Implementing fire history and fire ecology in fire risk assessment: the study case of Canton Ticino (southern Switzerland)

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The fire management approach presented in this work is based on the knowledge of fire history, fire ecology, and fire suppression strategies acquired for the study area in the frame of the research efforts coordinated by the author at the WSL in Bellinzona. In the first chapter we present the motivation and the objectives of the work. Chapter 2 is devoted to the definition of the fire management related terms. In chapter 3 the study area (Canton Ticino) is presented. The chapters 4 to 6 represent an original synthesis of the results achieved in the frame of different research projects (Swiss National Research Program 31 [Climate changes and natural catastrophes], ONU decade for natural disasters, EU-Prometheus s.v., EU Fire Paradox) and related publications (CONEDERA et al. 1996; HOFMANN et al. 1998; CONEDERA et al. 1999; MARXER & CONEDERA 1999; CONEDERA et al. 2007b; PEZZATTI et al. 2009), the PhD works supervised by the author (TINNER 1998; MORETTI 2003; MARXER 2003) and the many Master theses coordinated by the WSL in Bellinzona. The chapters 7 and 8 represent the core of the present work consisting in an original methodology for assessing fire danger, vulnerability to fire and fire risk.

Bellinzona, May 2009
Marco Conedera

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Abbreviations and acronyms

AD	Anno Domini
AMC	Acceleration Mass Spectrometer
AP	Arboreal Pollen
BA	Bronze Age
BC	Before Christ
BP	Before Present
cal.	calibrated
CIFFC	Canadian Interagency Forest Fire Centre
CRCS	Conti Resi al Consiglio di Stato (annual reports of the Cantonal administration)
DEM	Digital Elevation Model
e.g.	exempli gratia (for example)
FZ	Fire Zone (in sediment profiles)
GIS	Geographical Information System
i.e.	id est (that is)
IA	Iron Age
Ind.	Individuals
MA	Middle Ages
ML	Mesolithicum
MT	Modern Times
NAP	Non Arboreal Pollen
NL	Neolithicum
NWCG	National Wildfire Coordinating Group
PL	Palaeolithicum
RT	Roman Times
sd	standard deviation
se	standard error
Spp.	Species
uncal.	uncalibrated
vs.	versus

1 Introduction

Biomass burning and the resulting fire regimes may be widely considered one of the major disturbances and evolutionary forces patterning vegetation structures and generating disturbance-adapted ecosystems (PYNE et al. 1996; SAVAGE et al. 2000; BENGTSSON et al. 2000; SCOTT 2000; DONNEGAN et al. 2001; CALDARARO 2002). Fire evolved on the earth under the direct influence of climate (e.g. drought, wind, fuel moisture content) and the accumulation of burnable biomass at various times and spatial scales (SWETNAM 1993; SCOTT et al. 2000; HEYERDAHL et al. 2001; WITHLOCK 2004). During the past hundred of thousands of years humans have domesticated fire and therefore contributed essentially to the changing fire regimes of the planet, so that no place has completely escaped from the direct or indirect influence of anthropogenic burning practices. As a result, fire regimes depend not only on climatic and biological factors, but also greatly reflect the cultural background of how people do manage ecosystems and fire. All of these elements have evolved continuously in time and space producing unique fire histories across the landscape (PYNE et al. 1996).

In their simulation study at the global scale, BOND et al. (2005) concluded that fire presently determines general vegetation patterns and that it may prevent ecosystems from achieving higher biomass and dominant functional types that would be expected under the respective climatic conditions. According to this study, several of the word's major biomes in the tropics and in the southern hemisphere (and to a much smaller extent in the northern hemisphere) are fire-dependent ecosystems at least in regard to biomass production, tree cover or species composition. These regions include the humid grasslands and savannas of South America and Africa, the prairies of North America, the Asiatic savannas, the Mediterranean shrublands and the boreal forests.

For long time, modern managers were not aware of the prominent role of fire in preserving and shaping such ecosystems. Although practical and scientific evidence of the ecological role of fire has been continuously reported since the first half of the 20th century, fire suppression have been the dominant management strategy throughout Europe and the United States, with very few exceptions (PYNE et al. 1996). This practice corresponded to a symbolic and rooted pre-concept of fire as a destructive force (CONEDERA et al. 2009). With time the negative effects of systematic fire suppression such as fuel build up, densely stocked forest structures, and stagnation in the regeneration of fire adapted tree species became clear (LAGEARD et al. 2000; DEY & HARTMAN 2005). The occurrence of severe wildfires increased and continued fire suppression efforts have failed to protect homes and communities threatened by these blazes. This seemingly self-contradictory situation is commonly known as the fire paradox: the more efficient and successful the systematic fire suppression is, the more intense and catastrophic the few fires escaping from control will be (CASTELLNOU et al. 2002; INGALSBEE 2002).

This brought a new awareness among scientists and managers about the ecological role of fire and the necessity to understand its past natural and cultural dynamics in different ecosystems in order to preserve present ecosystem functionality and minimize management costs and negative impacts (FRIES et al. 1997; SWETNAM et al. 1999; BENGTSSON et al. 2000; WHITLOCK & LARSEN 2001; KALABOKIDIS et al. 2002; BERGERON et al. 2002). Some authors have gone even further advocating the paradigm of emulating (natural) disturbance and endorsing a forest and landscape management approach that replicates the disturbances that gave rise to the present forest ecosystems and species assemblage without limiting other ecosystem services (ATTIWILL 1994; ANGELSTAM 1998; BERGERON et al. 1999a,b).

Strong ecological and economical evidences of the unsuitability of the systematic fire suppression approach and the progressive overcoming of the view of fire as external agent of destruction of forest ecosystems (CONEDERA et al. 2009) triggered a shift from the fire control approach (i.e. concentration of the main effort in suppressing ongoing wildfires) towards the fire management approach (Fig. 1.1), where fire prevention, fire danger rating, fire ecology, fire pre-suppression and suppression strategies are fully integrated in the landscape management (SULLI 1993; LEONE 1988; BOVIO 2001; CASTELLNOU et al. 2002; VELEZ & MERIDA 2002; NEFF et al. 2004).

Unfortunately, implementing such theoretical concepts in fire management is a very difficult task that requires a sound understanding of past forest stand and landscape dynamics and management practices, including fire history and fire ecology. In fact, contemporary forest ecosystems are the result of very complex interactions between past natural and anthropogenic forces. Forest ecosystem services (protection, economic and recreational) are continuously evolving in modern society. In addition, the alteration of the framework of environmental conditions (climate change, pollution, invading alien species etc.) may be causing unforeseen and unprecedented ecosystem reaction patterns (Fig. 1.1). Thus, there is presently a broad concordance on the need of a systematic analysis and multidisciplinary approach to fire management, including comprehensive and quantitative fire risk assessment (FINNEY 2005) and prioritization of fire management measures at different scales and on different aspects (e.g. REYNOLDS & HESSBURG 2005; HESSBURG et al. 2007).

The main objective of this work is to propose a methodological approach for implementing knowledge derived from studies of fire history, fire ecology and fire suppression strategies in fire risk analyses at local to regional scale. To this purpose we propose the study case of Canton Ticino, the most fire prone region of Switzerland.

