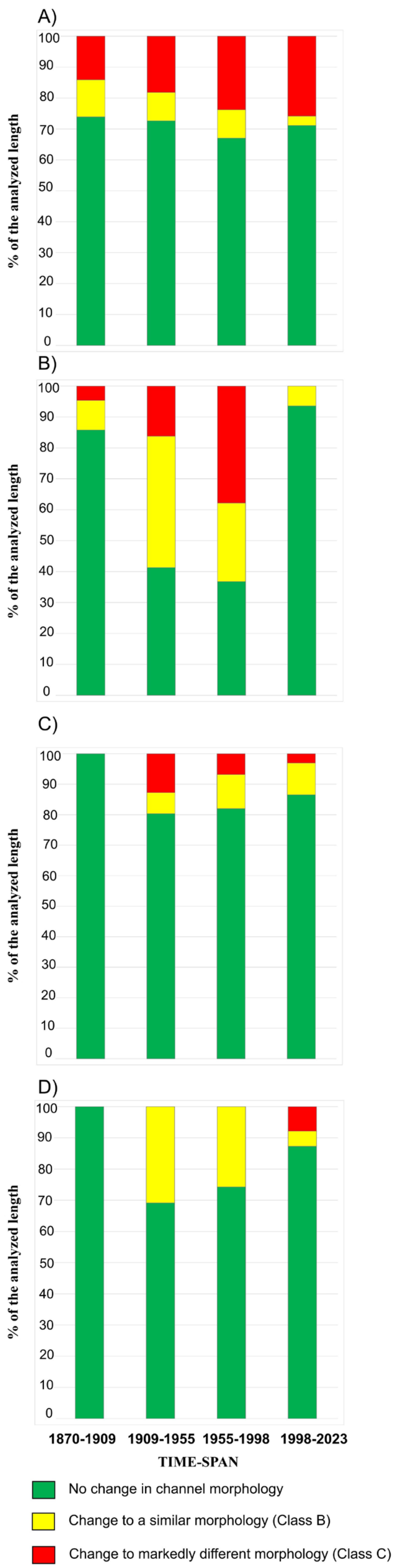

Figure 5 - Amount and type of channel morphology changes, according to Rinaldi *et al.* (2015; 2016), in the investigated rivers, expressed as percent of ARL, at the considered dates. A) Sele R.; B) Calore R.; C) Tammaro R.; D) Sabato R.

previous period (i.e. 63% of the ARL) and that no changes of Class C were observed in the same river between 1998 and 2023 (figs 4g-h; 5b). On the contrary, Class C changes were dominant in the Sele R., affecting 26% of the ARL, thus highlighting a different behaviour between the two largest rivers in this time-span (fig. 5a).

DISCUSSION

The analysis of the changes in channel pattern in the last 150 years highlighted some regional trends and some differences between major and minor rivers.

As it can be seen in fig. 3, the investigated rivers mainly showed a dominant single-thread channel pattern, especially in minor rivers (i.e. Sabato and Tammaro). This is in contrast with was observed in literature (Surian and Rinaldi, 2003; Scorpio *et al.*, 2015; and references therein), which found a dominant multi-thread channel pattern for Italian rivers between the last decades of XIX century and 1950s. According to Rinaldi (2003), this contrast could be explained by minor sediment supply from the slopes to the investigated rivers, even if accurate data about the causes of such difference are unfortunately not available and further researches are needed. Between the last decades of XIX and the beginning of XX century, changes in channel pattern were negligible in major rivers (i.e., Sele and Calore; fig. 5a-b), where more than 75% of the ARL remained unchanged, or even totally absent in minor rivers (Tammaro and Sabato; fig. 5c-d). This would be coherent with the findings by Scorpio and Piégay (2021), which reports changes in channel width but not in channel morphologies between the XIX century and 1950s. However, in our opinion, some considerations about these results should be made. In fact, several papers (Brunetti *et al.*, 2004; Diodato, 2007; Scorpio and Piégay, 2021) report, at least until 1930s, a humid climate with extreme rainfall events and an increase in frequency of floods. Humid climatic conditions, in turn, increased both the landslides triggering and erosion by water on slopes, which were also favoured by a diffuse deforestation (Scorpio *et al.*, 2015). All these conditions were coherent with an increase in sediment supply to the rivers. In this framework of increased sediment supply at the regional scale, the development of channel morphologies of transitional or even braided type was expected (Rinaldi, 2003). Thus, their almost total absence in minor rivers of the Campania region (fig. 3c-d) was quite surprising, also because such morphologies (especially the transitional ones) were quite widespread in the same rivers (i.e., about 30% of the ARL) in 1955 (fig. 3c-d) when, as we will clarify below, environmental conditions were coherent with a reduced sediment supply compared with the previous phase. Our suspect is that transitional morphologies in the minor rivers were more widespread than what was

Table 4 - Dominant channel pattern of the Sele R. reaches in the analyzed time-span. Legend - B: braided; W: wandering; Sab: sinuous with alternated bars; S: sinuous; M: meandering; St: straight.

