

MARK BERTOGLIATI (*)

HISTORICAL AND DENDROECOLOGICAL RECONSTRUCTION OF PAST DISTURBANCES AND DYNAMICS IN ANCIENT PROTECTIVE FORESTS: A CASE STUDY FROM SOUTHERN SWITZERLAND

In the European Alps, ancient protective forests have represented important landscape and cultural features for centuries. At the present time they often host interesting plant communities with varied structures and extreme age not far from those observed at the upper tree-line or in inaccessible sites. This is primarily a result of past management that precariously balanced the forest's strong protective properties and its resources. Therefore, ancient protective forests represent very interesting research topics, especially if they show unevenly-aged structures, century-old stand continuity and singular historic or naturalistic features. The present study aims to reconstruct past disturbances and the age structure of an ancient coniferous forest located on the southern slopes of the Swiss Alps (Canton Ticino, Switzerland), by means of historical and dendroecological data. Results show that during the last three centuries of human activity (especially logging but also traditional non-timber forest use) has had a considerable impact on the study area. In contrast, exogenous disturbances (natural events) are supposed to have influenced forest structure more on a local scale. Endogenous dynamics appear to be fairly significant, especially after a decrease in human activity and the abandonment of traditional forest practices. The timing and intensity of disturbances coincide reasonably well with potential anthropogenic causal factors. Knowledge of local forest dynamics and past disturbance regimes could help forest managers to better understand changes and, at the same time, help historians to analyse the impact of driving forces and single events on past landscapes.

Key words: dendroecology; forest history; protective forest; forest dynamics; Swiss Alps.

Parole chiave: dendroecologia; storia forestale; foreste di protezione; dinamiche forestali; Alpi svizzere.

1. INTRODUCTION

For centuries, protected forests have played an important role for local communities and society in general in the European Alps. Their institution is historically linked to protection against natural hazards (MOTTA & HAUDE-

(*) Forest engineer and PhD student. Swiss Federal Institute of Forest, Snow and Landscape Research (WSL). Research Group Insubric Ecosystems; via Belsoggiorno 22, 6500 Bellinzona, Switzerland; tel: +41 91 821 52 33; mark.bertogliati@wsl.ch

MAND, 2000), but also to socioeconomic and political motivations (SCHULER, 1992). Towards the end of the 18th century, the high demand for wood and charcoal from urban areas resulted in a dramatic increase in forest exploitation in alpine regions. In this context of drastic landscape changes, ancient protected forests increased in value in terms of their wood reserves and protective elements. In Switzerland, furious debate regarding natural hazards and socio-economic changes lead to the formulation of the first Federal forest law in 1876 and the official recognition of the public role of forests (the new and still actual concept of «protective forests»). Assuring adequate protection for human settlements and road systems is still the main focus of silvicultural intervention today, particularly in forests with a direct protective function. At the present time, ancient protective forests show varied structures and extreme ages not far from those observed at the upper tree-line or in inaccessible sites (RIGLING & SCHWEINGRUBER, 1997; RIGLING *et al.*, 2004). Furthermore, they often host interesting plant communities (CESCHI, 2006), partly as a result of a long ecological continuity and past human influence. Understanding past dynamics in these forests could provide useful information for their proper and responsible management based on their historical, ecological and silvicultural importance. The most common methodologies applied to study past forest dynamics involve the establishment of long-term experimental plots and the analysis of paleoecological data. In particular, dendroecological techniques have been used in several studies in order to reconstruct forest stand origin and disturbance regimes, both in old-growth (e.g., ABRAMS *et al.*, 1997; WINTER *et al.*, 2002; SPLECHTNA *et al.*, 2005; FIRM *et al.*, 2009) and managed forest ecosystems (e.g., FOSTER *et al.*, 1992; McLACHLAN *et al.*, 2000; MOTTA *et al.*, 2002). Historical records and other independent sources of data were integrated with dendroecological approaches, particularly where human activities were supposed to have played an important role in forest dynamics (MOTTA & LINGUA, 2005; MOTTA & EDOUARD, 2005). Given this, the present study aims to reconstruct past disturbances and age structure in a mixed coniferous forest located on the Southern slopes of the Swiss Alps (Canton Ticino, Switzerland), by means of historical and dendroecological data, with a view to providing information about the impact of human activity and natural events on the forest over the last centuries.