We first discuss and define some concepts related to fire management and present the study area of Canton Ticino. We then analyse the most relevant aspects of fire history, fire ecology, fire fighting strategies and fire suppression organization in the study area, implementing the results in the proposed fire risk analysis approach.

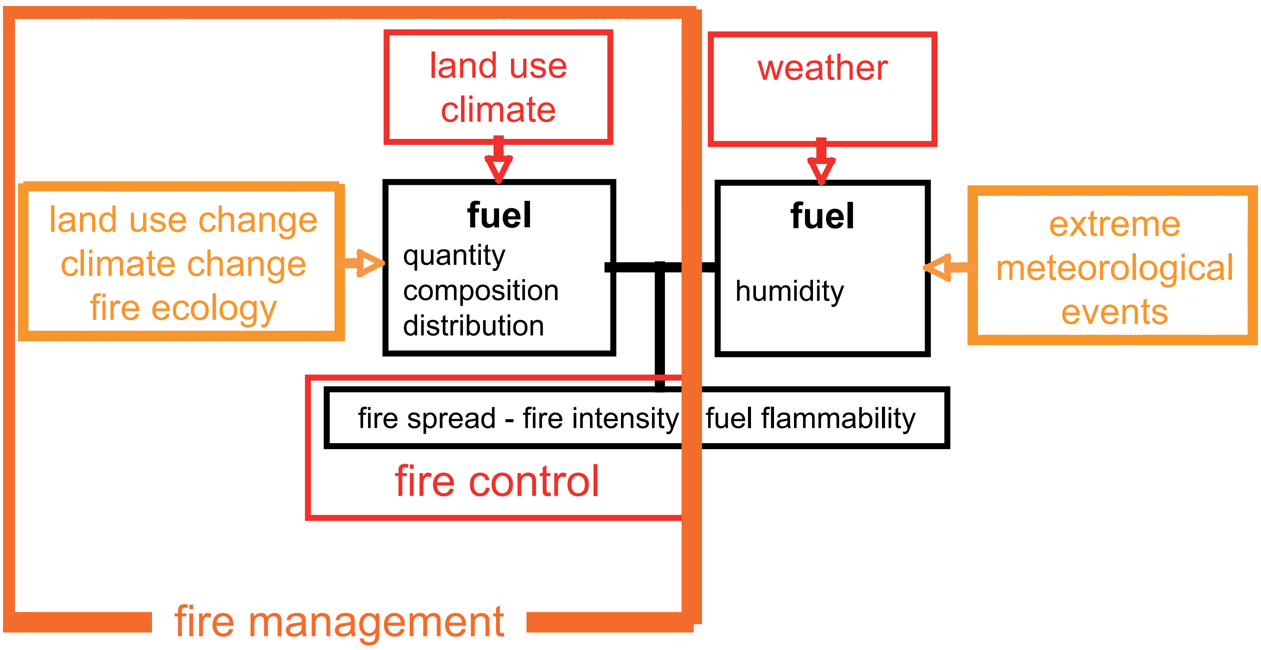


Fig. 1.1. Schematic representation of the driving forces asking for a shift from the fire control to the fire management approach. Climate change (including increase in frequency of meteorological extreme events such as droughts), land use abandonment, and increased awareness of the ecological role of fire made a shift from a fire control (e.g. just suppressing fires escaping from the control) to a fire management approach (e.g. integrating fire prevention and pre-suppression in land management) necessary.

2 Defining some key concepts and activities related to fire management

2.1 Problems related to the fire management terminology

As is the case for many other disciplines, fire management terminology is constantly evolving and is not uniformly used in all countries and in all fire contexts. HARDY (2005) notes how the terms we use to characterize resource management, particularly fire management, appear to have become less concise over time, and he displays the now numerous inconsistencies in the use of most terms. There are linguistic and cultural aspects behind this problem, partially due to different languages and partially due to the fact that fire is a complex phenomenon that involves very different categories of people (fire fighters, foresters, environmentalists, land owners, scientists, etc.) that may not share the same vocabulary (BACHMANN & ALLGÖWER 1999). According to BACHMANN & ALLGÖWER (2001) such a lack of clear definition constitutes an obstacle to sound research and management.

In this chapter we shortly present and discuss selected terminology related to fire management and define how each term is used within the scope of this work.

2.2 Fire management

As stated by BARNEY (1975), the term fire management appears to have emerged from the increasing acceptance that fire is not entirely a destructive agent, but rather an intrinsic and vital ecological force (and, in the case of prescribed burning, a useful tool) that must be integrated into land management activities. In this view, fire is an environmental factor that ranks in importance with climate, topography, soil, etc. (see also WEAVER 1955).

Consequently, fire management must be an integral part of land management activities and may be defined as the integration of fire-related biological, ecophysiological, and technological information into land management practices in order to meet desired objectives (BARNEY 1975; NWCG 2006).

Forest management and other land use objectives that invoke fire management activities (including the use of prescribed burning) are thus concerned with the protection of people, property, and forest areas from wildfires and should be framed in a manner that considers environmental, social, and economic criteria. Fire management represents both a land management philosophy and a land management activity and involves knowledge of fire regimes, probable fire effects, values-at-risk, level of forest protection required, and cost of fire-related activities (CIFFC 2002).

2.3 Fire management related terminology

Fire management activities may be divided into five main categories: fire prevention, fire pre-suppression, fire detection, fire suppression and post-fire management. According to the CIFFC (2002) and the NWCG (2006) they may be defined as follows:

- *prevention*: activities intended to reduce the occurrence and the outcome of wildland fires
- *pre-suppression*: activities undertaken in advance of fire occurrence to help ensure more effective fire suppression. Pre-suppression activities include overall planning, fire fighting organization (recruitment and training of personnel, procurement and maintenance of equipment), sylviculture (fuel treatments) and infrastructures (creating and maintaining fuel breaks, roads, water sources, etc.)
- *detection*: the act or system of discovering, locating, and reporting fires
- *suppression* (fire control): all activities concerned with controlling and extinguishing a fire, starting with its detection and continuing until the fire is completely extinguished
- *post-event management*: all sylvicultural and technical activities implemented after a fire is extinguished in order to reduce the secondary fire effects (erosion, insect outbreaks, etc.).

2.4 Fire risk related terminology

A short review of the existing definitions of the terms fire risk, fire danger, and fire hazard shows that there are presently various definitions, interpretations, and implementations of such concepts in fire management (HARDY 2005; EUFIRELAB 2004). In this work we adopt the definitions originally proposed by the EU research program SPREAD as reported in EUROFIRELAB (2004) (see also Fig. 2.1).

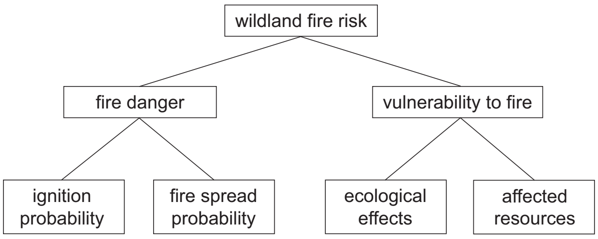


Fig. 2.1. Structure and major components of the Wildland fire risk (source: EUROFIRELAB 2004).

