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# Late Holocene history of the Moldova River Valley, Romania

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ABSTRACT

This paper describes the results of geomorphological, sedimentological and $^{14}C$ analyses of Late Holocene fluvial sequences in the Moldova River Valley of Romania. This river originates from the Carpathians mountains and is known for the extent of its large floodplain and sediment thickness. Between the Molid and Timişeşti localities (river length: 86 km), numerous large fossil trunks of oak, poplar and beech trees are exposed in the riverbanks. Six wood samples were selected for radiocarbon absolute dating (conventional method), and their ages ranged from 410 to 3200 cal yrs. BP. The thickness of the alluvial sediments above the sampled fossil trunks varied between 2 and 3 m, and these sediments predominantly consisted of coarse gravel materials that had similar granulometry to sediments that were present in the modern riverbed. Additionally, in the same investigated areas, successive floodplain cross-sections were constructed based on more than 20 hydrogeological boreholes. For each cross section, all data were used to calculate the local values of bed loads, and these values were compared to the absolute ages of the fossil trunks and were in the range of 300 $m^3$/m and 5500 $m^3$/m. Based on the calculated values, during the last 780 years, the floodplain sedimentation rates were estimated to be in the range of 0.4 $m^3$/year at the Molid Section, which was located in the mountainous area of the valley and 44 km downstream from the river headwater, and during the last 410 years, the sedimentation rate at the Praxia Section, which was located 125 km downstream from the river headwater, was 13.3 $m^3$/year. In the past 100 years, the fluvial processes along the Moldova River were dominated by a narrowing (by an average of 76%) and an incision (up to 2.5 m), and a channel metamorphosis from braided to wandering was reported. These results are discussed in the context of Late Holocene regional and local palaeoclimatic reconstructions as well as that of human interventions.


## 1. Introduction

The Holocene evolution of the Moldova Valley, especially in the piedmont area that developed at the region that contacted the Eastern Carpathians, represents a subject of much interest for Romanian geomorphologists (Amăriucăi, 2000; Donisă, 1968; Donisă and Martiniuc, 1980; Ichim, 1979; Ichim et al., 1995; Rădoane and Rădoane, 1976) because of the large extent of the floodplain and the thickness of the alluvial sediments between Gura Humorului and Roman (Fig. 1). Hydrogeological investigations in this area, which are based on approximately 200 boreholes (Cădere et al., 1967), have indicated the existence of some large, coarse-grained alluvial fans that are greater than 18 m thick. Amăriucăi (2000) identified the locations of three of these alluvial fans: the apex of the first is located at Gura Humorului-Păltinoasa, and its distal area is located after the confluence of the Moldova River with the Râşca River; the apex of the second is located in the vicinity of Drăgăneşti, its maximum development is located at Timişeşti, and its final remnants are located at Tupilaţi; and the apex of the third is located at Tupilaţi and is extended toward Roman (Figs. 1 and 6). Until recently, the ages of these alluvial fans, the history of the floodplain and the reworking rates of the alluvial sediments along the active channel have not been established.

It is known that fluvial materials conserve only fragmentary information on spatial and temporal channel behaviour. Furthermore, processes such as lateral migration and incision are responsible for the intersection and erosion of older sedimentary structures (Lewin and Macklin, 2003; Lewin et al., 2005; Macklin et al., 2006).

Currently, only two palaeohydrological studies on Romanian fluvial system behaviours during the Late glacial-Holocene have been performed. Howard et al. (2004) have constructed a model of the history of the Teleorman River, which is located in southern Romania, that is based on granulometric observations and the absolute chronology of alluvial sediments (*e.g.*, fluvial terraces, floodplain and alluvial fans) from approximately 19 boreholes that have maximum thicknesses of 3 m and are located in a 5 km valley bottom reach. The remains of fossil trunks were intersected in one borehole at a depth of 2 m. The two earliest, most extensive terraces (T1 and T2) were dissected by large, high-amplitude palaeochannels that were functional at

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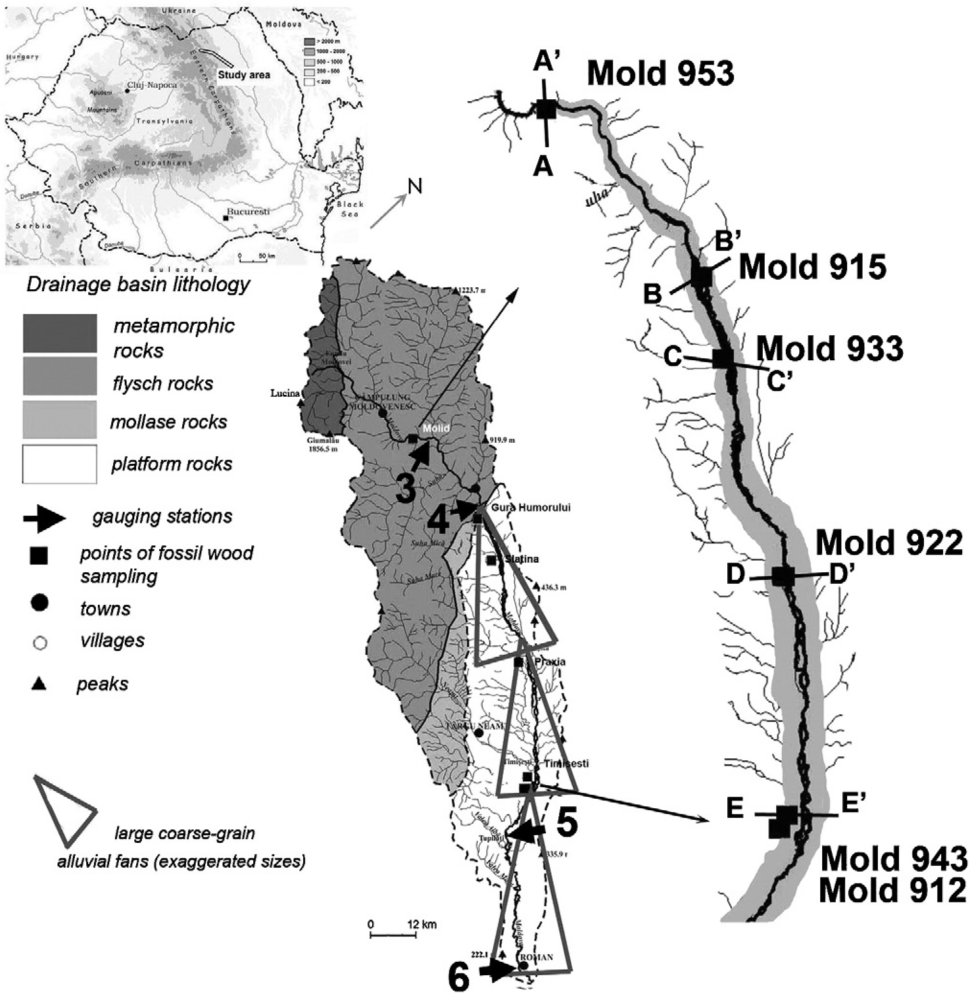


**Fig. 1.** Location of the study area: the Moldova River drainage basin (left); Moldova River floodplain and wood sample position (right). Sample numbers are given in Table 3.

approximately 12,800 yr. BP and were comparable with the large, Late glacial, meandering palaeochannels that were reported elsewhere in northern and central Europe. During the Holocene, changes in river activity and accelerated sedimentation are believed to have occurred approximately 4900–4800 yrs. BP, 4000–3800 yrs. BP, 3300–2800 yrs. BP, 1000 yrs. BP and within the past 200 yrs. To reconstruct the Holocene evolution of the Someşu Mic River (in NW Romania), Perşoiu (2010) analysed the spatial and vertical distributions of archaeological vestiges that were reported in the floodplain perimeter and of 21 natural or artificial openings that were located along the river or in the floodplain cross-section (*i.e.,* alluvial architecture, optically stimulated luminescence (OSL) and $^{14}C$ absolute dating). Unlike the Teleorman River, a braided channel of the Someşu Mic River was functional during the LGM-Early Holocene, and the channel changed to incised, sinuous/meandering at least 1000 years after the start of the Holocene. The causes for this atypical behaviour could include a slightly greater general slope downstream of a 400 m high knick-point or unknown drainage basin characteristics, either of which could affect the sensitivity of the


**Fig. 2.** *Quercus robur* sample with well-preserved growth rings. The sample prevailed from a fossil trunk with a 1 m diameter that was found in the Moldova River bank downstream from the Timişeşti Bridge.