REACH	Dominant channel morphology				
	1870	1909	1957	1998	2023
SE 01	B	B	S	S	S
SE 02	S	S	S	S	S
SE 03	S	S	S	S	S
SE 04	B	B	Sab	Sab	W
SE 05	W	W	W	S	S
SE 06	S	S	S	S	S
SE 07	S	S	S	S	S
SE 08	S	S	W	S	S
SE 09	S	S	S	S	S
SE 10	S	S	S	S	S
SE 11	W	S	S	S	S
SE 12	B	B	W	S	W
SE 13	S	S	B	S	S
SE 14	W	W	W	S	W
SE 15	S	Sab	Sab	S	W
SE 16	S	S	St	St	St
SE 17	Sab	S	S	S	W
SE 18	W	S	S	S	S
SE 19	M	M	M	M	M

Table 5 - Dominant channel pattern of the Calore R. reaches in the analyzed time-span. Legend - B: braided; W: wandering; Sab: sinuous with alternated bars; S: sinuous; M: meandering.

REACH	Dominant channel morphology				
	1870	1909	1957	1998	2023
CA 01	W	W	B	S	Sab
CA 02	W	Sab	S	S	S
CA 03	S	S	S	S	S
CA 04	S	S	W	S	S
CA 05	M	M	Sab	S	M
CA 06	S	S	S	S	S
CA 07	S	S	S	S	S
CA 08	S	S	Sab	S	S
CA 09	W	W	Sab	S	S
CA 10	W	W	W	S	S
CA 11	W	W	W	S	S
CA 12	M	M	M	M	M
CA 13	M	M	M	M	M
CA 14	W	M	W	S	S
CA 15	S	S	W	S	S
CA 16	S	S	Sab	S	S
CA 17	S	S	Sab	S	S
CA 18	S	S	S	S	S
CA 19	S	S	Sab	S	S
CA 20	S	R	S	S	S
CA 21	S	S	S	S	S
CA 22	S	S	Sab	S	S
CA 23	M	S	M	M	M
CA 24	S	S	M	M	M
CA 25	W	W	M	M	M
CA 26	W	W	W	S	S
CA 27	S	S	S	S	S
CA 28	S	S	W	S	S
CA 29	W	W	W	S	S
CA 30	W	W	W	S	S

reported on 1870 and 1909 topographic maps and, simply, not adequately mapped due to the map scale (1: 50,000) and the relatively small dimensions of the Tammaro and Sabato Rs. (table 1). Such hypothesis would also explain the highest frequency, in these two rivers, of transitional channel morphologies on the topographic maps from 1955 (fig. 3c-d), which were more detailed (i.e., 1:25,000-scaled) than the historical maps from 1870 and 1909. In this framework, also the percentages of braided and transitional morphologies in the major rivers (Sele and Calore; fig. 3a-b) are probably underestimated, strongly suggesting the use of maps of adequate scale in multitemporal analysis of channel pattern changes.

For the same reasons reported above, also the changes in channel pattern in the period 1909-1955 (fig. 5) should be interpreted cautiously. Apparently, all the investigated rivers evolved towards an increase of transitional and, subordinately, braided morphologies (fig. 3). Such changes affected percentages of the ARL ranging from ~20% to ~60% (fig. 5). These results look coherent with conditions of increased sediment supply to the rivers (Rinaldi, 2003). Unfortunately, also in this case the results are not fully coherent by literature data. In fact, Brunetti *et al.* (2000) report, for the Campania region, a drier climate at least since 1930s, with associated extreme rivers low-flows between July and October. In the same period, deforestation decreased and forest expansion occurred, due to natural reforestation and reforestation measures, reducing both erosion on slopes and sediment supply to the rivers (Scorpio *et al.*, 2015). These discrepancies suggest that the inadequate scale of the maps from 1909 could have affected the full reliability of the results for the period 1909-1955, at least for minor rivers. Difference in scale of the topographic maps could also partly explain the increase in spatial variability of channel morphologies in this period (fig. 2). However, because such increase is also evident for major rivers (Calore and Sele in fig. 2), for which the difference in scale of

Table 6 - Dominant channel pattern of the Tammaro R. reaches in the analyzed time-span. Legend - S: sinuous; W: wandering; Sab: sinuous with alternated bars.

REACH	Dominant channel morphology				
	1870	1909	1957	1998	2023
TA 1	S	S	W	W	W
TA 2	S	S	W	Sab	Sab
TA 3	S	S	S	S	S
TA 4	S	S	W	S	S
TA 5	S	S	S	S	S
TA 6	S	S	S	S	S
TA 7	S	S	S	S	S
TA 8	S	S	S	S	S
TA 9	S	S	S	S	S
TA 10	S	S	S	S	S
TA 11	S	S	S	S	S
TA 12	S	S	W	S	S
TA 13	S	S	S	S	S
TA 14	S	S	Sab	W	S
TA 15	S	S	Sab	Sab	S
TA 16	S	S	S	S	S
TA 17	S	S	S	S	S

Table 7 - Dominant channel pattern of the Sabato R. reaches in the analyzed time-span. Legend - S: sinuous; W: wandering; Sab: sinuous with alternated bars.