– *fire danger*: the chance of a given place to get fire. It is constituted by the probability of ignition (ignition danger, i.e. probability of starting a fire in a given place) and the chance of a fire to spread over an area, regardless of the place of ignition (fire spread danger)
– *vulnerability to fire*: the potential outcome of a fire in terms of ecological effects, damage to infrastructure and properties and human losses
– *fire risk*: the combination of fire danger and vulnerability to fire for a given area.

Concerning the time scale of reference, we will focus on structural and static factors that change very slowly and describe the mean relative risk level along an average fire season (*long term fire risk*, for details see chapter 7). According to EUROFIRELAB (2004), the long term fire risk is the most appropriate time scale in providing information for fire prevention and pre-suppression activities such as fire suppression plans and planning of fire fighting infrastructures such as water points.

2.5 Fire regime

The concept of fire regime originated in the early 1960's in the United States, when the idea of fire disturbance as a basic natural force shaping ecosystems was widely accepted and implemented in the wildlife management strategies of the national parks (LEOPOLD et al. 1963). The adoption of the term fire regime in the early 1960's reflects the need for fire ecologists and managers to summarize in a concept all the ecologically relevant characteristics and dimensions of fire occurrence over a certain period and in a defined area or in a specific ecosystem (CONEDERA et al. subm.). Recently the term 'fire regime' has developed into a generalized and structured description of the role of fire in ecosystems and may therefore be defined as parameterization (that is, a description by means of variables) of a sequence of fires that occur in a defined space-time window (FALK and SWETNAM 2003).

In our definition, a fire regime consists of a broad collection of fire characteristics that may be assembled and implemented in very different ways according to the needs of the users. A fire regime may thus refer to different times and time windows (past, present, future; single event, years, decades, centuries, millennia), different spatial units (single ecosystem, single vegetation type, specific geographical areas, etc.), different origins of fire (natural, anthropogenic), and may consider not only the fire characteristics (fire type, fire intensity, fire behaviour), but also conditions that determine fire occurrence (fuel type, fire weather, etc.) and immediate fire impact (fire severity, etc.). Beside such a basic fire regime definition describing which fires occur when and where (frequency, size, seasonality, type, and intensity) there are also a significant quantity of other attributes and derived variables that may be combined for building ad hoc fire regime definitions (CONEDERA et al. subm.). In this study, when referring to a fire regime we mainly consider fire frequency (the number of fires in a given period of time); time since last fire and fire seasonality (winter vs. summer fire); origin of the fire (anthopogenic vs. natural); and type of fire (surface, soil, or crown fire).

One major point that remains open when defining a fire regime is the heterogeneity and variability that a fire regime may display in a specific area or in a determined period before one starts to speak about different fire regimes or about a shift in fire regime. Fire regimes are not static. Long-term periodicity for cyclical disturbance combined with long-term trends and even random variation often result in a gradual drift of the disturbance regime over time (SUFFLING & PERERA 2004). The definition of a historical or natural range of variability of a fire regime is thus crucial in defining apparent changes in fire regime at a given temporal scale of analysis (MORGAN et al. 1994). In this study we present a long term fire history based on charcoal particles in lake sediments as a long term reference for defining the historical fire regimes.

3 The study area

3.1 Criteria for selecting the study area

Fire management objectives and related assessment procedures strongly depend on the spatial scale considered. Fire risk assessment at continental or global scale is mainly undertaken for establishing general guidelines and strategic objectives and for enhancing international cooperation (EUROFIRELAB 2004), whereas at local to regional scales the resolution and homogeneity of the information may allow the implementation of practical measures in fire management plans. Thus the study area has been selected so as:

– to be large enough to offer different vegetation cover, population density and fire regimes
– to display a long tradition in dealing with fire events both in the operational phase (detection, suppression) and from the administrative point of view (data reporting, etc.)
– to offer a sound and homogeneous set of thematic maps related with fire management issues (fire perimeters, forest cover, forest functions, population density, pre-suppression facilities, digital terrain model, etc.)
– to be homogeneous from the political point of view (administration rules, fire brigade organisation, legislation, etc.).

Following these criteria, the Ticino – a whole Canton in the most fire prone region of Switzerland – has been selected as study area.

3.2 Main historical, political and economic characteristics

The human colonisation of the territory of what is now Ticino probably started in the last post-glacial period in coincidence with the withdrawal of the ice cover. It is hard to estimate the length of the transition from the pioneer exploring phase to a sedentary colonized state. The first unambiguous archaeological remains of human settlements date back at around the sixth millennium BC at the site of Castle Grande in Bellinzona (CARAZZETTI 2000). Starting from this date, anthropogenic indicators in lake sediments such as pollen from cereal grains display a frequent and uninterrupted presence (CONEDERA & TINNER 2000a), highlighting the constant and growing existence of settlements in the area. Conspicuous are the necropolis found in the area starting from the Late Bronze Period and the Early Iron Age (DE MARINIS 2000; SCHINDLER & DE MARINIS 2000), mostly belonging Celtic tribes such as the Lepontii and the Insubrii. The area became then part of the Roman Empire after the Roman conquest of the Alps (I century AD) before being ruled by the Goths, the Longobards, and the Franks after the fall of the Western Empire (VISMARA et al. 1990). In the Late Middle Ages (starting around 1100 AD) the region became the center of struggles between different external powers from the South (Milan and Como) and from the North (Swiss Confederates) that alternately dominated part of the territory (VISMARA et al. 1990). The final conquest of the area representing the current boundaries of Ticino took place in 1512 by the Confederates, which at that time constituted 12 cantons. During this time the local communities benefited from a relative autonomy concerning the organization of every-day life and the use of the rural territory as attested by the medieval bylaws (e.g. MENEGALLI 1909; FRIGERIO & PISONI 1984; PISONI & BROGGINI 1993). The institutionalized system of the local communities became progressively looser during the short period of the Helvetic Republic (1798–1803) and was finally abrogated when the Canton Ticino joined the Swiss Confederation in 1803.

The Canton Ticino now represents the southernmost of the 26 Swiss Cantons. The official cantonal language is Italian. Together with four south-facing valleys (Calanca, Mesolcina, Bregaglia and Poschiavo) of the Canton of Graubünden it makes up the so-called Italian speaking part of Switzerland (Svizzera Italiana) (Fig. 3.1).

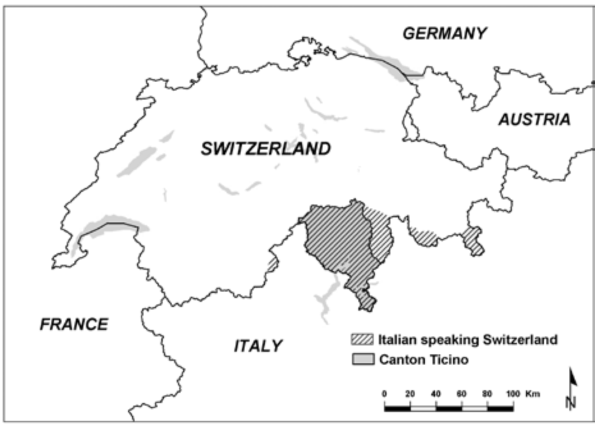


Fig. 3.1. Geographical and political location of the Canton Ticino.