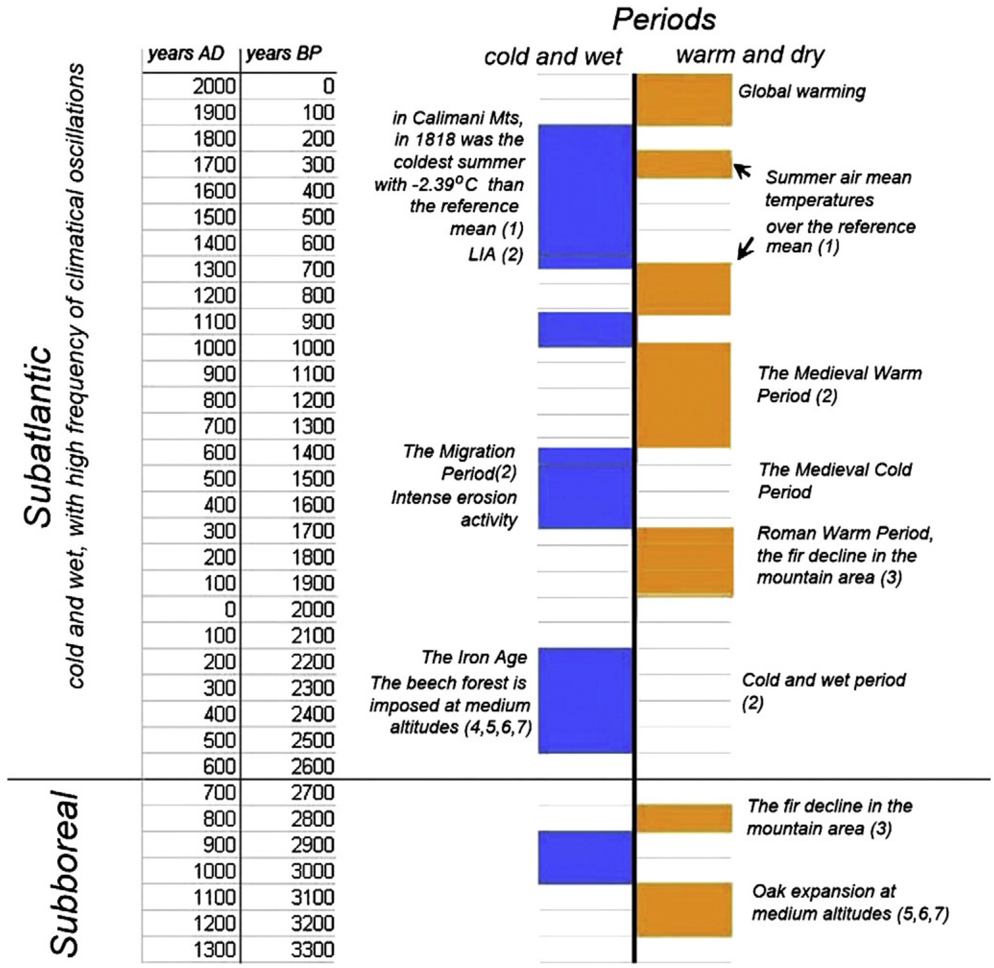


**Fig. 3.** General climatic characteristics in Mid- and Late-Holocene, as reflected by palaeoclimatic and palaeoenvironmental reconstructions in the NW, N and NE areas of Romania and Europe (1. Popa and Kern, 2009; 2, Lamb, 1995; 3, Feurdean and Willis, 2008; 4, Bodnariuc et al., 2002; 5, Feurdean et al., 2007; 6, Feurdean, 2005; 7, Bjorkman et al., 2002; Feurdean et al., 2007).

fluvial system to climate changes. Local or regional planform channel changes (*i.e.*, isolated flood events or more humid periods of time) were attributed to moments such as in 9300 yrs. BP, 8200 yrs. BP, 4700 yrs. BP, 2500 yrs. BP and during the Dark Ages Cold Periods and Little Ice Age.

During recent geomorphological field investigations along the Moldova River, numerous fossil trunks that were buried within the sedimentary structures of riverbanks were discovered. Fossil trunks are frequently used in palaeohydrological studies, including those that utilise quantitative measures of spatial and temporal channel planform dynamics (*e.g.*, Lewin and Macklin, 2003; MacVicar et al., 2009, Perşoiu, 2010; Starkel et al., 2006). Therefore, our interest was in establishing how the ages of fossilised tree trunks could help to reconstruct the history of the Moldova River channel and of floodplain processes and their rates of change. In accordance with Howard et al. (2009), we are aware that a relative, small number of absolute ages, as in this case, are an impediment to reconstructing landscape chronology. To counterbalance this shortcoming, we adopted an appropriate reserve in interpreting our results and added helpful information on the recent history of the river (*i.e.*, spatial and temporal channel planform and vertical behaviour).

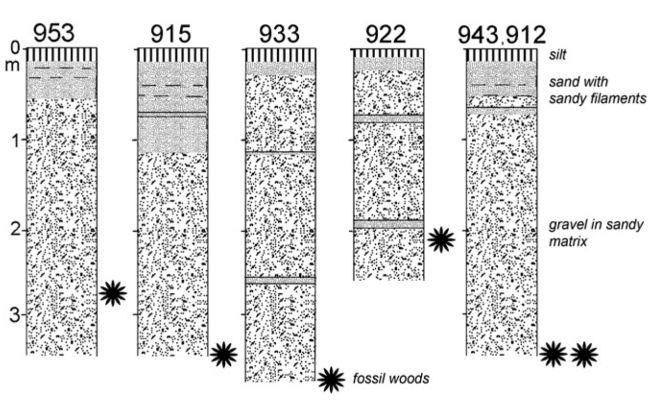


**Fig. 4.** The sedimentary context of the collected fossil trunks. The numbers of the columns correspond to the site numbers in Fig. 1.

The objectives of our study are the following: i) to evaluate the Late Holocene palaeoenvironmental conditions, which were based on previous studies in N and NE Romania in the perimeter of the Moldova drainage basin ii) to highlight moments/phases of the Late Holocene history of the Moldova River and their causes and iii) to compare these results with those that were obtained along other Romanian and European rivers.

## 2. Study area

The Moldova River is a 213 km long, right-bank tributary of the Siret River, and the confluence of these rivers occurs near Roman (Fig. 1). The most important tributaries of the Moldova River are the Moldoviţa, Suha Mare, Suha Mică, Râşca, Ozana and Topoliţa Rivers. Table 1 presents the main characteristics, which were derived from 5 gauging stations of the drainage basin and Moldova River (Fig. 1).

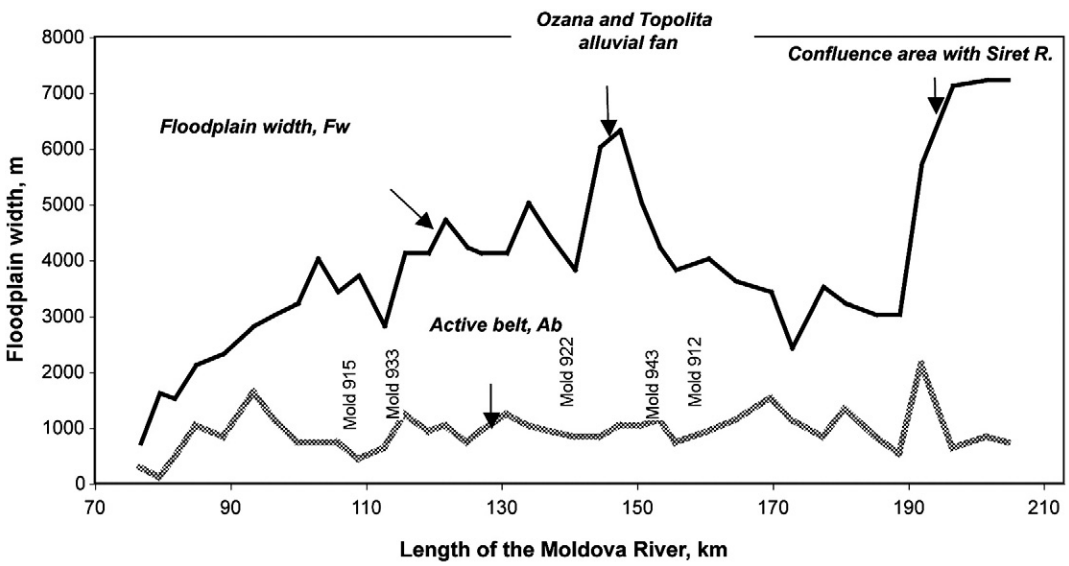


**Fig. 5.** Distribution of floodplain and active belt width along the Moldova valley (extra-Carpathian area) (Gura Humorului — confluence of the R. Siret). The positions of fossil trees that were sampled for dating are indicated in the active belt.

The area of the drainage basin is 4299 km2 and is superimposed on four lithostratigraphic units: the crystalline Mesozoic unit (which consists of crystalline schists, quartz, and crystalline limestones); the flysch unit (which consists of sandstones, limestones, conglomerates, marls, and shales); the molasse unit (which consists of marls, clays, gravel and sands, and salt); and the platform unit (which consists of sands, gravel, and loams) (Fig. 1). The Moldova River crosses the first two units diagonally between Lucina Peak (1588 m) and Gura Humorului (480 m), and downstream from Gura Humorului to Roman (180 m), the river flows into the extra-Carpathian region, where the last two units are present. Consequently, metamorphic rocks, which are the most resistant to erosion, are located in the upper area of the drainage basin; sedimentary rocks, such as sandstones, limestones, and marls, are found in the median area of the basin; and the most friable materials are present in the inferior part of the basin. The petrographic diversity of the perimeter of the drainage basin and the high, reworking rates of the sediments in this area are the main causes for the large extent of the extra-Carpathian floodplain of the Moldova River, which is an important area for exploitable mineral aggregates.

The high rate of alluviation in this "true piedmont plain" (Martiniuc, 1956) has had a decisive role on the spatial and temporal evolution of the fluvial forms and processes, which are expressed in the morphology of the alluvial terraces that are present at the bottom of the valley, the morphology of the active channel, the spatial distribution of bars and secondary channels and lateral migration rates.