REACH	Dominant channel morphology				
	1870	1909	1955	1998	2023
SA 01	S	S	S	S	S
SA 02	S	S	S	S	S
SA 03	S	S	S	S	S
SA 04	S	S	S	S	S
SA 05	S	S	S	S	S
SA 06	S	S	S	S	S
SA 07	S	S	S	S	S
SA 08	S	S	S	S	S
SA 09	S	S	S	S	S
SA 10	S	S	S	S	S
SA 11	S	S	S	S	W
SA 12	S	S	Sab	S	S
SA 13	S	S	Sab	S	S
SA 14	S	S	Sab	S	S
SA 15	S	S	S	S	Sab

topographic maps likely played a more negligible role, it is possible that, between 1910s and 1950s, channel morphologies actually underwent an increase in spatial variability along the active channels induced by local factors. Among these latter, because in-channel human interventions were negligible at that time (Scorpio *et al.*, 2015) and the climate was quite uniform at a regional scale, a possible role could have been played by different rates of reforestation in the tributary sub-basins, which, in turn, affected the rates of erosion and sediment supply to the main rivers (Scorpio *et al.*, 2015; Scorpio and Rosskopf, 2016).

The data from 1955 onward looks much more robust due to the adequate scale of topographic maps and aerial photos for the analysis of channel pattern of both major and minor rivers. Interpretations are corroborated by the major availability and detail of literature data.

The period 1955-1998 was characterized by a common morphoevolutionary trend for both minor and major rivers, consisting in an increase of sinuous channel morphologies at the expense of transitional morphologies (fig. 3; figs 4b-c; 4f-g; 4l-m; 4p-q). The changes were sharper and more diffuse in the major rivers (fig. 5a-b) than in minor rivers (fig. 5c-d). The evolutionary trend towards sinuous morphologies at the expense of transitional ones suggests a decrease in sediment supply to the rivers. This is fully coherent with literature data. In particular, afforestation was particularly intense in both the Calore R. basin (which includes also the Tammaro R. and Sabato R. sub-basins) and Sele R. basin. In the Calore R. basin, the forested area in the period 1960-1990 increased by 110%, i.e. from the 10.4% to 22.5% of the river basin (Magliulo *et al.*, 2022). Similarly, in the Sele R. basin, forested areas increased by 146%, and the forested portions of the basin increased from 21% to 53% (Magliulo *et al.*, 2021b). Besides, several papers converge in indicating a reduction in rainfall from 1950s onwards, with a peak at the end of XX century (Brunetti *et al.*, 2004; Polemio and Casarano, 2004, 2008; Diodato, 2007). Finally, because in the first part of such dry climatic period (i.e., 1960s), isolated extreme rainfall events were still relatively frequent, human interventions were carried out on slopes to further reduce the rates of erosion and landsliding. Given the above described environmental conditions, a reduction of erosion on slopes and sediment supply to the rivers was extremely probable. The latter, in turn, is in very good accordance with the reduction of channel patterns indicating high sediment supply (i.e., wandering and sinuous with alternated bars) and increase in sinuous patterns that we detected in all the investigated rivers (fig. 3). Such reduction may also be explained, at the local scale, by sediment extraction from the riverbed, which peaked between the 1960s and late 1980s and was progressively forbidden by the early 1990s (Scorpio *et al.*, 2015). Sediment extraction sites (hereinafter, SES) were identified along all the studied rivers, particularly the Calore River (thirteen SES; Magliulo *et al.*, 2013), and, to a lesser extent, along the Tammaro (three SES; Magliulo *et al.*, 2021a), Sabato (three SES; Martucci *et al.*, 2025), and Sele (three SES). Unfortunately, no reliable data were found regarding the extracted volumes.

From 1998 to 2023, channel morphologies remained substantially unchanged in more than 70% of the ARL in all the investigated rivers (figs 3; 4c-d; 4g-h; 4m-n; 4q-r; 5). This is coherent with the fact that, at least in the Calore, Sabato and Tammaro basins, the forested area remained almost unchanged (Magliulo *et al.*, 2022). Similarly, also the annual rainfall did not undergo remarkable changes, even if a slight increase was recorded compared to the previous period (Alilla *et al.*, 2024). Thus, no significant changes in sediment supply to the rivers probably occurred and this could explain the negligible modifications in channel pattern we detected (figs 3; 5). Generally speaking, artificial channelization is another possible controlling factor of channel pattern stability. However, among the four analysed rivers, only the Sabato R. experienced a significant increase in artificial confinement in the investigated timespan. Along this river, the total length of bank protections increased from less than 1 km in 1955 to approximately 20 km in 1998, then to ~27 km in 2004 and, finally, ~29 km in 2014 (Martucci *et al.*, 2025). Nevertheless, this factor alone is unlikely to account for the recent phase of channel stability observed across all rivers. In fact, the Sele, Calore and Tammaro Rs., even if displaying channel pattern stability, showed no significant channelization.