Until 1878, the three largest cities (Bellinzona, Lugano and Locarno) alternated as capital of the canton. In 1878, however, Bellinzona became the only and permanent capital.

In the Nineteenth Century Ticino was a poor country where people used to survive through the traditional agricultural activity. Unfortunately the territory did not supply enough staple food for the whole population and many young people were constrained to emigrate in Europe or abroad (CHEDA 1993). The situation changed dramatically in the last post-war period, when Canton Ticino experienced a drastic socio-economic change towards a more service-oriented economy that ensured prosperity and allowed a strong increase in the population (Fig. 3.2), but also caused the almost total abandonment of traditional agricultural, livestock breeding and land management activities and a corresponding increase of forested area (Fig. 3.3 and 3.4).

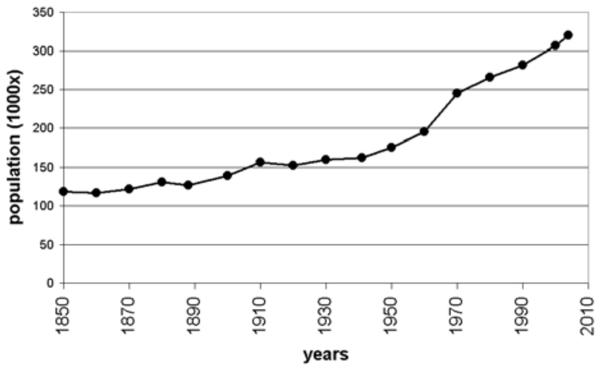


Fig. 3.2. Evolution of the population of Canton Ticino 1850–2005 (source: Ufficio Statistica del Canton Ticino).

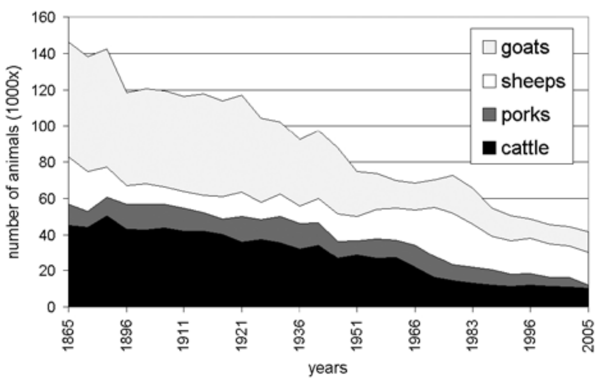


Fig. 3.3. Evolution of livestock breeding in Canton Ticino 1865–2005 (source: Ufficio Statistica del Canton Ticino).

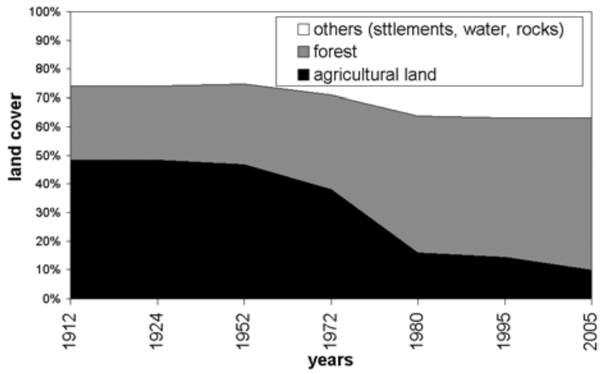


Fig. 3.4. Evolution of the land cover in Canton Ticino 1912–2005 (source: Ufficio Statistica del Canton Ticino).

3.3 Geography, geology and climate

The Canton of Ticino has a total area of 2812 km² and is almost entirely surrounded by Italy which lies to its east, west, and south. The Canton is split geographically by the Monte Ceneri pass into the northern and more mountainous part (Sopraceneri) and the southern hilly region (Sottoceneri), where most of the population is leaving (Fig. 3.5).

The area is characterized by a marked altitudinal gradient, ranging from 197 m a.s.l. around Lake Maggiore (Locarno) to 3402 m on the Adula Peak in Northern Ticino. Almost the half of the territory is located above 1500 m a.s.l. (Fig. 3.6).

The geology of the area mainly originated in the frame of the tectonics of the Alps and therefore has a high amount of heterogeneity. It is dominated by siliceous rocks from different origin: the Helvetic crystalline basement and the Penninic nappes in the northern part is separated by the Insubric (Iorio-Tonale) line from the Insubric basement and Permian vulcanits in the south. These siliceous rocks are alternated by different spots and veins of limestone such as the Helvetic nappes in the north and Southern sedimentary nappes in the south. In the very south of the area the geology is characterized by conglomerates and sediments of the Po Plain (KÖNIG 1978; COTTI et al. 1990; Fig. 3.7).

The meteorological processes in the study area are highly influenced by the presence of the Alpine barrier. Furthermore, there are special conditions in the lower elevation of the Central and the Southern part of the Canton Ticino which are under the influence of the lake masses that generate special climatic conditions usually known as the Insubric climate (Fig. 3.8; SPINEDI & ISOTTA 2004).

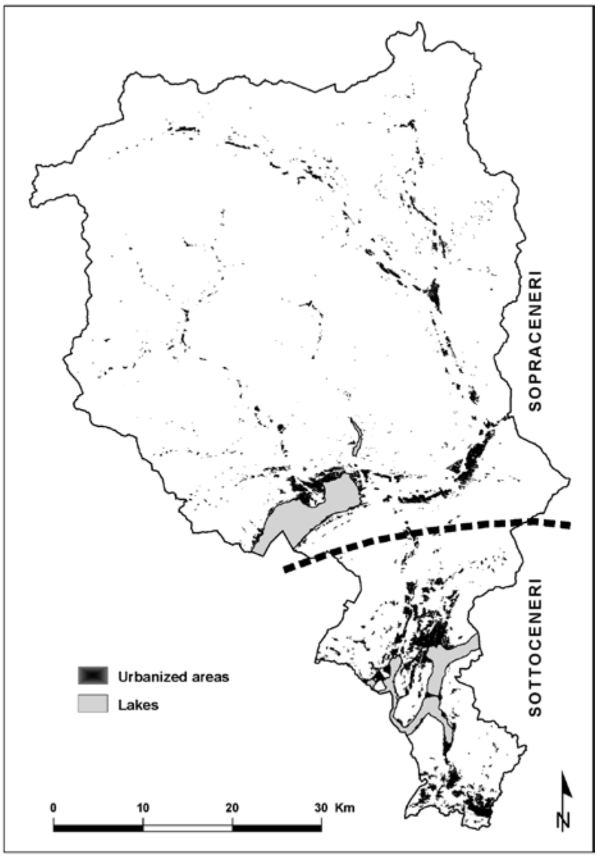


Fig. 3.5. Distribution of the urbanized area in Canton Ticino (source: Swisstopo, Bern).

