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ORIGINAL ARTICLE

Dendrogeomorphological analysis of shore erosion along Bolsena lake (Central Italy)

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Abstract

Dendrogeomorphological research was conducted along a volcanic caldera lake of Bolsena in central Italy, Latium region, in order to investigate the erosion process that affects its coastline. Most of the trees sampled were black poplars (*Populus nigra* L.) with root systems differently exposed. The cores taken from trunks show growth stress (suppression) at different times according to the distance of the tree from the shoreline. Results of the morphological analysis of the root systems were used as a qualitative estimate of the erosion process developing an erosion map of the lake's shoreline. The dating of suppressions was used to calculate the main horizontal erosion rate at different shoreline sectors. The most intense erosion was recorded on the southern and northern shore, affected by the strongest and long-lasting winds (mean erosion rate at southern coast = 0.092 m/year, northern coast = 0.064 m/year, eastern coast = 0.049 m/year, western coast = 0.028 m/year). The age of the living trees along the shore points out that the erosion started at least in the 1970s (one of the highest lake level episode) and it is still in progress.

Keywords: Dendrogeomorphology; Shore erosion; Exposed roots; Lake level fluctuation; Italy; Black poplar

Introduction

The present study can be broadly classified in a branch of dendrogeomorphology/dendrohydrology, that was firstly introduced by Alestalo (1971) and then widely developed, especially on rivers by Sigafoos (1964) and Hupp (1988) and summarised by Schweingruber (1996). Frey (1954) conducted a study on glacial lakes in north Carolina whereby the age of partly submerged cypresses living along the shore was assessed to detect and reconstruct the fluctuation of the lake level in the last 500 years. Stockton and Fritts (1973) described the formation of narrow rings in shoreline trees as a direct effect of flooding due to the changing level of the Athabasca lake. More recently, the effect of lake-level fluctuation was investigated in subarctic and arctic areas in Québec, Canada (Bégin and Payette, 1988, 1991; Begin et al., 1991; Leepage and Bégin, 1996; Tardiff and Bergeron, 1997; Bégin, 2000, 2001). In Europe, dendrohydrology was used to study Holocene lake-level fluctuations by analysing (sub)fossil trees from either submerged villages in France (Borel et al., 1985) or natural forest remains in northern Finnish Lapland (Eronen et al., 1999). In Sweden, subfossil trees provided information about tree-line fluctuation in the central Scandinavian Mountains lakes (Gunnarson, 2001). A similar dendrohydrological study was conducted in Italy in order to date subfossil trunks found on lake sediment deposits in Treviso in the Venetian Pre-Alps (Casadoro et al., 1976).

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The aim of this study was to use dendrochronology for the investigation of living trees that are stressed by geomorphological erosion processes occurring along the shoreline of the volcanic lake Bolsena.

Materials and methods

Study area

The investigated area is located in Central Italy, Latium region, 50 km east of the Tyrrhenian Sea, in the geological Pleistocene Volsini volcanic district (age 0.8–0.09 million years). The Bolsena lake has formed inside a volcanic caldera and covers an area of 448 km^2 and is located at a mean altitude of 304 m a.s.l. The length of the coastline is 48 km and the lake has a maximum depth of 226 m; its only outlet is located on the southeast side and it has many small inlets (Fig. 1). Bolsena lake was created after a tectonic–volcanic collapse of a caldera due to the huge amount of emissions from the volcano, which occurred in the upper Pleistocene, approximately 0.15 million years ago (Locardi et al., 1976). The coastline is mostly sandy with some rocky parts (lava flow or tuff outcrops) or modified by anthropogenic influences (little harbour or concrete/rocky defensive barriers).

Sample trees

During summer 1999 samples were taken from 46 trees that were growing directly along the shore. All sample trees show the typical symptoms of trees that are stressed by erosion along the shore, which are a partial exposure of the root system, sometimes up to 80–85%, or a tilted stem towards the shore, due to the slow erosion of the sandy beach, or both. In addition nine control trees were sampled that grow at some distance (10–50 m) from the lake. Most of the trees sampled (93%) were black poplars (*Populus nigra* L.), the others (7%) were common alder (*Alnus glutinosa* L.), black locust (*Robinia pseudoacacia* L.), white willow (*Salix alba* L.) and cluster pine (*Pinus pinaster* L.).

Morphological description for geomorphological analysis

A careful morphological examination of each sample tree was conducted whereby the "erosion step" (= axial length of exposed root system due to erosion; measured from the root collar to the actual shore level) (A) and the distance of the stem from the shore taken from the middle of tree trunk (B) (Fig. 2). The distance of the trees from the shore (B) were recorded in the same week to avoid variations due to lake-level fluctuation. This analysis of the morphology of trees, in particular of the erosion step, was used to develop a map of erosion along the entire coastline of the Bolsena lake.