2. MATERIAL AND METHODS

2.1. Study area

The study area is located in the municipality of Sobrio (46°23' N, 8°53'E), in the lower part of the Leventina valley (Canton Ticino, Switzerland). The studied forest is located above the village between 1,100

and 1,500 m a.s.l. and extends over 150 hectares (Fig. 1). It is dominated in the lower part by mixed coniferous stands with Scots Pine (*Pinus sylvestris* L.) and Norway spruce (*P. abies* (L.) Karst.) belonging to the unit *Luzulo niveae-Piceetum typicum* and, on more dry and shallow soils, to the unit *Calluno-Pinetum silvestris*. Stands in the upper part of the study area are characterized by a strong presence of Norway Spruce with considerable heights and good fertility, Scots pines and sporadically Larch (*Larix decidua* Mill.). The quite significant presence of Silver fir (*Abies alba* Mill.) over scattered pockets with deeper soils is attributable to vegetational suitability (unit: *Calamagrostio-villosae-Abieti-Piceetum melampyretosum*). In the steepest zones, the forest has developed relatively undisturbed over the last 50 years, according to local conditions, thus forming more or less dense stands, with only scattered recruitment on small-scale gaps and favourable micro-sites (TOGNINI & GRANDI, 2009). The studied stands show generally mature trees, reaching ages of more than 300 years, with considerable volumes particularly in the upper part of the area. The bedrock is composed of granitic and porphyric gneiss on which a mosaic of deeper brown and shallow ranker soils has developed. Annual precipitation is about 1500 mm and the mean annual temperature is 7.2°C.

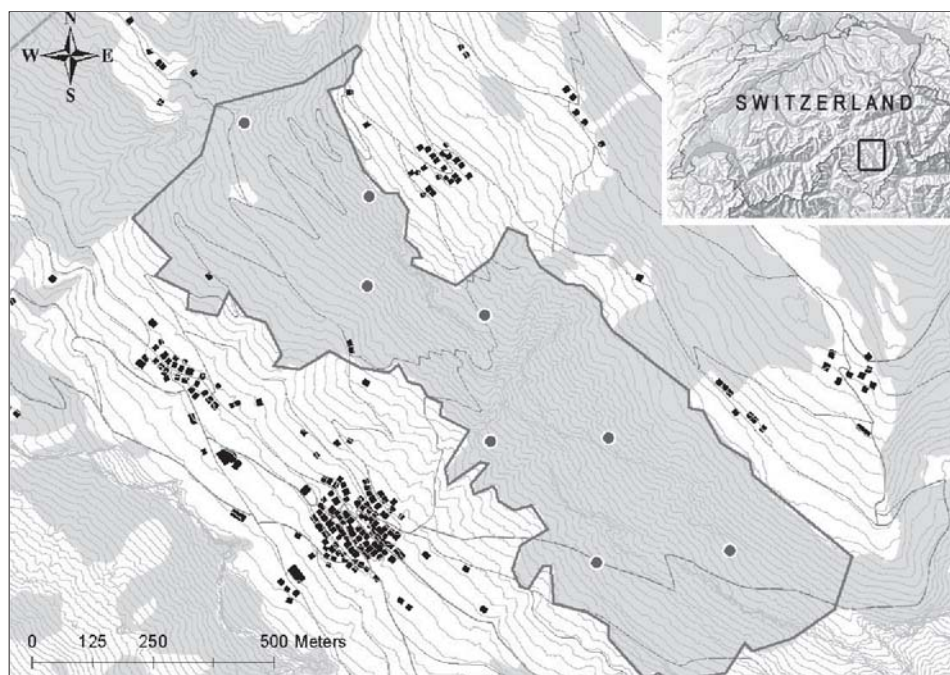


Figure 1 – Study area with 8 plots localised in the protection forest above the village of Sobrio. The dark shaded area represents forest cover. The equidistance between the contour lines is 10 m.