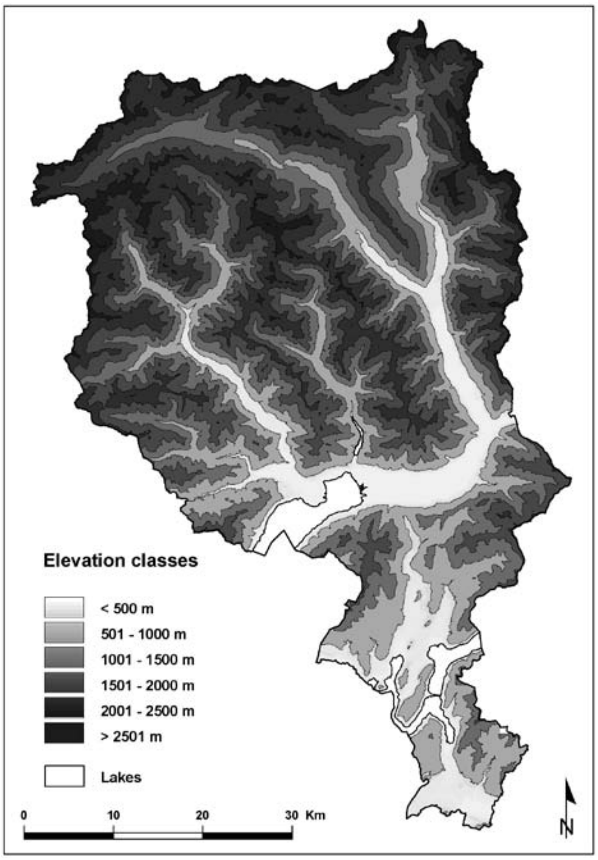


Fig. 3.6. Elevation map of Canton Ticino (source: DEM Swisstopo, Bern).

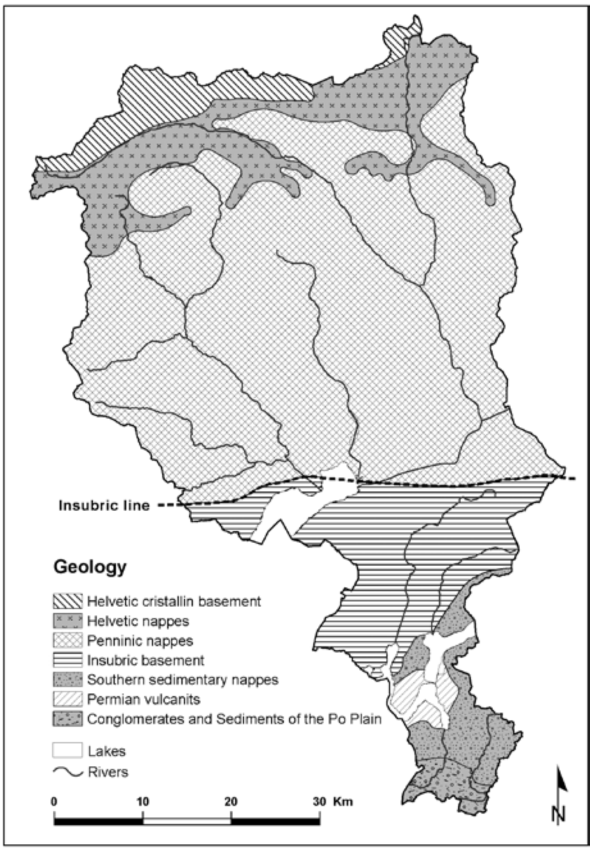


Fig. 3.7. Geologic map of Canton Ticino (source: COTTI et al. 1990).

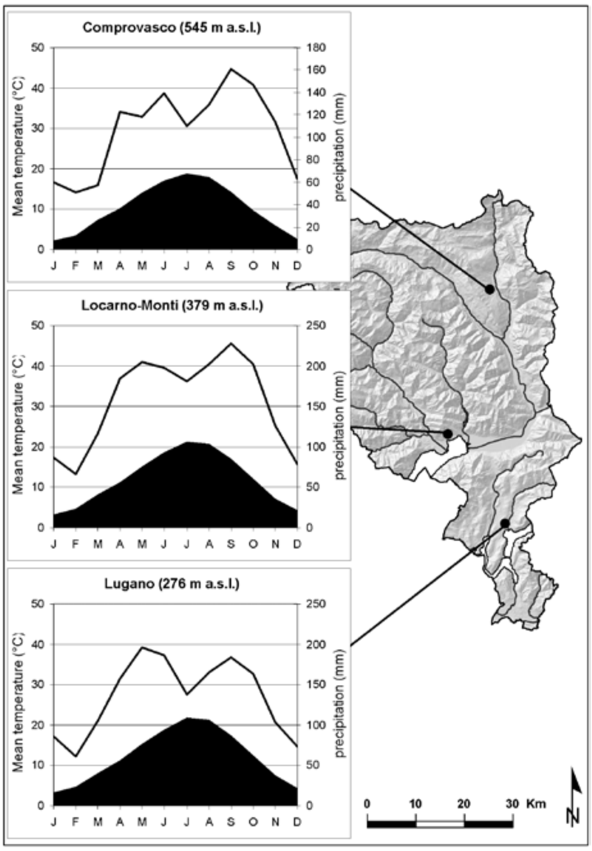


Fig. 3.8. Climatic diagrams of Lugano, Locarno-Monti and Comprovasco for the period 1971–2000 (source: SPINEDI & ISOTTA 2004).

The Insubric climate is characterized by dry and mild winters with some days (40 days a year on average) having strong gusts of a katabatic (descending) dry wind from the North (Nordföhn, favonio da nord), which causes drops in the relative humidity to values as low as 20 %. In summer long periods without rain or even of drought may alternated with thunderstorms and short, heavy spells of precipitation.

Depending on the elevation and the geographical position, the mean annual precipitation ranges from 1600 to 2600 mm and the mean annual temperature from 3 to 12 °C. The quantity of summer rain (June–September 800 to 1200 mm of precipitation, see also Fig. 3.8) contrasts with the low level of summer precipitation in the Mediterranean climate just south of Ticino. The duration of sunshine is high (1800 to 2150 h/y), although in some valleys during winter the sun may be absent for several weeks because they are in the shadow of the surrounding mountains.

3.4 Forest cover

Forest cover of the area is high (on average 50.5 %, see also Fig. 3.4). The forest vegetation is dominated at low elevations (up to 900–1100 m a.s.l.) by the chestnut tree *(Castanea sativa),* which was first cultivated (and probably first introduced) in the area by the Romans (CONEDERA et al. 2004a). Chestnut forests are anthropogenic monocultures occasionally interrupted by the presence of other broadleaved species, such as *Tilia cordata, Quercus petraea, Q. pubescens, Alnus glutinosa, Prunus avium, Acer* spp., or *Fraxinus* spp. At medium elevations (900–1400 m a.s.l.), the forests mostly consist in pure stands of *Fagus sylvatica*, followed by coniferous forests (*Picea abies* and, at higher elevations, *Larix decidua*). On the south-facing slopes sometimes the beech belt is completely missing. The presence of *Abies alba* has been reduced to small patches on north-facing slopes in the central part of the area, whereas Pine forests are confined on very particular sites (*Pinus sylvestris* on dry south-facing slopes, *P. cembrae* on the most continental areas of the upper regions) (CESCHI 2006). PEZZATTI et al. (2008) provided quantitative data and distribution maps for the main forest vegetation classes (Fig. 3.9), highlighting the marked altitudinal distribution gradient of the forest vegetation what results in different vegetation belts according to the elevation (Fig. 3.10).