Dendrogeomorphological analysis

In total, 108 cores were taken with an increment corer: usually two cores per tree (0.5 cm diameter) from opposite sides. The samples were analysed using dendrochronological standard methods: they were glued on wooden holders and cut with a stanley knife and sanded. Skeleton plots (Fritts, 1976) were made for visual crossdating of the samples and to trace missing or double rings (density variations). Afterwards tree-rings width was measured with a 0.001 mm accuracy using a Velmex measuring equipment and its software. The dated tree-ring series were statistically checked by using programme Cofecha (Holmes, 1983). Dendrochronological analysis were applied to detect growth anomalies in the tree-ring series of the sample trees. One important feature are prolonged suppressions in radial growth. However, also the occurrence of reaction wood in tilted trees, if discernible, was recorded. These features were related to the degree of exposure of the root system to get an indication about the temporal dynamic of erosion. The first year of a growth suppression recorded in a tree-ring series was considered as the *signal* indicating the year when stress caused by the erosion process was initiated (Fig. 3). The detection of these erosion signals in all trees was used in combination with the information of the distance of each tree from the shore (B) to compute the erosion rate for the northern, southern, eastern and western shoreline zones, respectively. The erosion rates were subsequently plotted for each of the sectors around the lake shoreline and the interpolated linear curves were utilised to calculate the mean annual rate of horizontal erosion along the shore (m/year). The growth suppression in the tree-ring series were analysed according to the methodology of visual growth analysis (introduced by Schweingruber et al., 1990), whereby three intensities classes are defined, related to the intensity of a sudden growth (>4 consecutive years) in comparison to the previous growth (during same number of years as in growth depression, Fig. 4). Category R1 describes a depression of 45–55%, R2 a depression of 56–70% and in category R3 a strong depression of more than 70% in relation to the previous growth occurs. The degree of root exposure was estimated for each sample tree whereby four classes are defined, i.e. 0–20%, 21–40%, 41–60% and 61–85%. The intensity classes of a suppression were compared to the degree of root exposure.

Fig. 1. Location map of Bolsena lake, Latium region, central Italy.

Wind and lake-level fluctuation data

To detect the possible causes for the erosion process the relation between wind direction and intensity at the study area and lake−level fluctuation were examined. Data records on wind intensity (speed in knots; 1 knot = 1.85 km/h) and direction (frequency in %) were available for the period from 1961 to 1990 from the nearest gauge station at Viterbo airport located at 15 km south from the lake, at 300 m a.s.l. (Fig. 1, Table 2).

This analysis was developed on 24 h constantly blowing winds whose results are summed up in Table 2. This has shown that the most intense winds with higher speed in knots were those blowing from N (18.92) and S (12.93) followed by those from NE (10.34) and SE (6.25). According to the frequency (%) of winds blowing on the area, the most frequent one is that from NE (17.93%), followed by that from S (14.11%) and then by N (8.57%), SE (4.72%) and SO (1.69%) while the calm period (no winds) cover the half of the year 52.98% (Table 2). There are of course winds blowing from other directions but their length is less than 24 h so they were not used for this study. The wind examination underline that the most intense and durable ones are blowing from the northern and southern directions, affecting, respectively, the southern coast and the northern coast of Bolsena lake.

Data on annual fluctuations of the lake level were available for the period from 1927 to 1998 from a hydrometer, sited in the town of Bolsena, at the northeast lake coastline (Fig. 1). These data records were used to detect periods of highest and lowest levels that could be related to the development of shore erosion (Fig. 5). The mean lake level elevation for the period analysed is 304.28 m a.s.l. By Fig. 5, it is evident a clear lower level of the lake in the 1940–1950 (mean~304.10 m a.s.l.) followed by two higher periods in '60 and '70 until beginning of '80 (mean~304.50 m a.s.l.). Since middle '80 to the end of '90 the level decreased around or below the mean (mean~304.20 m a.s.l.).

Even if there is a yearly variation of lake level with a maximum level in February/March and a minimum level during the period from October to December, with an annual amplitude around 0.3–0.4 m, in this study only the mean annual value was considered in order to detect general periods of higher or lower levels. The data on wind intensity and direction as well as the lake-level fluctuations were used to discuss possible causes of differences in erosion rates at different sections of the lake shore.

Fig. 2. Tree morphology survey: "erosion step" (height from root collar and actual shore level) and distance of tree from shoreline (B).