2.2. Data collection

To examine age structure and disturbance history, we localised 8 plots placed along two parallel transects running across the study area (Fig. 1). This number of plots was empirically set in order to limit the number of cored trees to a reasonable amount while reaching a quite homogeneous coverage of the study area, reducing at the same time the chance of studying a unrepresentative portion of the stand (LORIMER, 1980; FIRM *et al.*, 2009). The upper and lower edges of the forested area were avoided because of their recent formation following the abandonment of cultural practices that occurred in the last 5-6 decades. The plots have variable surface areas (mean size of 560m²), always corresponding to the space occupied by 10-15 dominant trees. Overall, 210 trees were cored (25-30 trees for each plot). The presence of stumps resulting from recent cuts allowed us to take 30 cross-sections. This was useful in order to build reliable master chronologies for Scots pine and Norway spruce. Cores were taken at a height of 50 cm above soil level, perpendicular to the slope, in order to avoid reaction wood. Sampling at this height has certain limitations because of the irregularity of growth in the lower part of the trunk (MOTTA & LINGUA, 2005) and the difficulty in estimating the exact age compared to sampling at the root collar level (PETERS *et al.*, 2002). Therefore, ages reported for all trees could be differentially underestimated depending on past canopy conditions, competition and ecological attributes of individual species. To account for any errors, age structure was constructed for 10-year classes (MOTTA & EDOUARD, 2005). In order to reduce cross-dating problems, we took a second core sample upslope at a height of 1.3 m from 80% of the sampled trees. Trees with a diameter at breast height (DBH) of < 16 cm were not cored, in order not to damage understory trees in this important protective forest. For each plot, we localised all living and dead trees. For every single tree or log $\geq$ 10 cm DBH, the diameter was measured at breast height. Furthermore, all stumps were identified and their diameters were measured at the base of the trunk. Finally, we examined available historical records in order to reconstruct the impact of human activity and natural events on the stands in question. We were able to find the most interesting documents in the local archives (registers, correspondence and forest regulations from the 16th to 20th century as well as a 1954 forest management plan). The aim was to calibrate information from tree-rings and written documents for the recent phase with maximal availability of historical records (after 1850). After having improved our methodology for the best documented period, we used the same interpretation pattern for the previous period that had mainly incomplete and heterogeneous historical records.

2.3. Analysis

The increment cores were dried, mounted on wooden supports and then sanded with progressively finer grades of sand paper. Single tree-ring series were measured to the nearest 0.01 mm with the DENDROTAB system (Walesch Electronics GmbH.) and then visually and statistically cross-dated using TSAP-WinTM software (Rinntech Inc.). Only samples with visible pith or showing complete arcs were included in the age structure analysis. For cores taken at a height of 1.3 m, the distance to pith was estimated using a graphical method, based on the convergence of xylem rays combined with an increment model (ROZAS, 2003). Age estimates obtained through this combination provided good results for the present study compared to a widely used geometric method (DUNCAN, 1989). For age structure analysis (age-class distribution), we used 180 samples overall from living trees and recent stumps. For the reconstruction of disturbance history, we statistically analysed growth trends in 210 samples. Growth pulses were identified using a running mean radial-averaging method (FRAVER & WHITE, 2005; RUBINO & MCCARTHY, 2004), by means of JOLTS software (version 6.01P, R.L. Holmes) from the LTRR library (BERG *et al.*, 2006; BROSE & WALDROP, 2006). We used conservative criteria, where only abrupt (> 100% growth increment) and sustained (> 15 years) growth releases were selected (MCEWAN & MCCARTHY, 2008; LORIMER & FRELICH, 1989). To complete the disturbance chronology, we also analysed early growth trends of complete samples. Individual trees with rapid growth rates within the first years since establishment and, for shade intolerant species, subsequent declining or constant growth patterns (LORIMER *et al.*, 1988; FIRM *et al.*, 2009), were considered to have originated in gaps (after so-called gap-origin events according to LORIMER & FRELICH, 1989). For the present study, we empirically assigned a rather conservative threshold to define a rapid early growth rate (mean radial increment of 1.5 mm/yr within the first 30 years). Based on all such gap-origin events and abrupt growth releases, a disturbance history for the 8 plots was constructed showing the percentage of trees in each decade that had experienced a disturbance event (MOTTA & NOLA, 2001). For both analyses (age structure and disturbance history), data were plotted in 10-year age classes to account for errors deriving from age estimates (MOTTA & NOLA, 2001) or delayed reactions of trees after disturbances (MOTTA & GARBARINO, 2003; LORIMER & FRELICH, 1989).