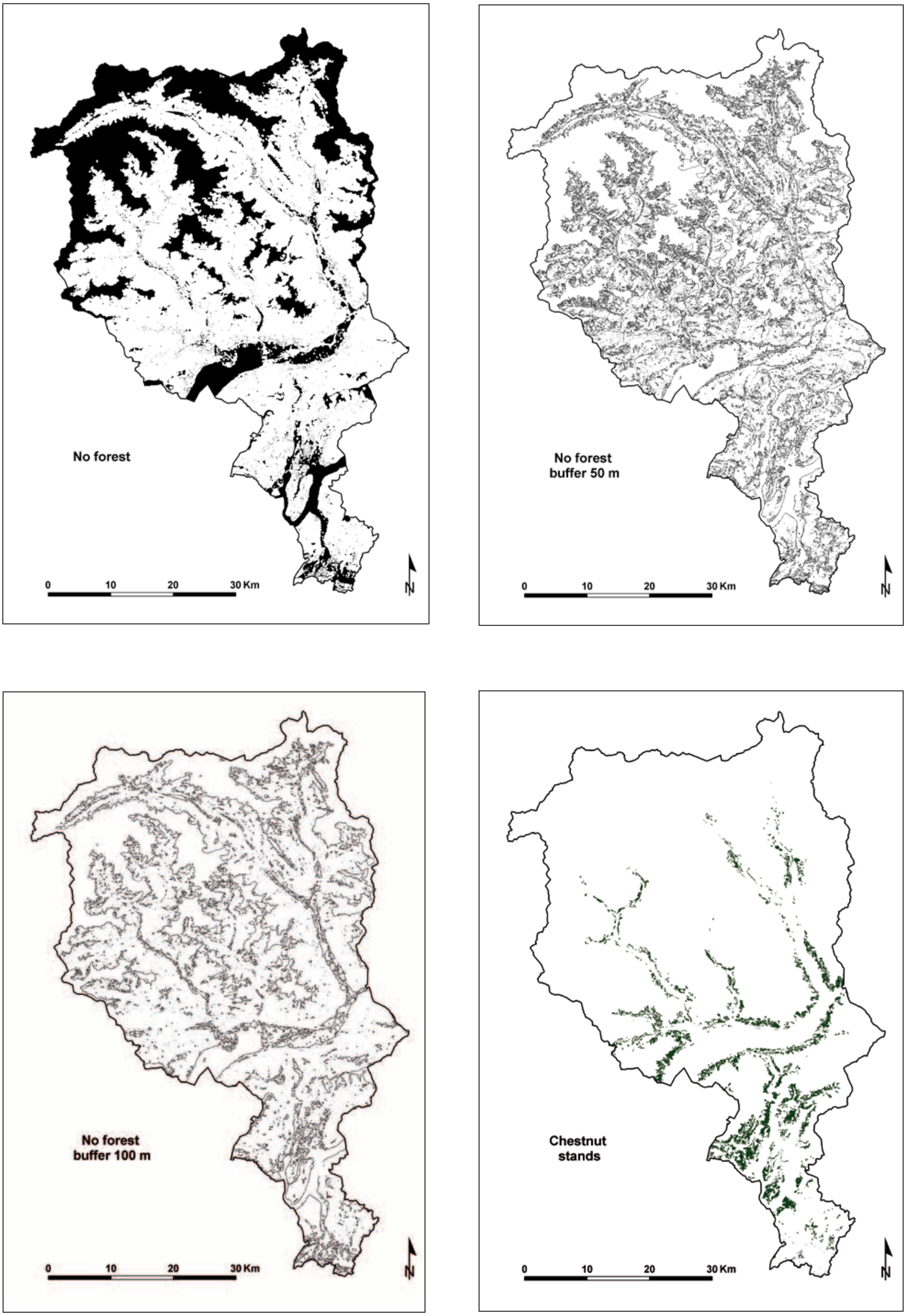


Fig. 3.9. Distribution maps of the main forest cover classes in Canton Ticino (source: PEZZATTI et al. 2009).