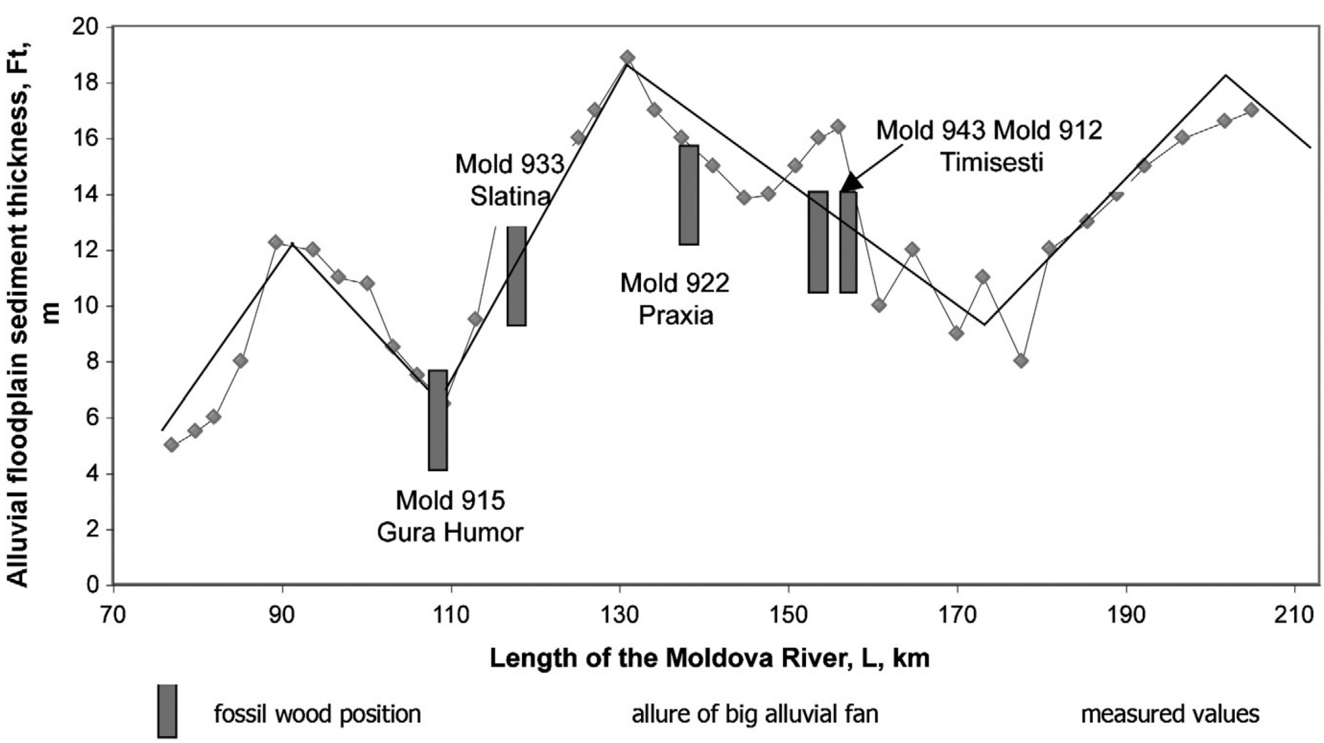


**Fig. 6.** Distribution of the thickness of the alluvial sediment along the Moldova valley (extra-Carpathian area) (Gura Humorului — confluence of the R. Siret).

**Table 1**
Physical characteristics of the Moldova River and its drainage basin from gauging stations.

| Hydrometric station | Drainage basin surface, A ($km^2$) | Elevation, H (m) | River lenght, L (km) | Mean annual discharge, Q ($m^3/s$) | Mean annual suspended load, Qs (kg/s) |
|---|---|---|---|---|---|
| Fundu Moldovei | 294 | 739 | 45 | 3.57 | |
| Prisaca Dornei | 567 | 657 | 94 | 7.30 | 2.44 |
| Gura Humorului | 1887 | 480 | 120 | 17.04 | |
| Tupilaţi | 4016 | 236 | 157 | 32.84 | 35.30 |
| Roman | 4299 | 180 | 213 | 35.27 | 16.10 |

Measurements of the flow regime, granulometric determinations of riverbed materials and cartographic maps were analysed to quantify the planform and vertical channel dynamics of the Moldova River at present-day and historical scales. In quasi-natural conditions (*e.g.*, reference moment: 1910), the river had a braided, coarse gravel channel (*e.g.*, D50 between 55 mm and 10 mm) and was 750 m wide (*e.g.*, bankfull level) (Chiriloaei, in preparation). Furthermore, its banks were non-cohesive and less than 2 m high (field observations). Successive sets of maps that covered the last 100 years showed a generalised channel narrowing (Chiriloaei, in preparation), and at-a-station measurements from four gauging stations (Figs. 1 and 8) indicated that an incision of the main channel occurred during the previous 50 years and was most likely a consequence of gravel mining and climate variability (Rădoane et al., 2010).

## 3. Methods

Between the autumn of 2009 and the spring of 2010, a series of detailed investigations on the Moldova riverbanks was made with respect to their morphometric characteristics, cohesive/non-cohesive materials, granulometric determinations, and active processes along the river. These investigations, which were based on quantitative measurements of orthophotos and over 200 boreholes that were located in the perimeter of the floodplain, included several variables that described the width of the floodplain, the width of the active channel and the maximum thickness of alluvial deposits.

As mentioned previously, numerous fossil trunks were found to be well-fixed in sediments, and many of these trunks were exposed because of recent channel activity, *i.e.*, lateral erosion and/or a vertical incision or because of stream gravel mining. The sizes (30–40 cm in diameter) of these logs had little variation along the river, but exceptions were recorded at Timişeşti, where the trunks had diameters of 1 m (Fig. 2). For all excavated logs from sedimentary structures, sampling material for dating was taken from the first 20–25 cm of the surface of the trunk after first removing the slightly rotten surface layer. A series of images (Fig. 9) of the collection of wooden materials illustrate this activity. The heights of the fluvial terraces, which were measured according to the low flow level, ranged from 1.5 to 3.5 m.

Based on the position of the trunk species along the river, the morphological indicators of their recent erosion activities, and their riverbank sedimentary structures, six sites were chosen to be representative of all sites (Fig. 1). Detailed observations on the morphology of channel cross-sections, stratigraphic and sedimentological characteristics of the alluvial materials that were exposed in the river banks, $^{14}C$ absolute dating of fossil trunks and, in a single case (Figs. 2, 10), dendrochronological measurements for local palaeoclimatical reconstructions of these sites were made. Additionally, classical dendrochronological procedures (Popa, 2004; Speer, 2010) were used to analyse and measure the width of the annual rings of the tree trunks.

The wood samples were dated using the liquid scintillation counting (LSC) method, which is also known as conventional or radiometric dating (www.carbon14.pl/c14lab/index.htm) by the Radiocarbon Laboratory at the Institute of Physics of the Silesian University of Technology in Gliwice, Poland. $^{14}C$ absolute ages were calibrated with the radiocarbon calibration programme OxCal v4.0.5 (Ramsey, 2007) and using the calibration curve IntCAL09 (Reimer et al., 2009) (Table 3).

## 4. Review of Late Holocene palaeoclimatic and palaeoenvironmental changes in the vicinity of the study area

Currently, no detailed Holocene palaeoclimatical or palaeoenvironmental reconstructions are available for the Moldova catchment area. However, some relevant studies were performed in the vicinity of the area (Table 2), *i.e.*, in the NW and SW areas of Romania (*e.g.*, Constantin et al., 2007; Feurdean et al., 2008, 2011; Perşoiu, 2011; Perşoiu and Pazdur, 2011; Popa and Kern, 2009; Tămaş et al., 2005).

Following the cold and dry Younger Dryas (Feurdean et al., 2008; Tămaş et al., 2005), the climate in NW Romania experienced a rapid but fluctuating warming period. Based on pollen analyses, Feurdean et

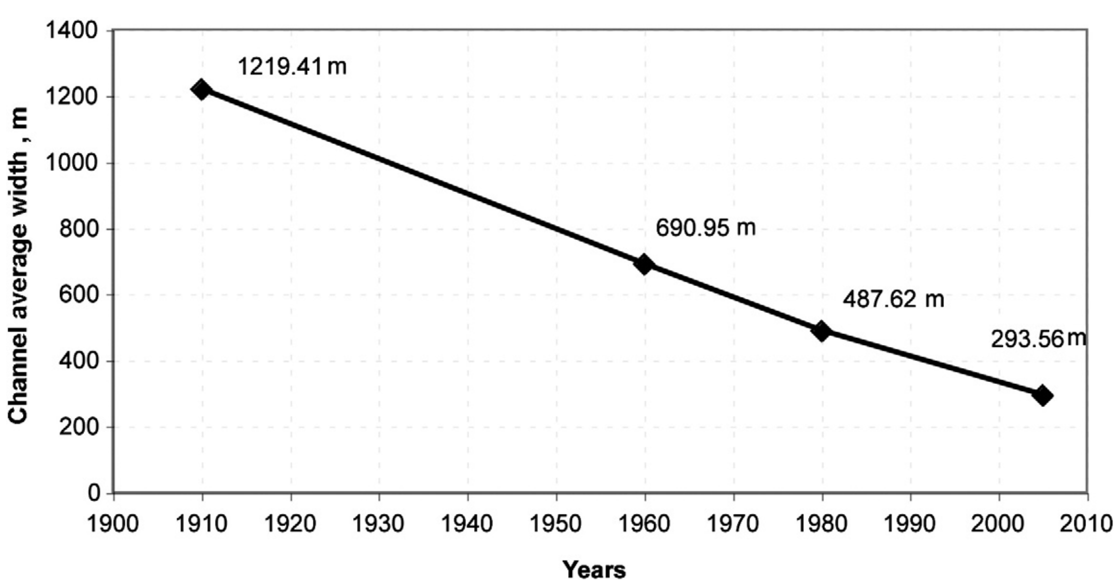


**Fig. 7.** The variation of the c width of the channel in the 1100 sub-reaches of the Moldova River channel between Gura Humorului and Roman (see Fig. 1) over the past 100 yrs. The channel width was narrowed more than four times between the years 1910–2010.