In this phase, only the Sele R. displayed a quite different behaviour, with an increase of wandering morphologies at the expense of sinuous morphologies (fig. 3a). Furthermore, changes to markedly different channel morphologies affected about 25% of the Sele R. ARL (fig. 5a). In this sense, it is worthy to note that the Sele R., which is normally characterized by a flow discharge higher than those of the other investigated rivers (table 1), was affected by an extreme flood on 8, 9 and 10 October 2010. Several papers converge in indicating that extreme floods were probably the main controlling factor of channel adjustments from 1990s onward (de Musso et al., 2020; Mandarino *et al.*, 2020; Mandarino, 2022). In particular, they erode, transport and deposit large amounts of sediments, leading to the development of transitional or even braided channel morphologies and channel widening (Nardi and Rinaldi, 2015; Surian *et al.*, 2016; Righini *et al.*, 2017). Thus, the Sele R. reaches displaying transitional (mainly wandering) channel morphologies are likely to be interpreted as the "remnants" of the morphological effects of the 2010 extreme flood.

Finally, it was noted that almost all the rivers were characterized by reaches displaying a straight channel pattern, even if the latter generally represented a negligible part of the ARL. Generally speaking, straight pattern is relatively rare. However, all the studied rivers are located in a tectonically active area, i.e. Southern Apennines. Thus, the straight pattern could characterize subsequent river reaches, i.e. flowing on tectonic discontinuities (Cartojan *et al.*, 2014).

CONCLUSIONS

This study provided a schematic, relatively simple and rapid approach to identify potential morpho-evolutionary trends at a regional scale that can be easily applied also to rivers located outside Italy. The selected rivers are representative of those of a much wider morphoclimatic scenario, i.e. the Mediterranean area. The main findings of the present study can be summarized as follows:

- Differently from other rivers in Italy (and in the whole Mediterranean area), between the last decades of XIX century and the 1950s the investigated rivers were characterized by a dominant single-thread pattern, while multi-thread patterns characterized only limited portions of the major rivers (i.e., Sele and Calore).
- Some regional trends in channel pattern evolution were recognized, at least from 1950s onwards. They consisted, both in major and minor rivers, in a progressive increase in sinuous channel patterns at the expense of transitional ones. Such changes were likely related to a decrease in sediment supply to the rivers, mainly controlled by LULC changes (mainly afforestation/deforestation) and changes in rainfall regimes and amounts, while sediment extractions from the riverbed and channelization played a minor role. The channel patterns remained substantially unchanged from 1990s onward. Any case, further analyses are needed to investigate in detail the effect of controlling factors on channel pattern change or stability.
- The study highlighted the paramount importance of using materials of adequate scale in channel pattern analysis to avoid erroneous interpretations, especially for minor rivers. Maps at least at 1:25,000 scale or more detailed should be used for minor rivers and results should be always carefully compared with literature data.
- The research highlighted some open and critical problems about the definition and the discussion of the oldest morphoevolutionary phases (i.e., from the end of XIX century to 1950s) that are, however, difficult to solve due to the lack of data, i.e. detailed topographic materials, LULC data and hydrometric data. Any case, the channel pattern analysis and evolution of other uninvestigated rivers of Southern Italy is planned, with the aim of better define a regional trend in future researches.
- The classification and morphological characterization of rivers, particularly in terms of channel planform, are increasingly acknowledged as fundamental components in interdisciplinary approaches aimed at understanding fluvial processes and informing effective and sustainable river management strategies. This perspective aligns with recent European frameworks, such as the Water Framework Directive and the Floods Directive, which promote an integrated approach to river as-

sessment and management based on geomorphological, ecological, and hydrological processes. Within this context, historical analyses of channel patterns and, more generally, planform dynamics, such as those developed in this study, provide critical insights into the morphological trajectories of river systems and serve as a valuable support for designing process-based and context-specific river restoration and management actions.

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REFERENCES

Alilla R., Capitanio F., De Natale F., Parisse B., Pontrandolfi A., 2024. *An agro-meteorological hazard analysis for risk management in a Mediterranean area: a case study in Southern Italy (Campania Region).* Theoretical and Applied Climatology, 155, 4289-4306. https://doi.org/10.1007/s00704-024-04878-x

Bandini A., 1931. *Tipi Pluviometrici Dominanti Sulle Regioni Italiane.* Il Servizio Idrografico Italiano, 111-118. Ministero dei Lavori Pubblici, Roma.