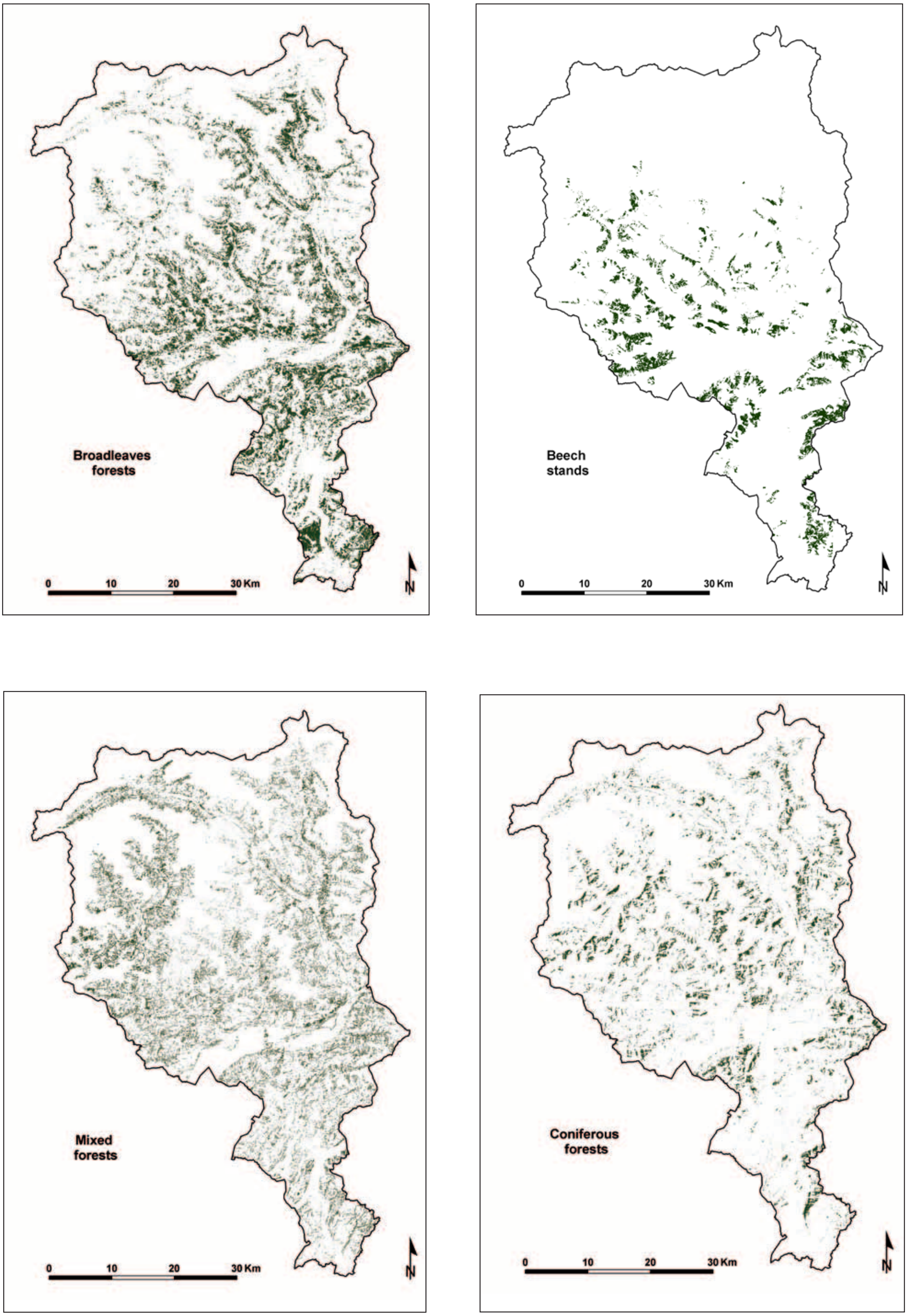
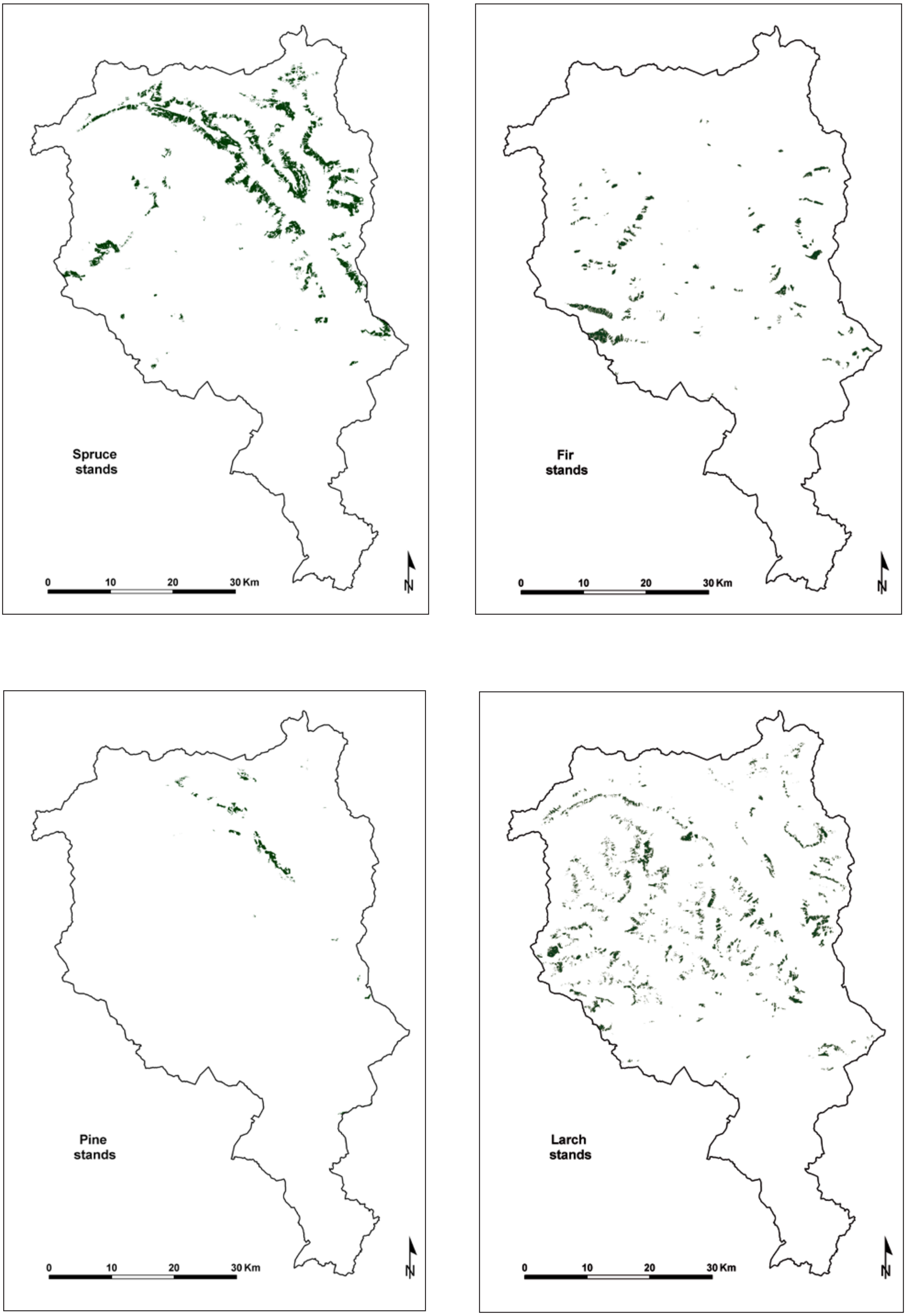


Fig. 3.9. Continued.



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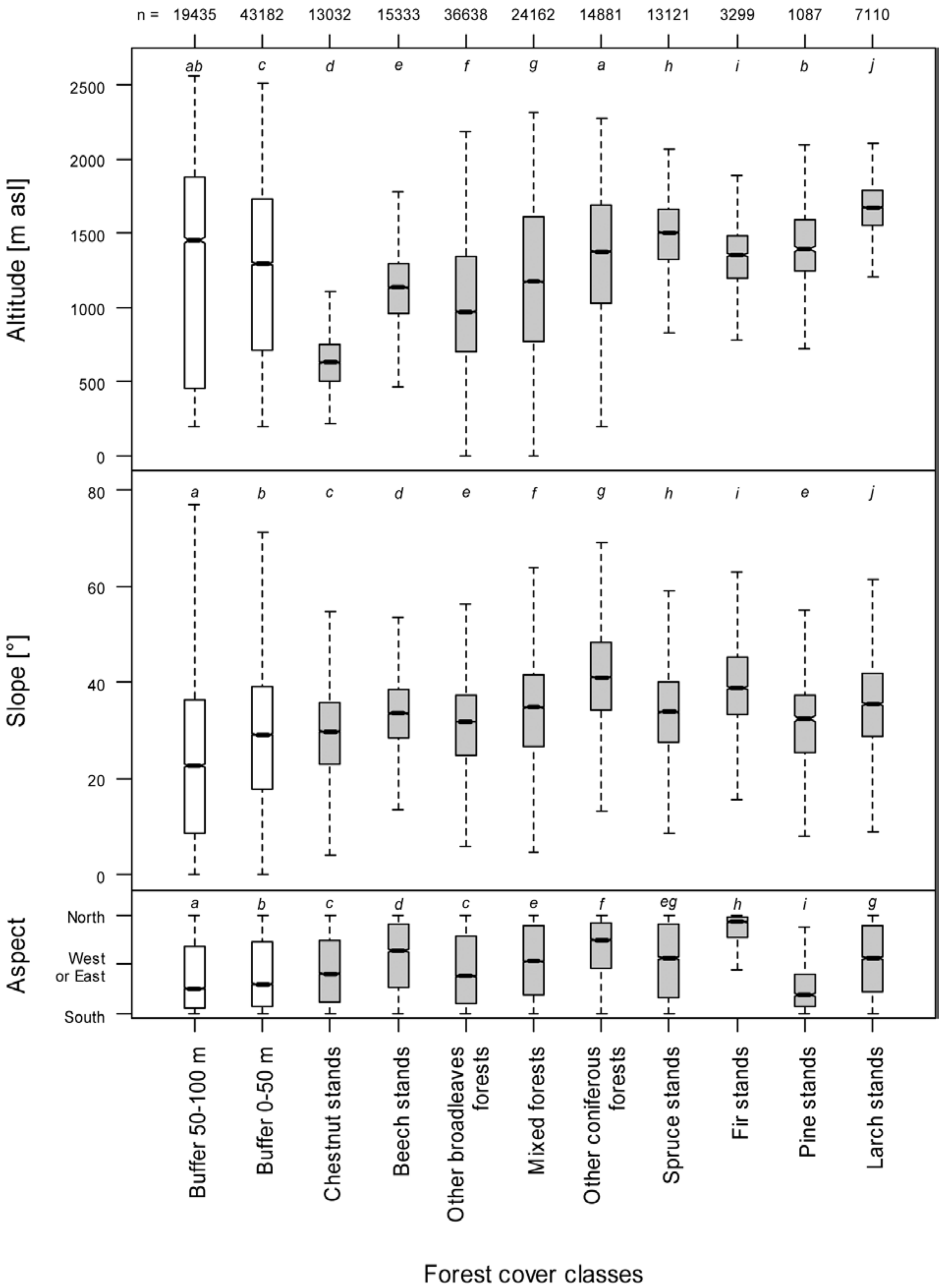