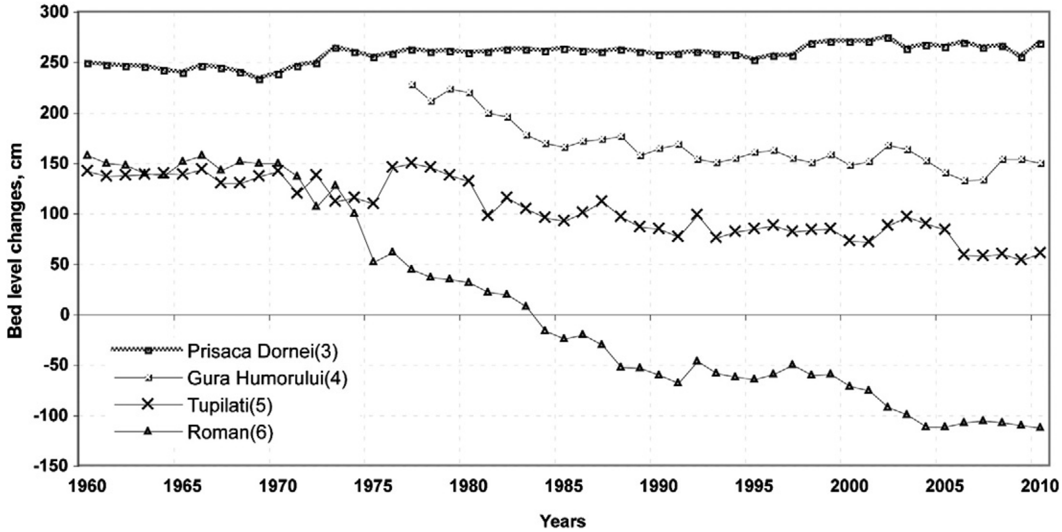


**Fig. 8.** Temporal trends of the bed-level changes at 4 cross-sections of the gauging stations along the Moldova river channel were deducted from the lowest annual stage (see Fig. 1 for the positions of the gauging stations).

al., 2008 calculated an increase of ~7 °C in the MAT (Mean Annual Temperature), which was mostly due to a strong (15 °C) increase of the MTC (Mean Temperature of the Coldest month) and, to a lesser extent, to the increase (2 °C) of the MTW (Mean Temperature of the Warmest month). For the same transitional period, Tămaş et al. (2005) documented an increase in soil wetness and productivity, which lagged behind the temperature increase by ~200 years. The increase in soil wetness could be linked to an increase in the amount of precipitation, which was relatively low (~700 mm/yr) and was most likely due to enhanced continental climatic conditions (Feurdean et al., 2008).

Following this rapid increase in temperature, the summer and mean annual air temperatures in Romania gradually increased through the mid-Holocene and reached a maximum between 6000 and 5500 yrs. BP in NW Romania (Perşoiu, 2011; Tămaş et al., 2005) and between 3000 and 5000 yrs. BP in SW Romania (Constantin et al., 2007). In contrast, using pollen data, Feurdean et al. (2008) found that the maximum Holocene MAT and MTC occurred during the early Holocene (8300–10,000 yrs. BP) and that the maximum MTW occurred approximately 5500 yrs. BP, which was in good agreement with the data from central (Davis et al., 2003) and northern Europe (Seppä and Poska, 2004). Therefore, we believe that summer air temperatures reached a maximum approximately 6500–5000 yrs. BP (*i.e.*, mid-Holocene Climatic Optimum), which followed the insolation curve for July–October at 50°N, but winter air temperatures peaked in the early Holocene and were possibly influenced by the climate of the North Atlantic. Following the (summer) maximum, the MAT and MTW decreased, most notably after 3000 yrs. BP (Constantin et al., 2007; Perşoiu, 2011), and reached a minimum after approximately 500 yrs. BP, during the LIA. However, Feurdean et al. (2008) have found that only the MTW decreased over this period, while winter and annual temperatures increased. It is possible that these divergent findings could be due to the less robust reconstruction of winter temperatures that was based on pollen data.

During the last 2000 years, a series of multi-centennial variations in summer temperature was recorded by analysing stable isotopes (Perşoiu, 2011), tree rings (Popa and Kern, 2009), and pollen data (Perşoiu and Pazdur, 2011, Feurdean et al., 2011). Thus, a somewhat warmer and stable Roman Warm Period (*i.e.*, 2000–1600 yrs. BP) was followed by the colder Dark Ages Cold Period (*i.e.*, 1600–1100 yrs. BP) and the Medieval Warm Period (*i.e.*, 1100–700 yrs. BP), both of which were relatively stable, and then by a colder and unstable Little Ice Age (*i.e.*, 700–100 yrs. BP).

A series of rapid cooling events were recorded and could be superimposed on this general climatic trend (Constantin et al., 2007; Perşoiu, 2011; Tămaş et al., 2005), and the most notable events occurred at 9500, 8200, 7900, 6000, 4200, 3200 and 900 yrs. BP.

Fig. 3 differentiates the cold and humid periods from the warm and dry periods. These periods were deduced from the palaeoenvironmental reconstructions of the surrounding areas of the Moldova drainage basin (Table 2) and covered the previous 3000 years (*i.e.*, Upper Sub-Boreal and Sub-Atlantic).

The mid-altitude expansion of oaks (*Quercus robur*) at 3200–3000 yrs. BP is an indicator of an increase in temperature and of a decrease in the amount of precipitation in the Moldova drainage basin. During the Early Iron Age, the advancement of beech (*Fagus sylvatica*) at mid-altitudes in this area replaced the previous oak forests and is an indicator of a colder and wetter climate. The Warm Roman Period (*i.e.*, ~1800–1600 yrs. BP), which is reflected in the paleoenvironmental reconstructions by fir (*Abies alba*) that declined in mountainous areas (Feurdean and Willis, 2008), was followed by a wetter and colder period (*i.e.*, the Dark Ages Cold Period). Fluvial archives indicate that this period was one of the most intensive periods of erosion activity during the late Holocene (Notebaert and Verstraeten, 2010; Perşoiu, 2010). The Medieval Warm Period (*i.e.*, ~1250–850 yrs. BP) was characterised by an increased MAT (1–2 °C), less precipitation, wet and warm winters and dry summers (Lamb, 1995). Between approximately 650–100 yrs. BP, another cold and wet period was registered and was known in Europe as the Little Ice Age. This period was characterised by lower and highly variable air temperatures and rapid shifts between wet and dry summers.

The nearest palaeoclimatic reconstruction was that of Popa and Kern (2009) in the Călimani Mountains (located some 80 km west of our research area). Based on tree rings in this area, an 800-year-long reconstruction of summer temperatures is available for the years 1163 (787 yrs. BP) to 2005 AD. This reconstruction shows similar temperature fluctuations as other Northern Hemispheric reconstructions; however, it also indicates periods of distinct differences. The fingerprint of the Little Ice Age in the Călimani area is visible between 1370 and 1630 AD (*i.e.*, 580–320 yrs. BP) and in the cold decades of 1820 and 1840 AD; which are followed by a slight warming. The coldest summer in the Călimani area during the past 842 years was in AD 1818, lower by −2.39 °C than the reference mean period (*i.e.*, 1961–1990). During the studied period, the year 2001 exhibited the warmest summer.