Bevilacqua P., 2005. *Breve storia dell'Italia Meridionale.* Donzelli Editore, Roma, 236 pp.

Blum A., Broers H.-P., Grath J. *et al.*, 2009. *Guidance on Groundwater Status and Trend Assessment.* Guidance Document No. 18: Common Implementation Strategy for the Water Framework Directive (2000/60/EC), Technical Report 2009-026. Office for Official Publications of the European Communities, Luxembourg.

Brancaccio L., Cinque A., D'Angelo G., Russo F., Santangelo N., Sgrosso I., 1987. *Evoluzione tettonica e geomorfologica della Piana del Sele (Campania, Appennino meridionale).* Geografia Fisica e Dinamica Quaternaria, 10, 47-55.

Brice J.C.,1975. *Air photo interpretation of the form and behaviour of alluvial rivers.* Final report to the US Army Research Office.

Brierley G.J., Fryirs K.A., 2005. *Geomorphology and River Management: Applications of the River Styles Framework.* Blackwell, Oxford.

Brierley G.J., Fryirs K.A. (Eds), 2008. *River Futures: An Integrative Scientific Approach to River Repair.* Society for Ecological Restoration International, Island Press, Washington D.C., 304 pp.

Brunetti M., Maugeri M., Monti F., Nanni T., 2004. *Changes in daily precipitation frequency and distribution in Italy over the last 120 years.* Journal of Geophysical Research – Atmospheres, 109, D05102. https://doi.org/10.1029/2003JD004296.

Brunetti M., Maugeri M., Nanni T., 2000. *Variations of temperature and precipitation in Italy from 1866 to 1995.* Theoretical and Applied Climatology, 65, 165-174. https://doi.org/10.1007/s007040070041

Cartojan E., Magliulo P., Massa B., Valente A., 2014. *Morphotectonic features of the Tammaro River basin, Southern Apennines, Italy.* Rendiconti Lincei, 25 (Suppl. 2), 217-229. https://doi.org/10.1007/s12210-014-0349-2

Church M., 1992. *Channel morphology and typology.* In: Calow P., Petts G.G. (Eds), The Rivers Handbook: Hydrological and Ecological Principles, 126-143. Blackwell, Oxford.

Church M., 2002. *Geomorphic thresholds in riverine landscapes.* Freshwater Biology, 47, 541-557. https://doi.org/10.1046/j.1365-2427.2002.00919.x

Church M., 2006. *Bed material transport and the morphology of alluvial rivers.* Annual Review of Earth and Planetary Sciences, 34, 325-354. https://doi.org/10.1146/annurev.earth.33.092203.122721

Cinque A., Guida F., Russo F., Santangelo N., 1988. *Dati cronologici e stratigrafici su alcuni depositi continentali della Piana del Sele (Campania): I «Conglomerati di Eboli».* Geografia Fisica e Dinamica Quaternaria, 11, 39-44.

de Musso N.M., Capolongo D., Caldara M., Surian N., Pennetta L., 2020. *Channel changes and controlling factors over the past 150 years in the Basento River (Southern Italy).* Water 12, 307. https://doi.org/10.3390/w12010307.

De Vita P., Allocca V., Manna F., Fabbrocino S., 2012. *Coupled decadal variability of the North Atlantic Oscillation, regional rainfall and karst spring discharges in the Campania region (Southern Italy).* Hydrology and Earth System Sciences, 16, 1389-1399. https://doi.org/10.5194/hess-16-1389-2012

Desloges J.R., Church M.A., 1989. *Wandering gravel-bed rivers.* The Canadian Geographer, 33, 360-364. https://doi.org/10.1111/j.1541-0064.1989.tb00922.x

Diodato N., 2005. *The influence of topographic co-variables on the spatial variability of precipitation over small regions of complex terrain.* International Journal of Climatology, 25, 351-363. https://doi.org/10.1002/joc.1131

Diodato N., 2007. *Climatic fluctuations in southern Italy since the 17th century: reconstruction with precipitation records at Benevento.* Climatic Change, 80, 411-431. https://doi.org/10.1007/s10584-006-9119-1.

Diodato N., Fagnano M., Alberico I., Chirico G.B., 2011. *Mapping soil erodibility from composed data set in Sele River Basin, Italy.* Natural Hazards, 58, 445-457. https://doi.org/10.1007/s11069-010-9679-2

D' Ippolito A., Ferrari E., Iovino F., Nicolaci A., Veltri A., 2013. *Reforestation and land use change in a drainage basin of southern Italy.* iForest – Biogeosciences and Forestry, 6, 175-182. https://doi.org/10.3832/ifor0741-006

Downs P.W., Gregory K.J., 2004. *River Channel Management. Towards Sustainable Catchment Hydrosystems.* Arnold, London, 395 pp.