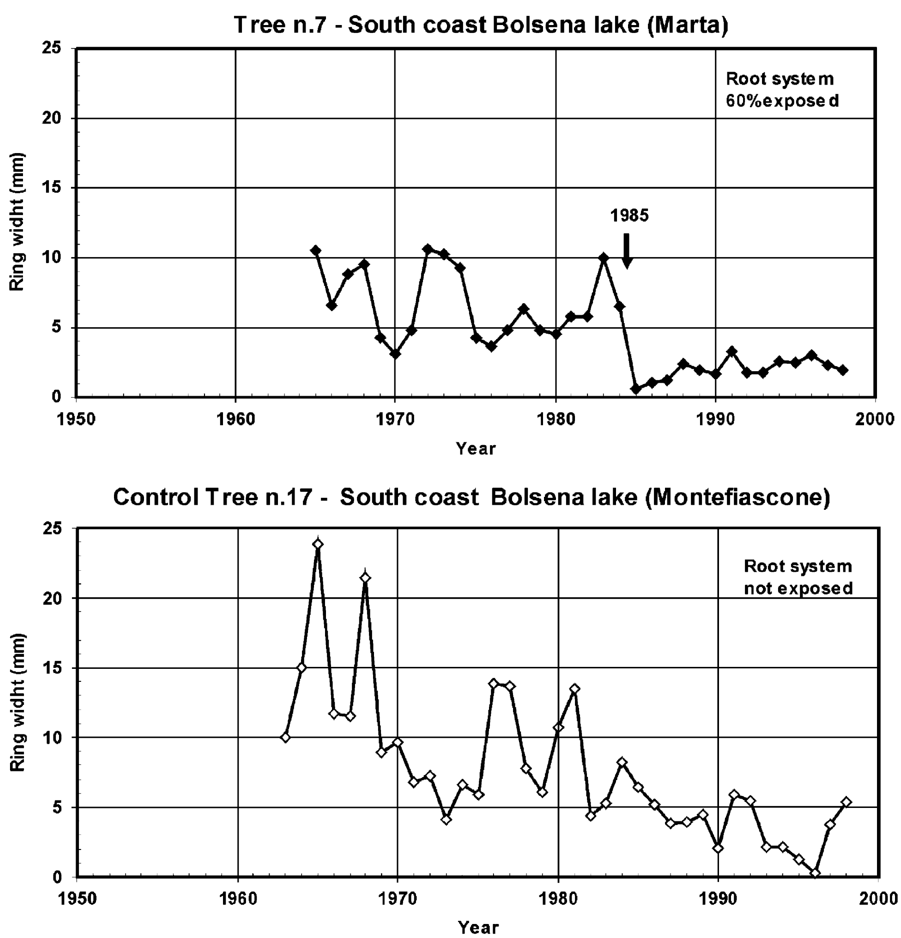

Fig. 3. Examples of black poplar tree-ring series of a tree affected by root exposure (no. 7) or not affected by erosion (control tree no. 17).

Results

Geomorphological results

From a geomorphologic point of view, the morphological analysis of the sample trees near the shore formed a perfect strategy to record the erosion since the trees have been planted and was essential to assess and understand the intensity and dynamic of the erosion that is affecting different parts of the lake shoreline. The erosion process influenced the whole shore with different intensities, testified by trees along the lake placed at different distance from the shoreline. Most the root systems of the sample trees are exposed at different degrees varying from 0% to 85% (Table 1). Exposed roots were often damaged and only if recently exposed were still alive. The recording of the erosion steps (Fig. 2) at all sample trees along the Bolsena lake coastline allowed to produce a map of the degree of erosion in 1999 (Fig. 6). Due to the degree erosion that was registered the shoreline was divided into four classes (no erosion step, erosion step 0–0.5 m, erosion step 0.5–1.2 m and rocky or anthropogenic coast; Fig. 6). Erosion steps higher than 1.2 m were not detected because of the shallow root system of black poplars. An erosion step higher than 1.2 m will induced trees to die because of complete uprooting and falling down into the lake. Fig. 6 clearly indicates that the most eroded zones are located at the northern and southeastern sides of the coast, besides some more fragmented areas occur at the eastern and western coast. This map can be considered as a photograph of the erosion effects, surveyed in 1999, along the entire coastline.

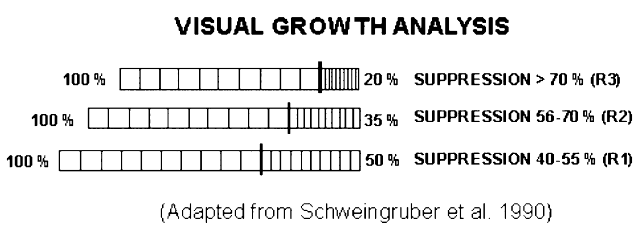

Fig. 4. Suppression classes of visual growth analysis (adapted from Schweingruber et al., 1990).

Dendrogeomorphological results

Dendrochronology was used to calculate the rate of horizontal erosion along different sectors of the Bolsena lake. The growth of most of the sample trees that are living along the coastline, was clearly affected by the erosion that uprooted a percentage of root system varying from 10% to 85% (Table 1). It becomes obvious that the most of the trees fall into the 41–60% category, followed by 21–40% and 61–85%. No trees with a percentage greater than 85% of root system exposed were found because those trees died or have been fallen down into the lake. A clear relation was found between the degree of exposure of the root system and the distance of the black poplars from the shore: trees close to the shoreline had the root system exposed up to 80–85% while those at greater distance were progressively less exposed. 34% of the sampled trees, in addition to growth suppressions, also showed tilting