Finally, present age structure and tree species composition were reconstructed by means of collected data. We tried to depict recent forest dynamics by comparing our results with the 1954 Forest Inventory (VIGLEZIO, 1954). To facilitate a meaningful comparison over the same area, we selected data from 5 plots (= 0.32 ha) corresponding to one 'section'

according to the old Forest Management Plan. Although we used the original diameter classes ($\geq 16\text{cm DBH}$) and the same tariff, interpretation of results must be cautious given the different methods employed to collect data in the two studies (full-callipering of all trees over 32 ha in 1954 vs. selection of 5 sample plots in the current study).

3. RESULTS

Historical evidence

The first evidence of significant forest exploitation dates back to the 15th century. We found evidence of large cuts in the area for the years 1445, 1554, 1636, 1676, 1685, 1804, 1843 and 1851. In 1559, the local community stipulated a forest regulation mentioning for the first time the protected forest above the village (locally known as 'Faura'). The 1804 document, a contract between the community of Sobrio and a timber merchant, mentions the selective cut of 500 trees in the same forest. According to the local statutes of 1767 wood concessions were not granted in the more sensitive part of the protected forest (area with rock fall activity and the presence of avalanche tracks). In the same area, wild-hay and forest litter collection were also restricted and limited. Nevertheless, significant dispensations were granted to people whose houses or properties had been destroyed by the dramatic fire of 1759, when, in a few hours, about 50 houses and 70 stalls had been burnt down. We estimated that more than 4,000 logs were needed for the entire reconstruction, completed probably before 1770. Furthermore, forest and biomass use were probably increasing in the second half of the 18th century. Complaints concerning wood stealing, other abuses and an increase in wood concessions are continuously mentioned until 1850. In the same period, a significant population growth is documented. That probably caused an uncontrolled increase in timber and non-timber forest use (wild-hay and forest litter collection) for local needs. The period after 1850 is also marked by an increase in emigration, following the great political and economic crisis of the years 1847-1855. Between 1843 and 1873 more than 1,600 people (about 17% of the valley population) emigrated from Leventina, primarily to France, Great Britain and the United States (CHEDA, 1976). Towards 1900, forest use started again, thanks to the new technique of using cableways and the construction of the main road connecting the village to the plain. Data from a local forest management plan (VIGLEZIO, 1954) confirm a mean annual utilization of 450 m^3 (tot.: $27,216\text{ m}^3$) between 1891 and 1954. For the period 1954-2009, utilization decreased to an annual mean of 240 m^3 (tot.: $13,212\text{ m}^3$). According to historical records, we can state that the forest in the

study area was relatively spared from large natural events, at least during the last two centuries. The most substantial avalanches (winters of 1794-95, 1924-25, 1950-51) caused damage only on the edges of the protected forest and above 1,700 m a.s.l. Flooding, debris flow, windthrow and rock fall had only a limited impact on the forest, compared to major events that occurred in other parts of the Leventina valley (DOTTA, 2004; ALBISETTI, 1924). In 1973, a large forest fire affected the south-eastern edge of the protective forest above the village, without causing damage in the study area.