Ellis E.C., Goldewijk K.K., Siebert S., Lightman D., Ramankutty N., 2010. *Anthropogenic transformation of the biomes, 1700 to 2000.* Global Ecology and Biogeography, 19, 589-606. https://doi.org/10.1111/j.1466-8238.2010.00540.x

Fuller I.C., Reid H.E., Brierley G.J., 2013. *Methods in Geomorphology: Investigating River Channel Form.* In: Shroder J.F. (Ed.), Treatise on Geomorphology, Volume 14, 73-91. Academic Press, San Diego. https://doi.org/10.1016/B978-0-12-374739-6.00374-2

Gilvear D.J., 1999. *Fluvial geomorphology and river engineering: future roles utilizing a fluvial hydrosystems framework.* Geomorphology, 31, 229-245. https://doi.org/10.1016/S0169555X(99)000860

Grant G.E., 2012. *The geomorphic response of gravel-bed rivers to dams: perspectives and prospects.* In: Church, M., Pascale, M.B., Roy, A.G. (Eds), Gravel-bed Rivers: Processes Tools Environments 2012. John Wiley & Sons Ltd., 165-181 pp.

Heitmuller F.T., 2014. *Channel adjustments to historical disturbances along the lower Brazos and Sabine Rivers, south-central USA.* Geomorphology, 204, 382-398. https://doi.org/10.1016/j.geomorph.2013.08.020

Henderson F.M., 1963. *Stability of alluvial channels.* Transactions of the American Society of Civil Engineers, 128, 657-720. https://doi.org/10.1061/TACEAT.0008682

Hooke J.M., 2006. *Human impacts on fluvial systems in the Mediterranean region.* Geomorphology, 79, 311-335. https://doi.org/10.1016/j.geomorph.2006.06.036

Knighton A.D., Nanson G.C., 1993. *Anastomosis and the continuum of channel pattern.* Earth Surface Processes and Landforms, 18, 613-625. https://doi.org/10.1002/esp.3290180705

Kondolf G.M., Montgomery D.R., Piégay H., Schmitt L., 2003. *Geomorphic classification of rivers and streams.* In: Kondolf G.M., Piégay H. (Eds), Tools in Fluvial Geomorphology, 171-204. Wiley, Chichester.

Kondolf G.M., Piégay H., Schmitt L., Montgomery D.R., 2016. *Geomorphic classification of rivers and streams.* In: Kondolf G.M., Piégay H. (Eds), Tools in Fluvial Geomorphology, 133-158. Wiley, Chichester. https://doi.org/10.1002/9781118648551.ch7

Leopold L.B., Wolman M.G., 1957. *River Channel Patterns - Braided, Meandering, and Straight.* United States Geological Survey Professional Paper 282 (B), Washington, D.C., 39-85. https://doi.org/10.3133/pp282B

Liébault F., Piégay H., 2002. *Causes of twentieth century channel narrowing in mountain and Piedmont rivers of southeastern France.* Earth Surface Processes and Landforms, 27 (4), 425-444. https://doi.org/10.1002/esp.328

Longobardi A., Villani P., 2010. *Trend analysis of annual and seasonal rainfall time series in the Mediterranean area.* International Journal of Climatology, 30, 1538-1546. https://doi.org/10.1002/joc.2001

Longobardi A., Villani P., Guida D., Cuomo A., 2016. *Hydro geo-chemical streamflow analysis as a support for digital hydrograph filtering in a small, rainfall dominated, sandstone watershed.* Journal of Hydrology, 539. https://doi.org/10.1016/j.jhydrol.2016.05.028.

Magliulo P., 2005. *Quaternary deposits and geomorphological evolution of the Telesina Valley (Southern Apennines).* Geografia Fisica e Dinamica Quaternaria, 28, 125-146.

Magliulo P., Bozzi F., Leone G., Fiorillo F., Leone N., Russo F., Valente A., 2021a. *Channel adjustments over 140 years in response to extreme floods and land-use change, Tammaro River, Southern Italy.* Geomorphology, 383, 107715. https://doi.org/10.1016/j.geomorph.2021.107715

Magliulo P., Cusano A., Russo F., 2021b. *Land-use changes in the Sele River Basin landscape (Southern Italy) between 1960 and 2012: comparisons and implications for soil erosion assessment.* Geographies, 1, 315-332. https://doi.org/10.3390/geographies1030017

Magliulo P., Cusano A., Sessa S., Beatrice M., Russo F., 2022. *Multidecadal land-use changes and implications on soil protection in the Calore River Basin landscape (Southern Italy).* Geosciences, 12, 156. https://doi.org/10.3390/geosciences12040156

Magliulo P., Valente A., Cartojan E., 2013. *Recent geomorphological changes of the middle and lower Calore River (Campania, Southern Italy).* Environmental Earth Sciences, 70, 2785-2805. https://doi.org/10.1007/s12665-013-2337-8

Makaske B., 2001. *Anastomosing rivers: a review of their classification, origin and sedimentary products.* Earth-Science Reviews, 53, 149-196. https://doi.org/10.1016/S0012-8252(00)00038-6

Malavoi J.R., Bravard J.P., 2010. *Éléments d'hydromorphologie fluviale.* ONEMA, Baume-les-Dames, 224 pp.