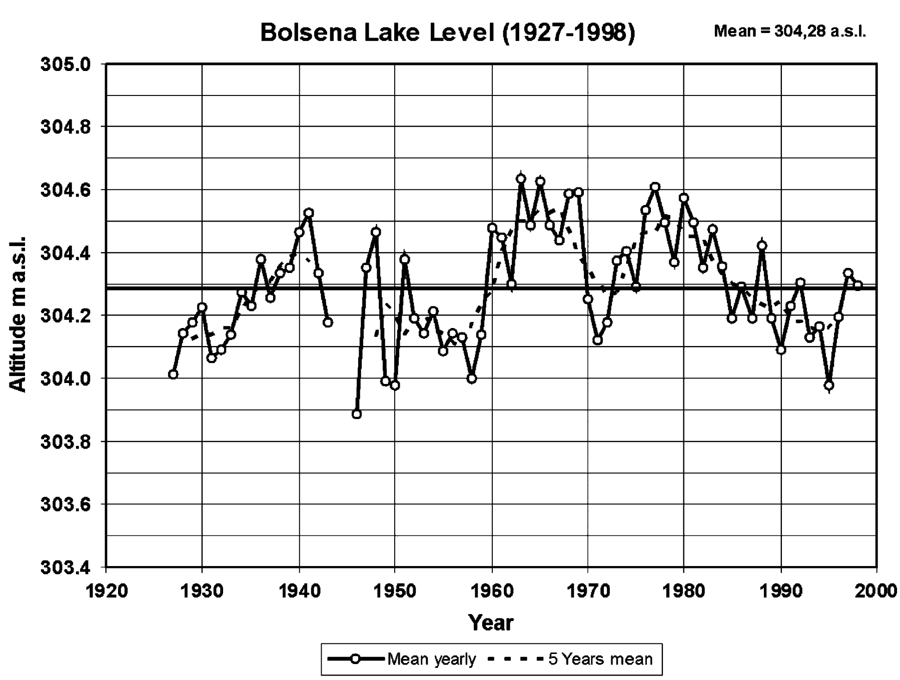

Fig. 5. Diagram of mean annual lake level data in Bolsena lake measured by an hydrometer, sited in Bolsena town (1927–1998).

Table 1. Root system exposure and suppression classes

Species	Exposed root classes (%)			
Black popular (n = 32 trees)	0–20%	21–40%	41–60%	61–85%
	6%	25%	47%	22%
	Ring growth suppression classes%			
1°R = 40–55%	1°R = 50%	1°R = 50%	1°R = 53%	1°R = 8%
2°R = 56–70%		2°R = 37%	2°R = 27%	2°R = 44%
3°R > 70%		3°R = 13%	3°R = 7%	3°R = 28%
	No = 50%	No = 0%	No = 13%	No = 0%

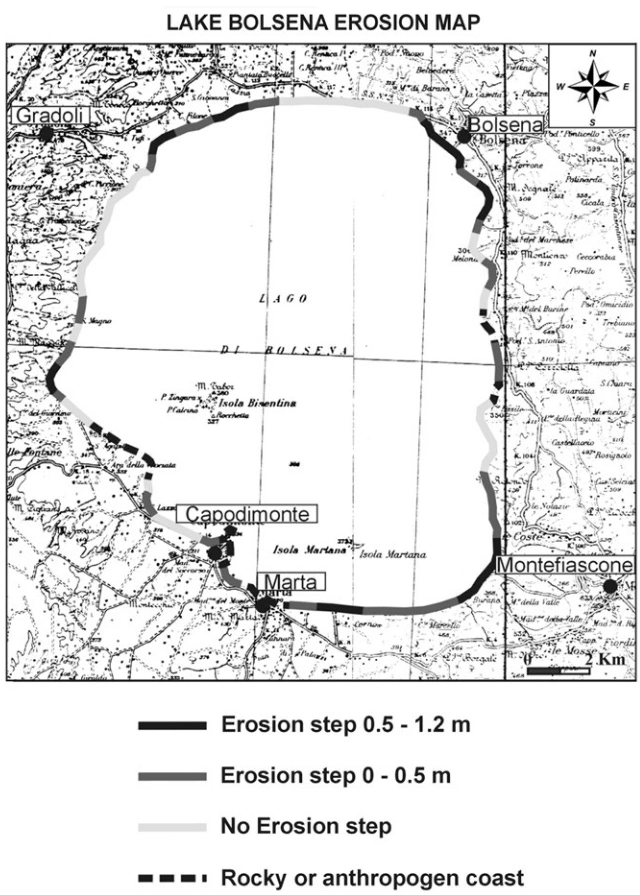

Fig. 6. Map of erosion along Bolsena lake coastline (1999) with different erosion classes and rocky or anthropogenic coast.

towards the shore, due to the abrasion of soil around the root system on shore side. All trees sampled and placed at a distance from the shore (10–50 m), not affected by erosion process, were used as control trees. As shown in Fig. 3, the sudden growth suppression on trees affected by erosion process, could last more than one decade; this growth anomaly was not detected in all control trees.