3.2. Stand characteristics

The studied stands show apparently natural structure and composition, with the presence of downed logs, uprooted and broken trees, as well as standing snags near the leftovers of recent cuts (Table 1). We were able to reconstruct recent forest dynamics by comparing collected data with the 1954 Forest Inventory (Table 2). Results show a clear increase in the percentage of trees in the highest diameter class (≥ 52 cm DBH) and a decrease in the 24-35 cm class. Moreover, the timber volume per hectare increased drastically over the last 6 decades. Trends in species composition show an increase in the presence of Silver fir

Table 1 – Structural characteristics of the stands (based on 8 plots = 0.49 ha).

	No. ha ⁻¹
Live trees *	582
Snags *	71
Logs *	41
Old Stumps	269
Recent Stumps (< 15 years old)	131

* ≥ 10 cm DBH

Table 2 – Forest evolution over the last 56 years.

	1954	2009
Inventory area (ha)	32	0.32 *
Diam. Classes (DBH) and Number of trees		
16 – 23 cm	31%	32%
24 – 35 cm	36%	13%
26 – 51 cm	28%	25%
≥ 52 cm	5%	30%
Volume (m ³ ha ⁻¹)	197	352 (388) **
Number of trees ***		
<i>Abies alba</i>	4%	8% (10%)
<i>Larix decidua</i>	2%	1% (1%)
<i>Picea abies</i>	50%	45% (57%)
<i>Pinus sylvestris</i>	44%	45% (32%)
<i>Sorbus aucuparia</i>	0%	1% (< 1%)

Source: Forest Inventory (VIGLEZIO, 1954) and data obtained from current study.

* for 2009 data from 5 plots and ≥ 16 cm DBH.

** using the same tariff (1948); the volume calculated using the most recent tariff (2000) in brackets.

*** ≥ 16 cm DHB; the percentage of species ≥ 10 cm DBH for 2009 in brackets.

and a slight decrease of Norway spruce and Larch. Such trends in the data would probably be only partially confirmed by selecting a smaller diameter threshold, as suggested by percentages marked in brackets in Table 2.

3.3. Disturbance history and age structure

Age structures and disturbance histories obtained from the 8 plots were quite similar, therefore we decided to present data for all plots combined. Within the periods 1770-1840 and 1900-1950, we can find major peaks in the disturbance chronology, with considerable decreases after 1840 and 1950 (Fig. 2). In the decades starting with 1770, 1780, 1800, 1830, 1900 and 1910, at least 15% of the trees indicate a disturbance event. Between 1770 and 1850, gap-origin events (suggesting establishment in open conditions) are very frequent. Prior to 1770 and after 1850, abrupt growth releases are more frequent than gap-origin events. Temporal recruitment patterns seem to coincide reasonably well with peaks in the disturbance chronology, particularly for the 1770s and 1900s (Fig. 3). Forest stands in the study area are uneven-aged with some individual trees older than 250 years. Young trees are scarce. However, this is partly a consequence of excluding trees with < 16 cm DBH from our analysis. For this reason, age class distribution was presented only until 1950. After 1760, there is a pronounced increase in the establishment of sampled trees with a slight decrease in the 1810s.