Mandarino A., 2022. *Morphological adjustments of the lower Orba River (NW Italy) since the mid-nineteenth century.* Geomorphology, 410, 108280. https://doi.org/10.1016/j.geomorph.2022.108280

Mandarino A., Pepe G., Maerker M., Cevasco A., Brandolini P., 2020. *Short-term GIS analysis for the assessment of the recent active-channel planform adjustments in a widening, highly altered river: the Scrivia River, Italy.* Water, 12, 514. https://doi.org/10.3390/w12020514

Martucci F., Angelone F., D'Onofrio E.G., Russo F., Magliulo P., 2025. *Short-term geomorphological changes of the Sabato River (Southern Italy).* Geosciences 2025, 15 (8), 308. https://doi.org/10.3390/geosciences15080308

Mazzoleni S., Di Pasquale G., Mulligan M., Di Martino P., Rego F., 2004. *Recent Dynamics of Mediterranean Vegetation Landscape.* Wiley, Chichester, 306 pp. https://doi.org/10.1002/0470093714

Meitzen K.M., Doyle M.W., Thoms M.C., Burns C.E., 2013. *Geomorphology within the interdisciplinary science of environmental flows.* Geomorphology, 200, 143-154. https://doi.org/10.1016/j.geomorph.2013.03.01

Migliozzi A., Cona F., di Gennaro A., Mingo A., Saracino A., Mazzoleni S., 2010. *Land-use management and changes in Campania Region (Southern Italy): examples from ten regional State Forests.* In: Azevedo J.C., Feliciano M., Castro J., Pinto M.A. (Eds), Proceedings of the IUFRO Landscape Ecology Working Group International Conference, Bragança (Portugal), 21-27 September 2010. Instituto Politécnico de Bragança,

Mollard J.D., 1973. *Air photo interpretation of fluvial features.* In: Fluvial Processes and Sedimentation. Proceedings of Canadian Hydrology Symposium, National Research Council of Canada, Ottawa, 341-380.

Mostardini F., Merlini S., 1986. *Appennino centro meridionale. Sezioni geologiche e proposta di modello strutturale.* Memorie della Società Geologica Italiana, 35, 177-202.

Nanson G.C., 2013. *Anabranching and anastomosing rivers.* In: Shroder J.F. (Ed.), Treatise on Geomorphology, Volume 9, 330-345, Academic Press. https://doi.org/10.1016/B978-0-12-374739-6.00244-X

Nanson G.C., Knighton A.D., 1996. *Anabranching rivers: their cause, character and classification.* Earth Surface Processes and Landforms, 21, 217-239. https://doi.org/10.1002/(SICI)1096-9837(199603)21:3<217::AID-ESP611>3.0.CO;2-U

Nardi L., Rinaldi M, 2015. *Spatio-temporal patterns of channel changes in response to a major flood event: the case of the Magra River (central-northern Italy).* Earth Surface Processes and Landforms, 40, 326-339. https://doi.org/10.1002/esp.3636

Osterkamp W.R., 1978. *Gradient, discharge, and particle-size relations of alluvial channels in Kansas, with observations on braiding.* American Journal of Science, 278, 1253-1268.

Polemio M., Casarano D., 2004. *Rainfall and drought in southern Italy (1821-2001).* The Basis of Civilization - Water Science IAHS Publications, 286, 217-227.

Polemio M., Casarano D., 2008. *Climate change, drought and groundwater availability in southern Italy.* Geological Society Special Publication, 288, 39-51. https://doi.org/10.1144/SP288.4.

Righini M., Surian N., Wohl E., Marchi L., Comiti F., Amponsah W., Borga M., 2017. *Geomorphic response to an extreme flood in two Mediterranean rivers (northeastern Sardinia, Italy): analysis of controlling factors.* Geomorphology, 290, 184-199. http://dx.doi.org/10.1016/j.geomorph.2017.04.01

Rinaldi M., 2003. *Recent channel adjustments in alluvial rivers of Tuscany, Central Italy.* Earth Surface Processes and Landforms, 28, 587-608. https://doi.org/10.1002/esp.464

Rinaldi M., Gurnell A., González del Tánago M., Bussettini M., Hendriks D., 2015. *Classification of river morphology and hydrology to support management and restoration.* Aquatic Sciences, 78. https://doi.org/10.1007/s00027-015-0438-z

Rinaldi M., Rodolfi G., 1995. *Evoluzione olocenica della pianura alluvionale e dell'alveo del Fiume Sieve nel Mugello (Toscana).* Geografia Fisica e Dinamica Quaternaria, 18, 57-75.