Table 1 also summarises the suppressions for each class of root exposure. In this context, it is interesting to mention that not all species reacted in the same way to the uprooting: black poplar, white willow and black locust show very sensitive growth reaction with the formation of prolonged suppressions while common alder only a weak suppression in growth even at 70% roots exposure. The general tendency in black poplar is that a higher degree of root exposure goes together with more intense growth suppressions (Table 1). This holds especially true for the strongest growth suppressions of the R3 category whereas the results for R1 and R2 are less consistent. The maximum growth suppression (R3) is most common when the percentage of root exposure exceeds 61%, but it can also be found when it is lower. Based on the dating of the beginning of growth suppression from the sample trees the main horizontal erosion rate along four sectors of Bolsena lake coastline was calculated (Fig. 7).

The relation between the beginning year of a growth suppression in each sample tree and the trees' relative distance from the shore (as recorded in January 1999) is shown in Fig. 7. All four graphs clearly show that trees close to the lake shore contain growth suppressions that date back to the early and mid-1970s whereas trees located further away from the lake shore show suppressions that started in the 1990s.

The main horizontal rate of erosion gives a quantitative evaluation on the speed of the erosion process and was calculated using the equation of linear regression trend for each lake sector (Fig. 7). The greater the slope of the interpolating line, the greater the rate of erosion. Fig. 7 clearly illustrates that the southern shore is the most affected zone where growth anomalies started as soon as early in the 1970s; the mean erosion horizontal rate was calculated as 0.092 m/year affecting trees from a minimum distance of 3–4 m up to 7–8 m from the shoreline. The second-most affected sector is the northern one, where the erosion started to be recorded by trees since the mid-1970s with a mean erosion rate of 0.064 m/year, affecting trees from a minimum of 1–2 m to a maximum of 4 m of distance from the shore. The eastern shore is less affected with a mean erosion rate of 0.049 m/year, affecting trees from 1 to 2 m up to 4 m of distance from the shore. Least affected were the trees of 0–1 m up to 3 m of distance from the shore at the

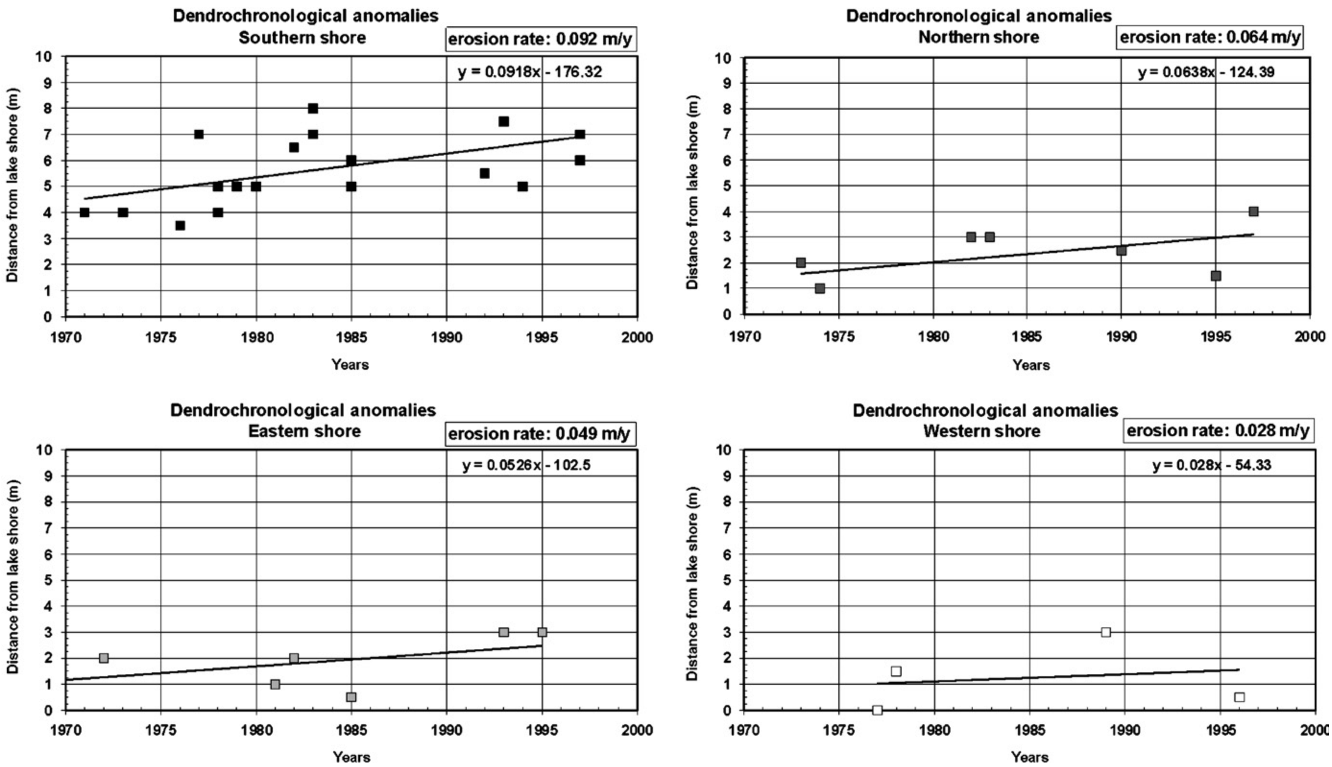

Fig. 7. Graphs of erosion rate (horizontal) computed on different zones of Bolsena lake coastline (northern, southern, eastern and western) through initial dating of tree suppression and their distance from the shoreline.

western shore with a mean rate of 0.028 m/year. However, the mean erosion rates at the eastern and especially the western shore are calculated from only a few observations and are therefore less reliable.