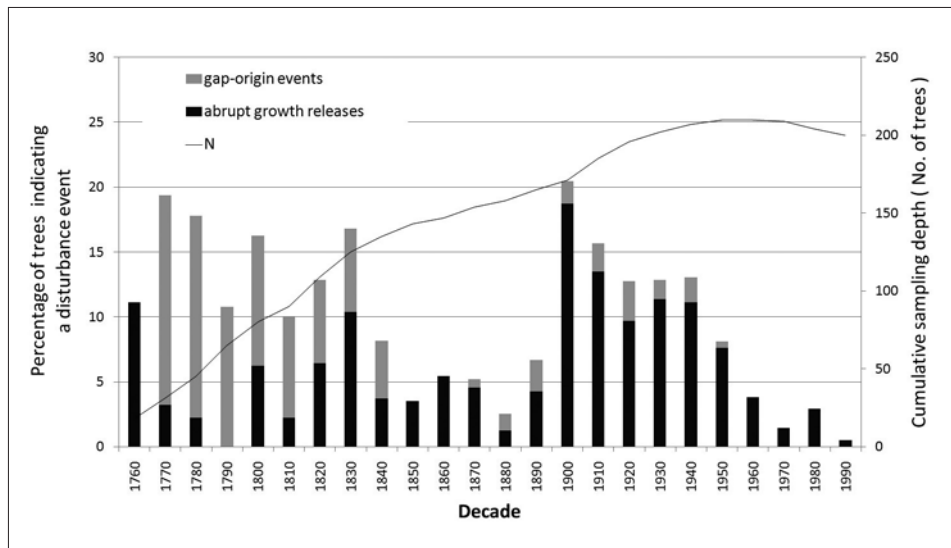


Figure 2 – Disturbance chronology in the 8 considered plots, based on the percentage of trees indicating both abrupt growth releases and gap-origin events. The chronology was truncated in 1760 when the sample depth dropped below 15 trees (according to FIRM *et al.*, 2009).

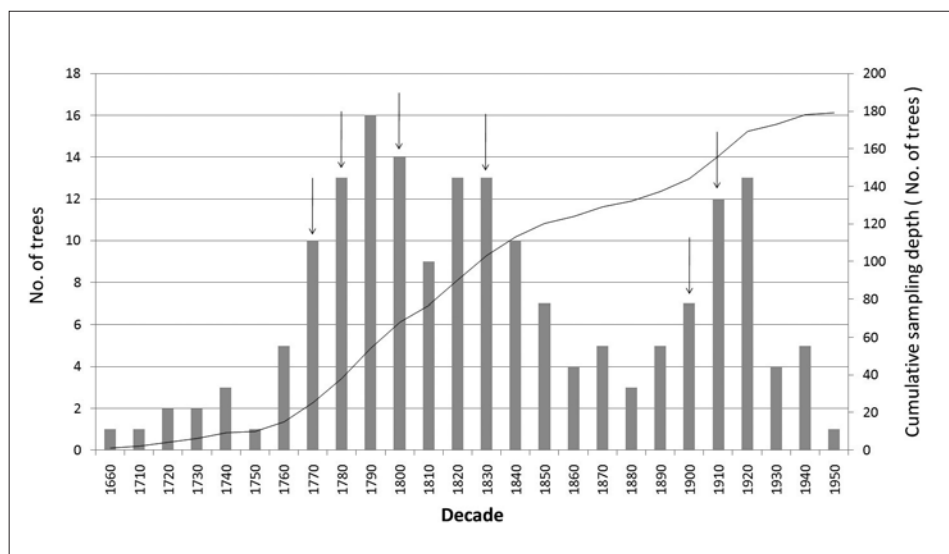


Figure 3 – Establishment of sampled trees per decade (0.5 m coring height). Arrows indicate peaks (> 15% of trees registering a disturbance event according to Fig. 1) in the disturbance chronology.

After 1850, there is an abrupt decline and a new increase after 1890. After 1930 and particularly after 1950, the number of established trees for each decade decreased drastically.

4. DISCUSSION

According to the dendroecological data, the studied stands became less dense after 1760, probably with the presence of large openings and scattered mature trees. This is probably due to a period of high anthropogenic disturbance, following the dramatic fire of 1759. Moreover, local population growth and a rise in wood demand from urban areas was also reflected in increased forest use, abuse and wood plundering towards the end of the 18th century. Peaks in the establishment of sampled trees and disturbance chronology between 1760 and 1850 seem to confirm this hypothesis. The emigration wave after 1850 and the stagnation of wood demand (CESCHI, 2006) probably caused a decline in timber forest use. This is also confirmed by a pronounced decrease in disturbances (Fig. 2). The renewed increase of selection cuts and thinnings after 1900 (VIGLEZIO, 1954) is also visible in the disturbance chronology. The decrease in forest use after the Second World War is confirmed by recent forest dynamics with an increase in trees in the

largest diameter class and the establishment of shade tolerant species (Table 2). According to historical records, natural events had only little influence over forest structure in the study area. The recurrence and intensity of all mentioned potential causal factors of forest changes in the study area over the last three centuries are summarized in Table 3.