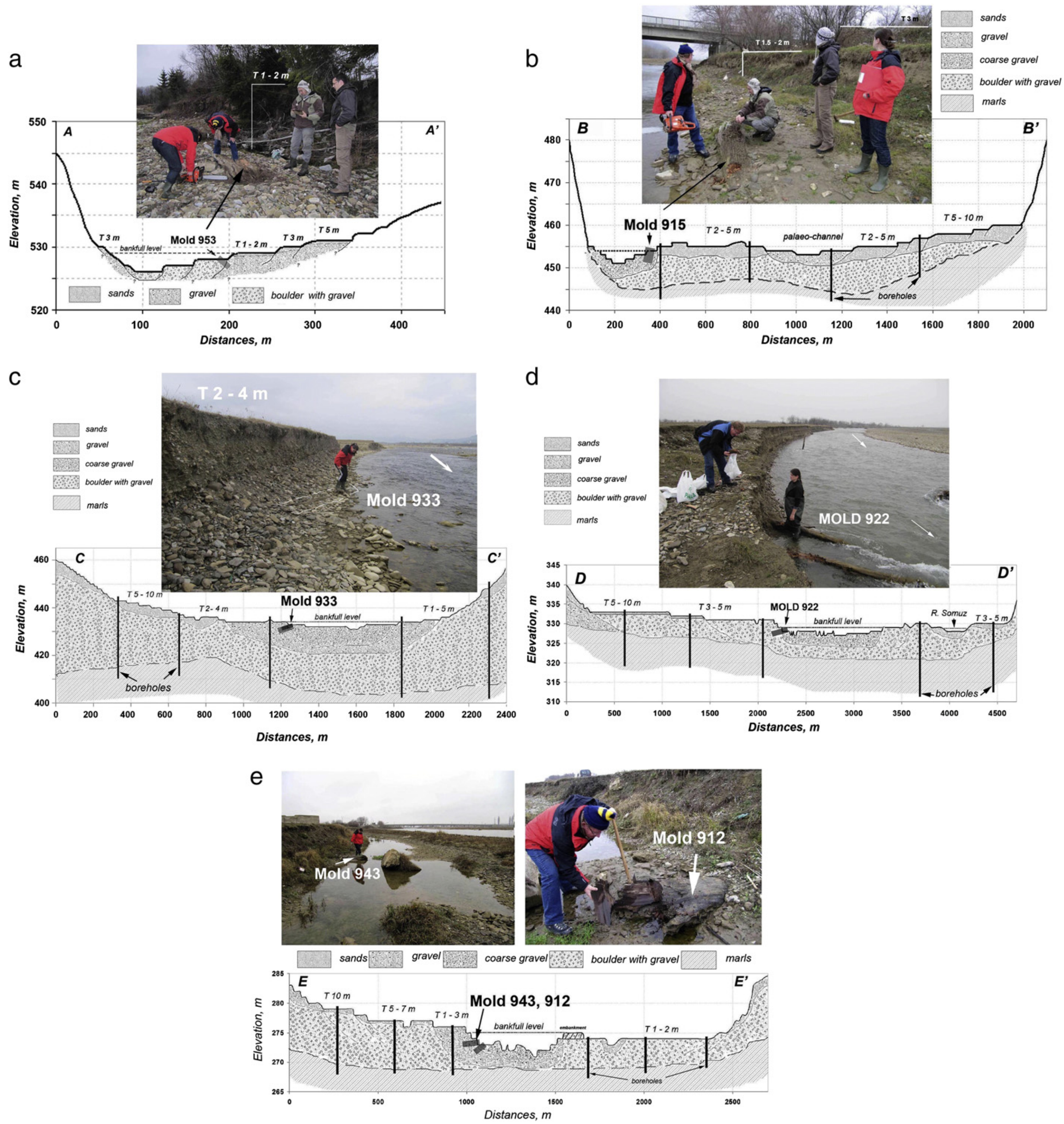


**Fig. 9.** a. Geomorphological profile of the Molid section of the Moldova Valley (Mold 953). Beech trunk was recently uncovered by lateral erosion; b. The geomorphological profile of the Moldova Valley downstream of Gura Humorului. A fossil trunk of approximately 2 m in length and approximately 30 cm in diameter was excavated from a 1.4 m incision of river bed in this sector after the year 1980 (Mold 915); c. Geomorphological profile of the Moldova Valley in the Slatina Section. Lateral erosion after the year 2009 excavated a fossilised poplar trunk of over 2 m in length and approximately 30 cm in diameter (Mold 933); d. Geomorphological profile of the Moldova Valley in the Praxia Section. The floodplain has a width of over 3.5 km, and the river is divided into 7 branches. Lateral erosion excavated a great number of logs that were under 30 cm in diameter (Mold 922); and e. Geomorphological profile of the Moldova Valley in the Timişeşti Section. Oak trunks were excavated from the front of the 1–3 m fluvial terrace (Mold 943, 912).

## 5. Results

### 5.1. *Morphology and recent fluvial processes of the Moldova River floodplain*

The width of the floodplain increases to nearly 7 km after emerging from the mountainous area because of the increased discharge that is supplied by the river and its right-hand tributaries, which build up the large alluvial fans (Ozana, Topoliţa, Fig. 5). The active channel has a maximum braiding index of 3.11 and a bankfull channel width of between 700 and 1000 m. The floodplain has three terraces: the first terrace is located 1 m above the water level, the second is located 1–2 m above the water level, and the third is located 3–5 m above the water level. Above the floodplain, the 5–7 m terraces are

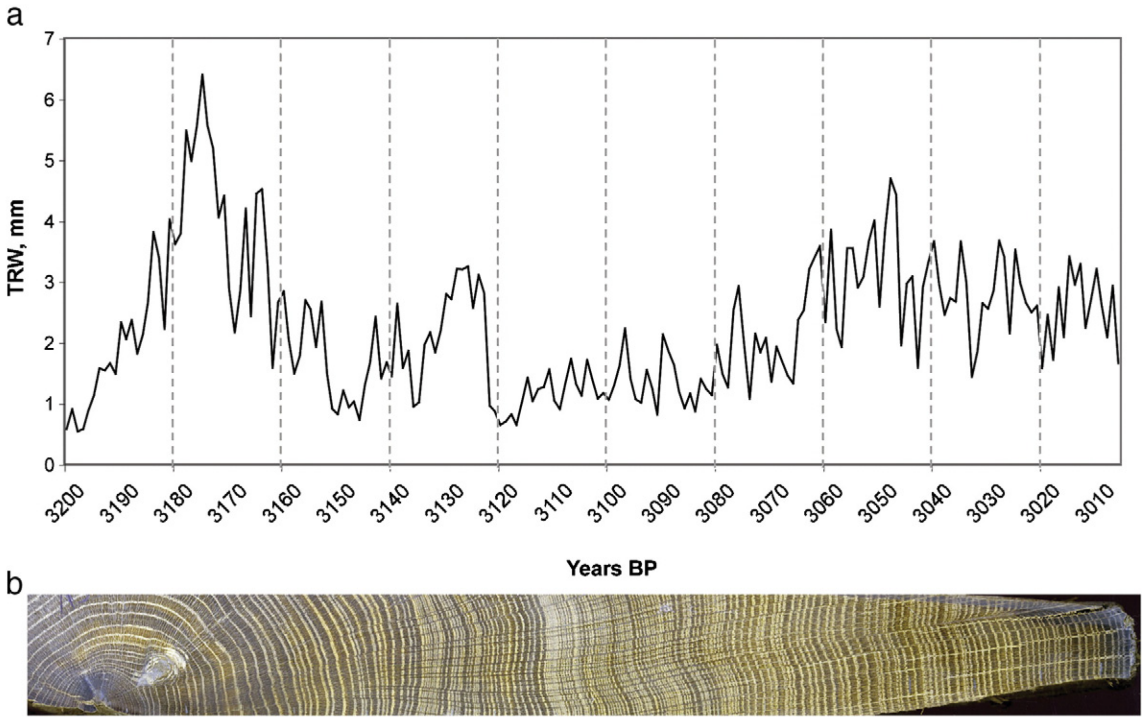


**Fig. 10.** The time series of residual tree growth (TRW) and the sequence of growing rings of the fossil *Quercus robur* that was sampled from the base of the 1–3 m fluvial terrace of the Timişeşti Section (Mold 943).

well developed and are mainly located in the Ozana and Topoliţa alluvial fans. The 1–2 m terraces border the active belt and were formed by river incision.

The sedimentary infill of the valley (Fig. 6) reaches its maximum 130 km downstream of the headwaters, which is located in an area where the floodplain is not at its maximum width. The variation in the thicknesses of the alluvial deposits along the Moldova River clearly highlights the succession of three alluvial fans (Fig. 1), and their geneses are related to longitudinal sedimentation of the river and lateral sedimentation of very effective tributaries that are located on the right side of the valley.

During the last one hundred years, the most important fluvial changes have been reported in the perimeter of the active belt: the lateral migration of the channel thalweg and banks, the gravel bar dynamics, and the narrowing and incision of the river. For example, the average value of the lateral migration of the channel was 7.7 m/year during the years 1894–1973.

In-channel gravel mining and local embankments near bridges and towns are the most important direct interventions that impact humans along the channel. For example, between Timişeşti and the confluence of the Moldova River with the Siret River (75 km long), 12.37 millions $m^3$ of alluvial sediments were extracted during the years 1969–1981 from 18 gravel mining sites that were distributed along the river (Brânduş, 1984). This high rate of gravel mining was interpreted by the author to be the cause of the generalised channel incision, although some local reaches continued to be characterised by in-channel aggradation. The average value of the incision was reported to be 1.5 m, and maximum values of 3–4 m were found between Timişeşti and Tupilaţi. During the last two decades, the number of in-channel gravel mining sites has doubled, and a similar trend most likely exists in the volume of extracted sediments, but no official records are available. Quantitative measures of channel changes during the recent period, which will eventually support a more detailed discussion that is related to the human impact on spatial channel and vertical dynamics, are presented in Figs. 7, 8.

Successive maps (1910, 1960 and 1980) and orthophotos from the year 2006 revealed an important active channel narrowing (bankfull channel width) (Fig. 7). The channel widths that were measured at 1100 cross-subsections along the river between Gura Humorului and Roman (L = 110 km) indicate that the river has narrowed by more than four fold in the last hundred years and has reached 24% of the bankfull width that was present in the year 1910. An important

**Table 2**
Recent palaeoclimatic and palaeoenvironmental reconstructions of N and NE Romania (i.e., the Eastern Carpathians, Subcarpathians and out-Carpathian regions).

| Site | Location | Elevation (m) | Proxy data | Years BP | References |
|---|---|---|---|---|---|
| Poiana Ştiol | Rodna Mountains | 1540 | Peatbog | 9220–2170 | Tanţău, 2006 |
| Putredu | Rodna Mountains | 1550 | Dendrochronology (*Picea abies*) | 1793–2000 | Popa, 2005 |
| Tomnatec | | 1650 | | 1822–2000 | |
| Bila | | 1500 | | 1769–2000 | |
| Iezerul Călimani | Călimani Mountains | 1650 | Peatbog | 14800–1710 | Fărcaş et al., 1999 |
| Călimani National Park | Călimani Mountains | 1780–1860 | Dendrochronology (*Pinus cembra* L) | 1163–2005 | Popa and Kern, 2009 |
| Crater Mohoş 1 | Harghita Mountains | 1050 | Peatbog | 9750–120 | Tanţău et al., 2003 |
| Mohoş 2 | Harghita Mountains | 1050 | Peatbog | 8740–1090 | Tanţău, 2006 |
| Luci | Harghita Mountains | 1079 | Peatbog | 11850–2460 | Tanţău, 2006 |
| Bisoca | Buzau Subcarpathians | 890 | Peatbog | 9680–300 | Tanţău et al., 2009 |
| Intorsura Buzăului | Curvature Carpathians | 1150 | Dendrochronology (*Picea abies*) | 1721 and 2006 | Sidor, 2009 |
| Moldova Valley, between Molid and Timişeşti | Moldova River floodplain | 527–261 | Fossil trunk in alluvial deposits | 2060–1872 | This study |
| Timişeşti | Moldova River floodplain | 261 | Dendrochronology (*Quercus robur*) | 3340–3061 | This study |

consequence of this general narrowing (and incision) trend during this time interval is that the river has changed its channel type from braided to wandering.

The rates of channel incision were estimated by analysing the lowest annual stage of the Moldova River at 4 gauging stations (Figs. 1, 8). Along the river, the incision rate (absolute values) increased from −80 cm at the exit of the mountainous area to −2.60 m at the confluence with the Siret River.