Fig. 7 also demonstrates an inverse relationship between the distance of the trees from the shoreline and the intensity of erosion process. On the southern shore with a high intensity of erosion (erosion step >1.2 m) all trees closer than to 3–4 m were completely uprooted and swallowed by the lake. At the least affected coastline, the western side, however, where the erosion process was less intense, it was possible to sample trees very close to the shoreline (0–1 m). Moreover, information about the temporal pattern of erosion in the four lake sectors was available by looking at the date when growth depressions started; i.e. earliest in the trees with most exposed roots at the southern coast (beginning 1970s), somewhat later at the northern coast (mid-1970s) and latest in the trees with least exposed roots (middle–late 1970s on western coast).

Discussion

This study, conducted at the Bolsena lake, is the first in Europe where the effect of an erosion process on living trees is investigated. In previous studies such as the one by Bégin et al. (1991) tree morphology was used to reconstruct isopachs (thickness of sediment removed from the base of trees) maps of erosion along the St. Lawrence estuary in Canada (Bégin et al., 1991). A similar approach was used in this study whereby the morphological patterns of trees sampled along the Bolsena lake were analysed. By relating the distance of the trees from the shoreline and the height of the erosion step it was possible to develop an erosion map for lake Bolsena (Fig. 6) which can be considered as a valuable tool to monitor the erosion in time. By repeating the morphological survey of trees along the shore coast like it was done in 1999 it will be possible to follow development of the erosion process in future. The erosion map (Fig. 6) clearly evidences that the southern and northern coastlines are more affected by erosion than the other parts (Fig. 8). By looking at available data of wind direction, wind speed and wind intensity (Table 2) it becomes obvious that the southern and north (eastern) coast are directly hit by the most intense and persistent winds, which generate high and powerful waves. Wind intensity and fetch length (the longest distance without obstacle along which winds can blow on the lake surface) are responsible for the creation of waves that directly induce abrasion on the sandy shore. This explains the strong relationship between the degree

Fig. 8. Erosion along Bolsena lake, southern shore, in January 1998 with an evident increase of uprooting in October 2005.

Table 2. Wind data

Direction	Speed (knots)	Frequency (%)
N	18.92	8.57
NE	10.34	17.93
E	0	0
SE	6.25	4.72
S	12.93	14.11
SO	12	1.69
O	0	0
NO	0	0
	Calm	52.98

of erosion and the uprooting of trees and the exposure to prevailing winds along the shore of the Bolsena lake with the southern coastline being most affected.

Trees growing around the Bolsena lake that were subjected to erosion stress show striking prolonged growth suppressions. This feature was taken as dendrohydrological evidence to date the beginning of erosion stress. The same dendrohydrological evidence was found by Bégin et al. (1991) on trees, living along the estuary of St. Lawrence river in Québec, Canada. In both studies, uprooted trees showed sudden radial growth decrease (suppression) and similar "erosion steps" were detected. A comparison between the intensity of the suppression (categorized in the three classes R1, R2, R3) and the percentage of root system exposure found on trees (Table 1) showed that already a low percentage of root exposure ($<20\%$) is enough to induce a growth suppression of class R1 in black poplar trees. The intensity of growth suppression classes, found on sampled trees, generally tended to increase from R1 (growth reduction 40–55%) to R2 (growth reduction 56–70%) or to R3 (growth reduction $>70\%$) with the increasing exposure of the root system (Table 1), with some exceptions. This analysis proves that growth suppressions can be used as indicator for the intensity and timing of root exposure. This is in accordance with results of previous studies where dendrochronological analysis was used to calculate past erosion rates along slopes (Valmore et al., 1968; Carrara and Carroll, 1979; Hupp and Carey, 1990), streams (Valmore and LaMarche, 1966) or gully erosion (Vandekerckhove et al., 2001) as well as erosions along the shore of the upper St. Lawrence Estuary in Québec (Bégin et al., 1991).

In this study, the horizontal erosion rate (= erosion in metres per year) along different sectors of Bolsena lake was reconstructed by dating the beginning of growth suppressions in trees at different distance from the shoreline (Fig. 7). Again, it was found that erosion proceeds fastest (0.092 m/year = 9.2 cm/year) at the southern shore, which is most beaten by intense and frequent winds, followed by the northern side (6.4 cm/year) and then by the eastern (4.9 cm/year) and western (2.8 cm/year) lake coastline (Fig. 7). According to the data of mean annual lake level fluctuation (Fig. 5), the initial dating of growth anomalies recorded by trees goes up to the 1970s and seems so connected to one of the highest lake level period (1960–1970) since the trees' planting. Some of trees sampled that reached the pith are 40–60-year old and planted during the lowest lake level period of the hydrometer records (1940–1960).