Table 3 – Intensity and recurrence of natural and historical events or phenomena having potential influence over the study area during the last three centuries.

Period	Historical evidence					Dendroecological evidence	
	Large cuts	Evidence of abuse and concessions	Local forest regulations	Emigrations to France and the U.S.	Natural events *	Disturbance events	Establishment of sampled trees
1700-1749							(X)
1750-1799		X	X		(X)	X	X
1800-1849	X	X	X			X	X
1850-1899	(X)	(X)	X	X	(X)	(X)	(X)
1900-1949	X	(X)	(X)	(X)	(X)	X	X
1950-1999			(X)		(X)	(X)	(X)

X: major intensity

(X): minor intensity

* Only affecting forest

5. CONCLUSIONS

The use of different sources of independent data allowed us to formulate a convincing hypothesis about forest dynamics in the study area. The timing and intensity of past disturbances coincide reasonably well with potential anthropogenic causal factors. During the last three centuries, human activity had considerable impact on the studied stands, either directly through forest use or indirectly after a decrease in human activity and the abandonment of forest practices. At the present time, forest structure is varied, with a mosaic of different species, the presence of overmature individuals and small-scape gaps. Results show the important role of past human activities in shaping present forest structure in the study area. Thanks to the significant protective function provided by the studied forest stand, it will be possible also in the future to assure regular silvicultural intervention. However, the long-term maintenance of its present composition and structural variety will need appropriate strategies in order to face some important problems (lack of natural regeneration, menace of wild ungulates). The awareness of local forest dynamics and past disturbance regimes could help forest managers to understand changes and develop appropriate tools.

Additionally, historians could also profit from dendroecological evidence, which is very helpful in analysing the impact of single events and wider dynamics on past landscapes.

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RIASSUNTO

Analisi storiche e dendroecologiche in antiche foreste di protezione: un caso di studio dalle Alpi svizzere

Nell'arco alpino europeo le foreste di protezione hanno rappresentato per secoli importanti elementi culturali e paesaggistici. Oggi esse ospitano sovente formazioni forestali di interesse naturalistico, con strutture diversificate e età massime elevate prossime a quelle osservate al limite superiore del bosco o in luoghi inaccessibili. Ciò è in massima parte da ricondurre alla passata gestione forestale, in precario equilibrio tra rigida tutela e necessità di risorse. Le antiche foreste di protezione rappresentano soggetti estremamente interessanti per la ricerca, soprattutto laddove sono presenti strutture disetanee o irregolari, una plurisecolare continuità della copertura arborea e particolari contenuti storici e naturalistici. Il presente studio ha l'obiettivo di ricostruire per mezzo di dati storici e dendroecologici il passato forestale di un antico bosco di conifere situato sul versante sud delle Alpi svizzere (Canton Ticino). I risultati mostrano che durante gli ultimi tre secoli le attività antropiche (taglio di alberi e altri tipi di utilizzazioni) hanno esercitato un impatto rilevante sull'area di studio. Per contro disturbi di tipo esogeno (eventi naturali) sembrano aver influenzato l'attuale struttura forestale su una scala più ridotta. Le dinamiche endogene s'impongono invece nei periodi che seguono l'allentamento della pressione antropica sul territorio e l'abbandono delle pratiche forestali. Ricorrenza e intensità dei disturbi coincidono piuttosto bene con i potenziali fattori causali di origine antropica, ricostruiti attraverso l'indagine storica. La conoscenza delle dinamiche evolutive e del regime dei disturbi di questi boschi potrà fornire in futuro dati utili per una gestione coerente con gli attuali obiettivi selvicolturali e il loro valore naturalistico e storico.

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