### 5.2. Description and interpretation of sampled cross-sections

The locations of the six study areas along the Moldova River, the $^{14}C$ absolute ages of the fossil trunks, the species of the trees, and the sedimentary contexts are presented in Figs. 1, 4 and Table 3. The investigation of the fluvial history at the six sites also takes into account the cross-section morphology and sedimentology of the floodplain. The morphological profiles are based on recent orthophotos (year of survey: 2006, scale 1:5000), and the nature and thickness of the alluvial sediments are based on hydrogeological boreholes that were analysed between the years 1960–1970 (Amăriucăi, 2000; Cădere et al., 1967) and on our own observations.

#### 5.2.1. Molid section

*5.2.1.1. Description.* In this location, the Moldova Valley has an asymmetric section where the fluvial terraces have developed only on the left side of the valley. No published information on the thickness of the alluvial sediments (*i.e.*, no boreholes are present) in this region is available; therefore, Fig. 9a only provides an estimation of these values. However, in the mountainous area, where the Molid Section is located, bedrock channel reaches provide a direct clue that the sediments are not thick in this area.

A comparison of the channel planform configurations at two successive reference points, *i.e.*, the years 1980 (topographic maps, scale 1:25.000) and 2006 (orthophotos, scale 1:5000), have shown that lateral erosion over this interval of time was between 45 m and 2.8 m and had an average value of 24 m. The hydrometric measurements at the Prisaca Dornei gauging station, which is located 15 km downstream of the Molid Section (Fig. 1), have shown that, during the same period, channel thalweg migration to the right and an average incision of 1.1 m occurred. The high discharges that were recorded in 2006 and 2008 indicated that significant changes in channel cross-section morphology occurred (personal field observation) and that a trough increased the channel incision and lateral erosion during exceptional flood events. The lateral activity of the channel after 2008 was responsible for the exposure of a *Fagus sylvatica* fossil trunk, which was located at the base of the 1–2 m high floodplain terrace. The fossil tree was 40 cm in diameter and 835–725 yrs. old (*i.e.*, 1116–1225 AD, Mold 953, Table 3).

The lower floodplain terrace, which is located below the 1–2 m relative altitude, consists of coarse gravel alluvial sediments (*i.e.*, gravel-bed river deposits) that are similar to those present in the riverbed (D50: 69 mm). Furthermore, thick, sandy materials (25–30 cm) in combination with organic remains (overbank deposits) are superimposed on this sediment.

*5.2.1.2. Interpretation.* The absolute age of the fossil trunk places its existence at the end of the Warm Medieval Period (Fig. 4). Therefore, it is possible that the tree could have fallen, at the earliest, during the beginning of the Little Ice Age, which is a period that is known for its increased fluvial activity and its more frequent and ample floods (Kalicki et al., 2008). Two alluvial facieses are visible in the terrace: coarse gravel lateral accretion sediments and fine materials that resulted from the vertical accretion of the floodplain (Fig. 4).

The position of the fossil trunk at the base of the 2 m high floodplain terrace and its absolute age suggests that this morphological unit is more than 700 years old. Additionally, the thickness of the two sedimentary units suggests that during this interval of time, when the river occupied a position that was interrupted by the returning of the present channel (which has been functional for at least the last 40 years), the predominant fluvial process of the floodplain was in-channel aggradations with a relatively short phase of vertical aggradation. Today, the terrace is developed on the left side of the river and is 64 m broad, and during the years 1980–2006, the river eroded 24 m from this terrace. From these quantitative values, it can be deduced that the width of this terrace, which is partially preserved only on the left side of the river, was more than 100 m and was most likely 200 m.

#### 5.2.2. The section located downstream from Gura Humorului

*5.2.2.1. Description.* This section is located where the mountains and hills contact (*i.e.*, the piedmont zone) and where the floodplain of the Moldova River is more than 1.5 km wide. On the surface of this section, a set of 1–2 m and 2–5 m high fluvial terraces and a palaeochannel were mapped.

The hydrogeological boreholes (Fig. 9b) indicate the existence of a coarse gravel layer that is 1200 m wide and approximately 5 m thick, on which finer sediments of two floodplain terraces (*i.e.*, pebbles, sands, silts and clays), palaeochannel in-fills and present-day, active channel deposits are superimposed. These morphological and sedimentological elements and their spatial relations in the floodplain perimeter are interpreted as pieces of evidence of repeated avulsion processes, which are specific for a piedmont alluvial fan surface during as early as the Late glacial-Holocene.

The hydrometric measurements at the Gura Humorului gauging station have shown that during the last three decades, the active channel of the Moldova River has registered a continuous incision of 1.4 m and a narrowing of 41 m. The incision is responsible for the exposure of fossil trunks that are fixed in the alluvial sediments of the 1–2 m high floodplain terrace. The terrace (with an inset bellow from the 2–5 m high floodplain terrace) is composed of coarse gravel sediments (*i.e.*, coarse river-bed sediments) with median diameters between 32 and 64 mm and on which are superimposed 110 cm thick sandy sediments with silt intercalations (*i.e.*, overbank deposits) (Fig. 4). One of the *Fagus sylvatica* fossil trunks that was

**Table 3**
The $^{14}C$ absolute ages of the fossil trunks collected along the Moldova River.

| No. sample | Tree species | Location | Sedimentary context | Depth (m) | Absolute age (BP) | $^{14}C$-calibrated ages (94.5%) yrs. BP |
|---|---|---|---|---|---|---|
| Mold 953 | Beech | Molid | Alluvial coarse gravels | 2 | 875 ± 35 | 910–840 BP (26.0%)<br>**834–725 BP (68.2%)** |
| Mold 915 | Beech | Gura Humorului | Alluvial coarse gravels | 3 | 1150 ± 45 | **1178–960 BP (95.4%)** |
| Mold 933 | Poplar | Slatina | Alluvial coarse gravels | 3.5 | 650 ± 45 | **674–550 BP (95.4%)** |
| Mold 922 | Poplar | Praxia | Alluvial coarse gravels | 2 | 380 ± 45 | **510–315 BP (95.4%)** |
| Mold 943 | Oak tree | Timişeşti | Alluvial coarse gravels | 3 | 2995 ± 45 | **3340–3061 BP (93.8%)** |
| Mold 912 | Oak tree | Timişeşti | Alluvial coarse gravels | 3 | 2005 ± 40 | **2060–1872 BP (94.4%)** |

exposed in the river's bank and was 30 cm in diameter had a $^{14}C$ absolute age of 1178–960 yrs. BP (772–990 AD, Mold 915, Table 3).

*5.2.2.2. Interpretation.* The presence of the fossil trunk in the coarse gravel sediments of the river bed of the 1–2 m high floodplain terrace and its absolute age suggest the existence of an active channel of the Moldova River that was present during the end of the Dark Ages Cold Periods. The sedimentary structure of the floodplain terrace also indicates the existence of two main fluvial depositional processes that occurred after the channel was abandoned: in-channel aggradation (*i.e.*, coarse gravel deposits) and floodplain vertical aggradation with overbank deposition (*i.e.*, fine materials). The absolute age of the fossil trunk suggests that the accumulation of the two types of facies that were superimposed on the trunk (Fig. 4) was deposited during the last 1000 years, and the thicknesses of the fine, overbank deposits suggest a longer period of floodplain aggradation than in the Molid Section.

### *5.2.3. Sections located at Slatina and Praxia*

*5.2.3.1. Description.* At Slatina, the alluvial sediments of the floodplain are greater than 15 m thick, and its lateral extension is nearly 2 km wide (Fig. 9c). At Praxia, the width of the surface of the floodplain increases to 4 km, and the 1–2 m high floodplain terrace is 600–1000 m broad and has a maximum thickness of 2–2.5 m (Fig. 9d). In the vicinity of the Slatina and Praxia sections, no hydrometric stations are available, but the temporal behaviour of the channel can be deduced by performing hydrometric measurements upstream (at a 12 km distance) and downstream (at a 23 km distance) from these sections and by obtaining field evidence on the effects of the fluvial processes in these regions. According to these data and the two successive sets of maps, the tendency for narrowing of the channel between 1980 and 2006 is recognisable and has an incision that is estimated to be 1.5 m. As in the previous sections, during the last decades, the channel incision, which was most likely more accentuated during the high discharges in 2006–2008, has exposed fossil trunks that were fixed in alluvial sediments of the 2–4 m high floodplain terrace. Samples of *Populus* were $^{14}C$ dated as being 674–550 yrs. BP (1276–1400 AD, Mold 933, Table 3) and 510–315 yrs. BP (1440–1635 AD, Mold 922, Table 3) old. Furthermore, the alluvial sediments were coarse (D50 = 32–75 mm) in the 2–4 m terrace and in the riverbed.

*5.2.3.2. Interpretation.* At Slatina, the lower terrace is 600–1000 m wide and 2–2.5 m thick. Only two layers of sand, which are a few centimetres thick, are recognised in the upper part of the terrace sediments. This finding suggests that in-channel lateral and/or vertical aggradation was the dominant sedimentary process that occurred in this region. The 3.5 m thick, coarse gravel sediments (Fig. 4) that were found on top of the dated fossil trunk were deposited approximately 670 yrs. BP (*i.e.*, 1280 AD) ago, which corresponds with the end of the Medieval Warm Period/start of the Little Ice Age. At the Praxia section (Fig. 9d), the 2 m thick, coarse gravel sediments began to accumulate after 470 yrs. BP (*i.e.*, 1480 AD), but the overbank deposits were insignificant, which suggests a similar history as those of the Slatina and Molid Sections.

### *5.2.4. Timişeşti section*

*5.2.4.1. Description.* At the Timişeşti section, the 1–3 m high terrace is approximately 800 m wide and has a maximal thickness of 5 m (Fig. 9e). The present day river is incised on its surface, has three main channels, and has well-developed, median and lateral bars. The channel reach is located upstream from the junction with the Ozana River, which is one of the leading suppliers of sediments for the Moldova River, and is superimposed on the large, alluvial fan of this tributary, which contains the main groundwater reserve in the area. The river is approximately 500 m wide (at bankfull level) and has a flow that is diverted into three branches that are imposed by two median bars.