Rinaldi M., Surian N., Comiti F., Bussettini M., 2015. *A methodological framework for hydromorphological assessment, analysis and monitoring (IDRAIM) aimed at promoting integrated river management.* Geomorphology, 251, 122-136. https://doi.org/10.1016/j.geomorph.2015.05.010

Rinaldi M., Surian N., Comiti F., Bussettini M., 2016. *IDRAIM – Sistema di valutazione idromorfologica, analisi e monitoraggio dei corsi d'acqua. Versione aggiornata 2016.* ISPRA – Manuali e Linee Guida, 131, Roma, 400 pp.

Rosgen D.L., 1994. *A classification of natural rivers.* Catena, Vol. 22, 169-199. Elsevier Science, Amsterdam. https://doi.org/10.1016/0341-8162(94)90001-9

Rust B.R., 1978. *A classification of alluvial channel systems.* In: Miall A.D. (Ed.), Fluvial Sedimentology, Canadian Society of Petroleum Geologists Memoir 5, 187-198.

Schumm S.A., 1963. *A Tentative Classification of Alluvial River Channels.* United States Geological Survey Circular 477, Washington, D.C.

Schumm S.A., 1977. *The Fluvial System.* John Wiley & Sons, New York. https://doi.org/10.1002/esp.3290040121

Schumm S.A., 1985. *Patterns of alluvial rivers.* Annual Review of Earth and Planetary Sciences, 13, 5-27. https://doi.org/10.1146/annurev.ea.13.050185.000253

Scorpio V., Aucelli P.P.C., Giano S., Pisano L., Robustelli G., Rosskopf C.M., Schiattarella M., 2015. *River channel adjustment in Southern Italy over the past 150 years and implications for channel recovery.* Geomorphology, 251, 77-90. https://doi.org/10.1016/j.geomorph.2015.07.008

Scorpio V., Comiti F., Liébault F., Piegay H., Rinaldi M., Surian N., 2024. *Channel changes over the last 200 years: A meta data analysis on European rivers.* Earth Surface Processes and Landforms, 49, 2651-2676. https://doi.org/10.1002/esp.5848

Scorpio V., Piegay H., 2021. *Is afforestation a driver of change in Italian rivers within the Anthropocene era?* Catena, 198, 105031. https://doi.org/10.1016/j.catena.2020.105031

Scorpio V., Rosskopf C.M, 2016. *Channel adjustments in a Mediterranean river over the last 150 years in the context of anthropic and natural controls.* Geomorphology, 275, 90-104. https://doi.org/10.1016/j.geomorph.2016.09.017

Sear D.A., Newson M.D., Brookes A., 1995. *Sediment related river maintenance: the role of fluvial geomorphology.* Earth Surface Processes and Landforms, 20, 629-647. https://doi.org/10.1002/esp.3290200706

Slama C.C., Henriksen S.W., Theurer C., 1980. *Manual of Photogrammetry.* In: American Society of Photogrammetry, 4th edition. EEUU, Falls Church, VA, USA, p. 1056.

Surian N., Righini M., Lucía A., Nardi L. Amponsah W., Benvenuti M., Borga M., Cavalli M., Comiti F., Marchi L. Rinaldi M., Viero A., 2016. *Channel response to extreme floods: Insights on controlling factors from six mountain rivers in northern Apennines, Italy.* Geomorphology, 272, 78-91. http://dx.doi.org/10.1016/j.geomorph.2016.02.002.

Surian N., Rinaldi M., 2003. *Morphological response to river engineering and management in alluvial channels in Italy.* Geomorphology, 50, 307-326. https://doi.org/10.1016/S0169555X(02)00219-2.

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

Tadaki M., Brierley G., Cullum C., 2014. *River classification: theory, practice, politics.* WIREs Water, 1, 349-367. https://doi.org/10.1002/wat2.1026

Taylor J.R., 1982. *An Introduction to Error Analysis.* University Science Books, Sausalito, CA, 327 pp.

Thorne C.R.,1997. *Channel types and morphological classification.* In: Thorne, C.R., Hey, R.D., Newson, M.D. (Eds), Applied Fluvial Geomorphology for River Engineering and Management, 175-222. Wiley, Chichester.

Tichy F., 1962. *Die Wälder der Basilicata und die Entwaldung im 19. Jahrhundert. Vorgänge, Ursachen und Folgen.* Keysersche Verlagsbuchhandlung, Heidelberg-München, 175 pp.

Winterbottom S.J., 2000. *Medium and short-term channel planform changes on the Rivers Tay and Tummel, Scotland.* Geomorphology, 34, 195-208. https://doi.org/10.1016/S0169-555X(00)00007-6

Yao Z., Xiao J., Ta W., Jia X., 2012. *Planform channel dynamics along the Ningxia–Inner Mongolia reaches of the Yellow River from 1958 to 2008: Analysis using Landsat images and topographic maps.* Environmental Earth Sciences, 70, 97-106. https://doi.org/10.1007/s12665-012-2106-0

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