In this context, it has to be mentioned that Bégin (2000) in a study on black spruce in Canada found a time lag between stress occurrence (root exposure) and growth reaction (growth suppression) of 2–3 years. At the moment no information is available on the length of a possible time lag for trees growing around the Bolsena lake. Photographs that have been taken during the last decade along the lake coast (Fig. 8) seem to support that the time necessary to expose a great amount of root system is quite short (within 5 years). Consequently, growth suppressions as a reaction to exposures are expected to occur with only a short delay of probably 1–3 years depending on the intensity of the erosion.

A promising tool with the potential to exactly date the exposure of roots is to study changes in wood anatomy. It has been shown that sudden changes in the root wood structure occur when roots are exposed (Gärtner et al., 2001). A preliminary study on 20 root cores of black poplar from the Bolsena lake indicated a striking change in wood anatomy with a shift from large and dense vessels to little vessels after exposure (Fig. 9). Using

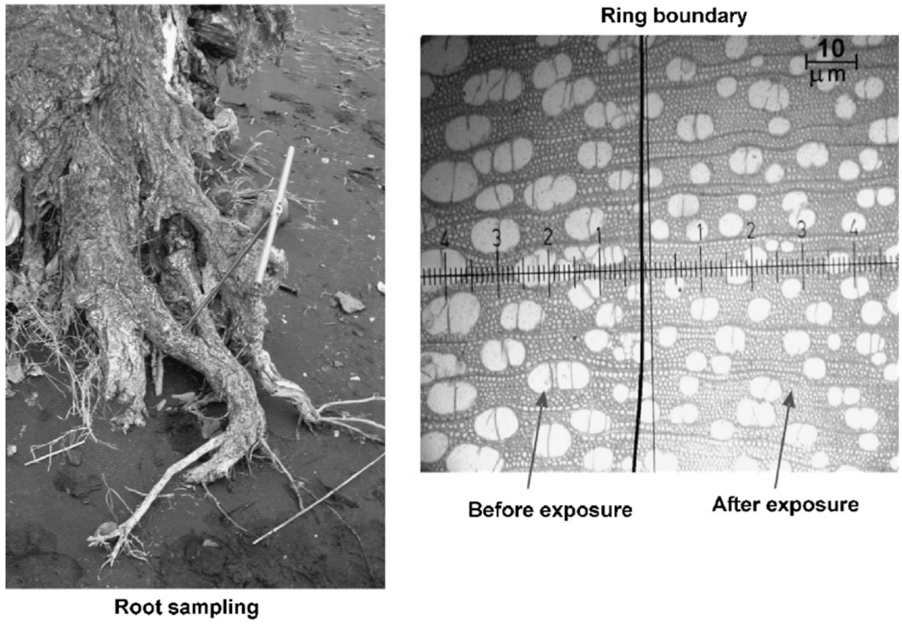

Fig. 9. Wood anatomy changes in black poplar roots with sudden decrease of vessels size after exposure.

roots to investigate erosion process is still at the beginning, and it was used mostly on conifers trees.

Erosion can be considered as a discontinuous process, carried on during windy times by lake waves abrasion on the sandy shore. Therefore, the collected data on the starting date of the suppressions were considered as uniform along the whole coastline meaning that a possible time shift would not considerably change the results.

Due to the limited age and type of species of sample trees (mostly planted, ~50-year age) they have shallow root system, without deep anchoring roots. This can be considered as a limiting factor in this dendrogeomorphic analysis because it did not allow to analyse the erosion process further back in time. However, older trees growing close to the shore at Bolsena lake were not available because they got completely uprooted and carried off into the lake; moreover black poplar does not get usually very old (<100 years). Despite this, dendrochronology was successfully used to investigate the intensity and timing of the erosion process affecting the whole coastline of the Bolsena lake during the last 30 years. The horizontal erosion rates (m/year) calculated are in good agreement with the photographic records taken in the southern part of lake during the last decade (Fig. 8). The occurrence and intensity of growth suppressions due to erosion agrees very well with the exposure to winds with the most exposed sectors of the coast being most affected by more and intense suppressions in tree growth. However, the first growth suppressions recorded by (the relatively young) sample trees occurred around 1970 and thus are connected to one of the peaks in lake level (1960–1970) since the time when the sample trees were planted. It is likely that the erosion phenomenon established in the lake between 1960 and 1970 when the lake level was higher but it continued to develop until nowadays even when the lake level was lower (1980-late 1990) as testified by growth anomalies constantly found on trees all along the shoreline since 1970 until the end of 1990 (Fig. 7) and recorded by photographs (Fig. 8). This suggests that the erosion process occurring along the Bolsena lake, besides the direct effect of winds and lake-level fluctuation, belongs to a more complex problem that could involve other changes that probably occurred also before the 1960–1970 on the hydrographic lake basin. Possible candidates are land-use modification or regional shifts in climate or hydrology. Interestingly, similar uprooting on shoreline trees were also found at the Bracciano lake, another volcanic lake, close to Rome (Fig. 1), suggesting that a wider regional erosion process might be going on in the Latium region in Central Italy (Fantucci R. *unpublished data*).