During the last three decades, this area of the Moldova River has registered the same general trend of channel narrowing (119 m) and incision (more than 1 m) as in the upstream sections. Lateral erosion of the right bank has exposed the coarse-grained (D50: 20–36 mm), alluvial sediments of the 1–3 m high floodplain terrace, which have similar granulometry (D50: 20–36 mm) to the sediments that are present in the riverbed. In these gravel bed channel deposits, numerous and well-preserved, large fossil oak trees are incorporated (approximately 1 m in diameter, Fig. 2). The oldest oak tree (Mold 943, Table 3), which is of the species *Quercus robur*, is 3340–3061 yrs. BP old, while the second sample of oak tree (Mold 912, Table 3), which is located 200 m downstream, is 2060–1872 yrs. BP old.

*5.2.4.2. Interpretation.* Although they are trapped at the bottom of the same sedimentary structure, the ages of the two trunks differ by approximately 1000 years. Given the 200 m distance between these trees, we suggest that discontinuities might exist in the sedimentation of the 1–3 m terrace, although this is not visible on the top of the terrace. The 3340–3061-yrs.-BP-old trunk suggests that the channel was active during the Iron Age, while the 2060–1890-yrs.-BP-old trunk indicates the continuation of the flow that was accompanied by channel bed aggradation during the Roman period. Therefore, we suggest the following: 1) the channel was stable on a millennial scale and was accompanied by channel bed aggradation and 2) after the Roman Period, the river maintained its evolution until complete abandonment that was followed by floodplain aggradation with fine sediments.

The existence of the fossil trees in warm conditions is confirmed by dendroclimatological observations on the oldest fossil oak tree (see Section 5.3) that suggest that high temperature values and lower precipitations occurred at approximately 3100 BP. The removal and burial of these trees probably occurred as a result of exceptional events (*e.g.*, floods) after 2850 yrs. BP, when short, humid phases are registered (Stuiver and Braziunas, 1993).

## *5.3. Estimates of floodplain sedimentation rates*

In Europe, the colder and wetter climate during the LIA (Macklin et al., 2006) caused in-channel aggradation at the regional scale and was often associated with riparian tree detachment and transportation during flood events (*e.g.*, Starkel et al., 2007). Therefore, using our data, the volumes of coarse gravel alluvial sediments that were deposited in each sampled floodplain section were estimated using the unit cube. The obtained values were used to calculate the initial floodplain sedimentation rate in $m^3$/year (column 7, Table 4), which was then transformed into mm/year (column 8, Table 4). All of these parameters were determined to allow for a quantitative comparison (although premature at this stage) of fluvial processes along the Moldova River with similar processes that were reported elsewhere in Europe. For example, the maximum values of the floodplain sedimentation rates that were registered in the Slatina and Praxia sections, 4–6 mm/year, were also reported for the Rhine River and its tributaries (1–8 mm/year, Hoffman et al., 2009) and for the Morava River (2–6 mm/year, Grygar et al., 2010).

Along the Moldova River, the maximum value of the floodplain sedimentation rate was recorded 120–140 km from the river headwater, where a large, extra-Carpathian alluvial fan is present and crosses the Timişeşti Section (Figs. 5, 6). In the last one hundred years, this great reservoir of construction aggregates has declined considerably, as is shown in the latest trends of the processes of the Moldova channel (Figs. 7, 8).

**Table 4**
Fluvial processes and volumes of alluvial materials that eroded at a historical scale (between the years 1980–2006) were compared with the volumes of accumulated materials and floodplain sedimentation rates in the six studied sections (Late Holocene).

| Section (km below headwaters) | Channel lateral erosion, *Ce*, m 1980–2006 | Channel incision (*Ci*, m) | Channel narrowing (*Cn*, m) 1980–2006 | Total volume of eroded sediments (*Ve*, $m^3$/m) | Rate of channel narrowing (*Ri*, $m^3$/m/yr) | Total volume of accumulated sediments (*Va*, $m^3$/m) | Floodplain sedimentation rate (*Sr*, $m^3$/m/yr) | Floodplain sedimentation rate (*Sr*, mm/yr) |
|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Molid (83 km) | 2.8 - 45 | − 1.1 (1975–2003) | | 83 | 3.19 | 300 | 0.38 | 1.28 |
| Gura Humor (110 km | | − 1.4 (1980–2006) | 41 | 57 | 2.21 | 2400 | 2.25 | 1.87 |
| Slatina (118 km) | | | 179 | 197 | 7.57 | 2400 | 3.92 | 4.08 |
| Praxia (146 km) | | − 1.5 (1980–2003) | 180 | 269 | 10.35 | 5500 | 13.35 | 6.07 |
| Timişeşti 163 km) | | | 116 | 174 | 6.69 | 4800 | 1.50 | 0.94 |
| Timi e ti | | | 116 | 174 | 6.69 | 1600 | 0.81 | 1.53 |

*Ce* — lateral erosion inferred from measurements on topographic maps from 1980 to 2006.
*Ci* — channel incision inferred from measurements at the gauging stations.
*Cn* — channel narrowing inferred from measurements on topographic maps from 1980 to 2006.
*Ve* — volume of eroded sediments calculated using the overlapping cross sections 1980 and 2006.
*Ri* — by dividing column 4 to the number of years between 1980 and 2006.
*Va* — by multiplying the thickness of sediments above the trunk fossil with the alluvial body width (respectively, the fluvial terrace considered).
*Sr* — by dividing column 6 to the number of years BP for each cross section.

### 5.4. Dendrochronological observations

The base of the trunk of the well-preserved oak tree (Mold943) (Fig. 2) was used for dendrochronological investigations (Fig. 10). The length of the growing sequences covered 195 years and had an average tree-ring width of 2.27 ± 1.14 mm; the mean sensitivity, as a measure of the relative difference in the width between consecutive rings, of the chronology was 0.28. The first-order autocorrelation coefficient was relatively high and statistically significant (0.76) because the physiological processes within the tree created a lag in its response to climate. The dynamics of the tree-ring width indicated that an active growing period occurred during the first two decades of the life of the tree, and this period was followed by a significant decrease in growth between 3120 and 3065 BP. The inner area of the wood sample was represented by juvenile wood with a specific, high growth rate (3200–3175 BP) and could not be associated with a modification of climate conditions. The growth series was standardised to remove the non-climatic trends that were induced by the age of the tree and competition factors that were specific for forest ecosystems using a spline function. This residual, tree-ring index chronology showed the following negative pointer years: 3122, 3046, 3162, 3033 and 3074 yrs. BP.

The growth rhythm was abruptly changed between 3124 BP (3.1 mm) and 3122 BP (0.96 mm), and this strong decrease in tree-ring width was most likely caused by a radical environmental change that was maintained for the following two decades (until 3080 BP). The next progressive growing trend of tree-ring width marked a possible climatic amelioration. To understand if this signal was an individual one (*e.g.*, limitative factors, such as breaking canopy) or a more collective one, similar investigations on other fossil oak samples from the same area are necessary. The positive growing trend between 3134 and 3124 BP was induced by a significant modification of growing space that was generated by the death of old, neighbouring trees, which is a characteristic, natural forest dynamic. The annual variation of tree-ring width, sometimes with high rates similar to those between the years 3047 and 3046 BP or 3034 and 3033 BP, correlates with the variability of the annual climate.

Interestingly, the abrupt climatic change occurred at approximately 3100 BP, which marked the transition to the cold and wet climate during the Iron Age, as mentioned by Stuiver and Braziunas (1993) and Perşoiu (2011), and this occurrence is noticeable in the 195-year growth chronology of the analysed oak sample.

## 6. Discussion

Fig. 11 illustrates the fluvial activity of the Moldova River in comparison with the Teleorman (Howard et al., 2004) and Someşu Mic Rivers (Perşoiu, 2010), which are Romanian rivers where absolute dating methods were also used to investigate their behaviour during the Holocene. Our synthesis refers only to the last 3200–3000 years, which is the oldest $^{14}$C absolute age that was obtained along the Moldova River.

During this interval of time, isolated events or periods with a higher incidence of flooding that were responsible for channel repositioning in the floodplain perimeter (*i.e.*, median- and small-scale avulsions), re-activations of abandoned channels, and overbank sedimentation that were sometimes associated with interruptions of soil formation along the Someşu Mic River were registered. Isolated events occurred at 2500 yrs. BP, during the Dark Age Cold (*i.e.*, V-VIII century AD) and Medieval Warm Periods (*i.e.*, IX-XV century AD), while the Little Ice Age was a period with a higher incidence of floods (*i.e.*, XVI-XIX century AD).

In southern Romania, sedimentological evidences and $^{14}$C absolute ages along the Teleorman River have indicated that 3300–2800 yrs. BP and 1000 yrs. BP were periods of increased fluvial activity (*i.e.*, the increased frequency of floods is correlated with high rates of alluvial sedimentation along the Teleorman floodplain) that were separated by incision phases. Howard et al. (2004) did not insist that fluvial changes during the Little Ice Age occurred because the river is characterised by only slight aggradation with sandy materials and as free meandering.

For the Moldova River, fossilised trees are interpreted to be indirect proof of moments or intervals of time with higher fluvial activity. In this context, the ages of these trees place such events at 3100, 2000, 800–1000, and 500–700 yrs. BP. Additionally, the massive character of coarse, alluvial sediments on the top of fossil trunks suggests a continuity of in-channel, vertical aggradation (*i.e.*, braided environment) during the last three millennia and no significant channel changes during flood events.

The moments of increased fluvial activity in the Teleorman and Someşu Mic Rivers show a good temporal correlation with similar moments in Poland and other parts of Central Europe. This association

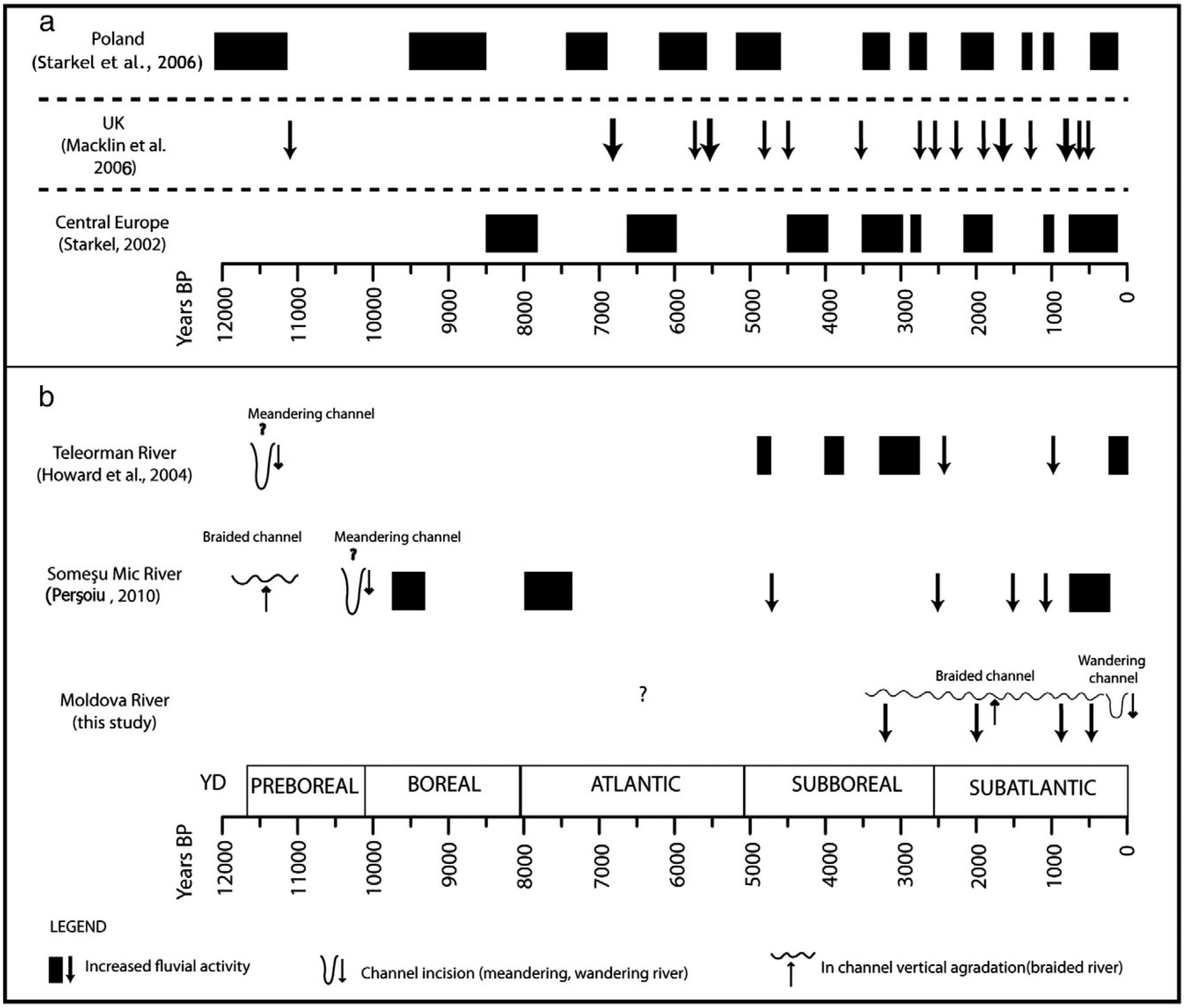


**Fig. 11.** Temporal correlation of periods with increased fluvial activity: a) in Europe: UK (Macklin et al., 2006), Poland (Starkel, 2006) and Central Europe (Starkel, 2002); and b) Romania: Teleorman River (Howard et al., 2004), Someşu Mic River (Perşoiu, 2010) and Moldova River (this study).

is also observed for the Moldova River, especially during 3100, 700–1000 (DACP) and 500–700 (LIA) yrs. BP. This finding confirms previous observations (Howard et al., 2004; Perşoiu, 2010) that Romanian rivers, despite where they are located in relation to the Carpathian Mountains, evolve in very similar, climatic conditions as those of Central Europe because they are all under the influence of the Nord Atlantic Air Circulation.

In the pan-European synthesis by Macklin et al. (2006), the most prominent of these episodes occurred at approximately 1830–1950 yrs. BP (*i.e.*, during the Roman period in Great Britain and Poland) and 860–880 yrs. BP (*i.e.*, during the Middle Ages in all three regions), which were periods when significant agricultural expansion, deforestation and land-use changes occurred. In our study, the periods of 2000 and 800–1000 yrs. BP are superimposed on these two historical intervals, which suggest the potential of this river to contribute valuable information on these periods.

European syntheses of fluvial archives indicate that the Little Ice Age (*i.e.*, which occurred approximately during the years of 1350–1850 yrs. AD) was a period (Macklin and Lewin, 1997) when climate had an important role in the dynamics of the fluvial systems and is appreciated as having the most impressive effect on fluvial processes during the entire Holocene by inducing the alternation of wet periods (at higher frequencies and amplitudes of floods) with dry periods. It is largely accepted that during this interval of time, rivers adjusted to new discharge regimes by straightening and widening their channels, thus becoming more susceptible to higher avulsion and in-channel aggradation. This action was accentuated by land use changes over the last three centuries, which were an important source of river load (Lamb, 1995). Comparisons between these periods and the climate variability during the Late Holocene reveal a good correlation between the aggradation phases that are registered along the Moldova River and wet and cold periods with a higher incidence of floods. This temporal correlation suggests a common climatic control that takes place on a continental scale.

Direct measurements of historical planform and vertical dynamics (*i.e.*, approximately during the last 200 years) of numerous European rivers (*e.g.*, Liebault and Piegay, 2002; Rinaldi, 2003; Surian et al., 2009), including those in Romania (Perşoiu and Rădoane, 2011; Rădoane et al., 2010), confirm that generalised channel incision and the narrowing of rivers after the LIA occurred. Moreover, measurements of the Moldova River confirmed this tendency (Figs. 7,8). The recent climate warming and direct human interventions on fluvial systems are identified as the main causes for this regional fluvial trend, but no consensus exists on which of these factors play the most significant role.

## 7. Conclusions

The spatial and vertical development of the Moldova River floodplain in the extra-Carpathian area prompted high interest among Romanian geomorphologists concerning the types and rates of fluvial morphological and sedimentological processes in this region at contemporaneous (annual–decadal) and historical-Holocene scales (centennial–millennial).

In the present study, six successive floodplain cross-sections along the Moldova River were analysed. Radiocarbon dating of fossil trunks that were exposed in the river banks as well as sedimentological observations of the openings, published hydrogeological boreholes in the floodplain perimeter, instrumental measurements at hydrometric stations, and channel planform measurements on two successive cartographic materials (reference moments: 1980 and 2006) were combined to reconstruct the history of the Moldova River during the last 3000 years.

The fossil trunks that were recently exposed in the Moldova riverbanks had a maximum age of 3000 years, which indicates that the 1–2 m fluvial terrace was formed in the Late Holocene. However, one cannot exclude the possibility that the cutting occurred recently because of the incision and narrowing of the river in recent decades.

The ages of the fossil trunks and their burials in coarse sediments at the bottom of the riverbed suggest a predominance of a braiding-type aggradation process on the riverbed, which was active at least during the last three millennia. This process seems to have diminished or even stopped in recent years (possibly after 1850, *e.g.*, Perşoiu and Rădoane, 2011) and is associated with the metamorphosis of the channel from braided to unstable meandering (*i.e.*, wandering channel).

Overbank deposits on the upper side of the investigated profiles, which were mostly underdeveloped, suggest two aspects: a) the existence of relatively short periods of drainage reorganisation in the floodplain area and an abandonment of the old channels; these abandonments were not necessarily synchronous and reflected the local evolution of the river; and b) the interruption of this process when repositioning the recent flow; a series of topographic maps attested to such a position, at least beginning in 1910 (Chiriloaei, in preparation).

The ages of fossilised trees in the riverbed, which were placed during the Roman Age, the end of DACP (*i.e.*, the Migrations Period), the end of the Medieval Warm Period and the beginning of the Little Ice Age, support the hypothesis of their falling after extensive floods. Interestingly, these moments of intense activity along the Moldova River correspond to similar periods in Poland, Central Europe and Romania (Fig. 11).

The detailed climate reconstruction (covering 295 years) for the 3340–3061-yrs.-BP interval confirms similar findings from western Romania. This finding suggests that the climate signal was regional, which also favours the observation that periods with enhanced fluvial activity along the Moldova River may be associated with those that were reported in Central Europe.

The aggradation rate of the floodplain, at least for the period between 1300 and 1910 yrs. BP, in the Slatina-Praxia sector had the highest values (4–6 mm), which were comparable to other floodplains in Europe and coincided with the highest thickness of the alluvial deposits along the Moldova River (Fig. 7). After 1910, Moldova's riverbed narrowed by approximately 76% and was incised by 180 cm (*i.e.*, from −80 cm, at the exit of mountainous area, to −260 cm, at its mouth). This finding is a signal that restoration and management measures must be taken that take into account that the Moldova River and possibly others in the region are trending towards severe effects on hydraulic, ecological and other environmental aspects. The most important measure to be taken is the development of a sustainable strategy for gravel exploitation because its recovery has been dramatically altered in the last decades.

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