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References

Alestalo, J., 1971. Dendrochronological interpretation of geomorphic processes. Fennia 105, 1–140.

Bégin, Y., 2000. Reconstruction of subarctic lake levels over past centuries using tree rings. Journal of Cold Regions Engineerings 14 (4), 192–212.

Bégin, Y., 2001. Tree-ring dating of extreme lake levels at the subarctic–boreal interface. Quaternary Research 55 (2), 133–139.

Bégin, Y., Payette, S., 1988. Dendroecological evidence of lake-level changes during the last three centuries in subarctic Québec. Quaternary Research 30, 210–220.

Bégin, Y., Payette, S., 1991. Population structure of lakeshore willows and ice-push events in subarctic Québec, Canada. Holarctic Ecology 14, 9–17.

Bégin, Y., Langlais, D., Cournoyer, L., 1991. A dendrogeomorphic estimate of shore erosion, Upper St. Lawrence Estuary, Québec. Journal of Coastal Research 7 (3), 607–615.

Borel, J.L., Brochier, J.L., Lundstrom-Baudais, K., 1985. Water level fluctuations of the lake of Paladru (Isère, France) in the Xth and XIth centuries AD. Ecologia Mediterranea 11 (1), 179–183.

Carrara, P.E., Carroll, T.R., 1979. The determination of erosion rates from exposed tree roots in the Piceance Basin, Colorado. Earth Surface Processes (4), 307–317.

Casadoro, G., Castiglioni, G.B., Corona, E., Massari, F., Moretto, M.G., Paganelli, A., Terenziani, F., Tondello, V., 1976. Un deposito Tardowurmiano con tronchi subfossili alle Fornaci di Revine (Treviso). Bollettino del Comitato Glaciologico Italiano 24, 22–64.

Eronen, M., Hyvärinen, H., Zetterberg, P., 1999. Holocene humidity changes in northern Finnish Lapland inferred from lake sediments and submerged Scots pines dated by tree-rings. The Holocene 9 (5), 569–580.

Frey, D.G., 1954. Evidence for the recent enlargement of the "bay" lakes of North Carolina. Ecology 35 (1), 78–88.

Fritts, H.C., 1976. Tree Rings and Climate. Academic Press, London/Orlando, 567pp.

Gärtner, H., Schweingruber, F.H., Dikau, R., 2001. Determination of erosion rates by analyzing structural changes in the growth pattern of exposed roots. Dendrochronologia 19, 81–91.

Gunnarson, B.E., 2001. Lake level changes indicated by dendrochronology on subfossil pine, Jamtland, central Sandinavian Mountains, Sweden. Arctic, Antarctic and Alpine Research 33 (3), 274–281.

Holmes, R., 1983. Computer-assisted quality control in tree-ring dating and measurements. Tree-ring Bulletin 43, 69–78.

Hupp, C.R., 1988. Plant ecological aspects of flood geomorphology and paleoflood history. In: Baker, V.R., Kochel, R.C., Patton, P.C. (Eds.), Flood Geomorphology. Wiley, New York, p. 335−356.

Hupp, C.R., Carey, W.P., 1990. Dendrogeomorphic approach to estimating slope retreat, Maxey Flats, Kentucky. Geology (18), 658–661.

Locardi, E., Lombardi, G., Funiciello, R., Parotto, M., 1976. The main volcanic groups of Latium (Italy); relations between structural evolution and petrogenesis. Geologica Romana 15, 279–300.

Leepage, H., Bégin, Y., 1996. Tree-ring dating of extreme water level events at Lake Bienville, subarctic Québec, Canada. Arctic and Alpine Research 28 (1), 77–84.

Schweingruber, F.H., 1996. Tree Rings and Environment: Dendroecology. Paul Hapt Verlag, Berne, 609pp.

Schweingruber, F.H., Eckstein, D., Serre-Bachet, F., Braker, O.U., 1990. Identification, presentation and interpretation of event years and pointer years in dendrochronology. Dendrochronologia 9, 9–38.

Sigafoos, C.R., 1964. Botanical evidence of floods and floodplain deposition. United States Geological Survey Professional Paper 485-A, 35pp.

Stockton, C.W., Fritts, H.C., 1973. Long-term reconstruction of water level changes for Lake Athabasca by analysis of tree rings. Water Resources Bulletin 9, 1006–1027.

Tardiff, J., Bergeron, Y., 1997. Ice-flood history reconstructed with tree-rings from the southern boreal forest limit, western Québec. The Holocene 7 (3), 291–300.

Valmore, C., LaMarche Jr., V.C., 1966. An 800-year history of stream erosion as indicated by botanical evidence. Geological Survey Research (550-D), D83–D86.

Valmore, C., LaMarche Jr.,V.C., 1968. Rates of slope degradation as determined from botanical evidence White Mountains California. Geological Survey Professional Paper, pp. 341–377.

Vandekerckhove, L., Muys, B., Poesen, J., De Weerdt, B., Coppé, N., 2001. A method for dendrochronological assessment of medium-term gully erosion rates. Catena 45, 123–161.