Fig. 3.10. Box-plot distributions of elevation, slope and aspect for the main forest cover classes in Canton Ticino (outliers not plotted). Letters represent significant different distributions ($p<0.05$) according to pairwise Wilcoxon tests, with Bonferroni adjustment for p value (source: PEZZATTI et al. 2009).

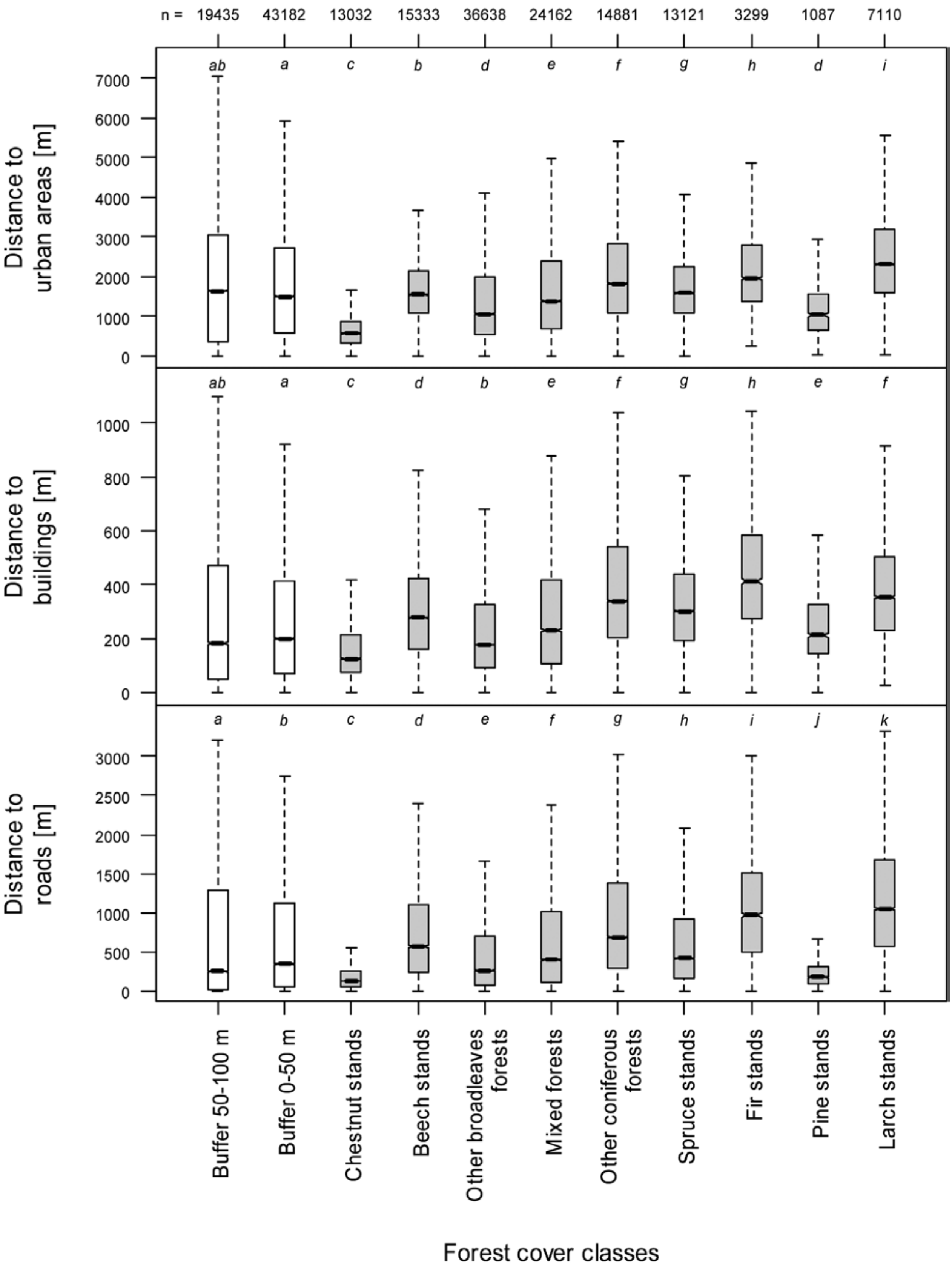

Fig. 3.10. Continued.

4 Forest fire history

4.1 Methodological approach

The reconstruction of the Fire history in Canton Ticino is based on four different data (or proxy) sources: charcoal particles in lake sediments, written documents related to forest fire or wildfire problems, local names related to burning activities, and historical documented forest and wildfires.

a) Charcoal particles in lake sediments
Studies of charcoal in lake sediments are limited to the southern part of the study area and concern the Lago di Origlio (416 m a.s.l.) and Lago di Muzzano (337 m a.s.l.) situated near Lugano in southern Switzerland (Fig. 4.1) (TINNER et al. 1999). Two parallel cores 1 m apart were taken with a Streif modification of the Livingstone piston corer (MERKT & STREIF 1970) from the deepest point of the lakes. During coring the water depth was 5.35 m at Lago di Origlio and 2.8 m at Lago di Muzzano. 19.55 m of lake sediment were cored at Lago di Origlio, and 16.45 m at Lago di Muzzano. The core sections analysed consist of a uniformly silty fine-detritus gyttja at Lago di Muzzano and of discernible layers of gyttja and silt at Lago di Origlio.
The sediment was sampled in cubes of 1 cm^3. Lycopodium tablets were added for estimation of pollen and charcoal concentration and influx. After chemical and physical treatment charcoal was identified as black, completely opaque, angular fragments. The number of charcoal particles longer than 10 µm (or > 75 $µm^2$) in pollen slides was counted by W. Tinner with a light microscope at 200x magnification. The regression equation proposed by TINNER et al. (1998) was used to estimate the charcoal area concentration (mm^2 cm^{-3}) from the particle number concentration (charcoal particles cm^{-3}), which was assessed by counting the Lycopodium spores added to the pollen slides. Pollen grains were identified under a light microscope using the reference collection of the Institute of Geobotany at the University of Bern and different keys available in the literature (see references in TINNER et al. 1999).
To determine the age of the sediments, 25 terrestrial macrofossils from Lago di Origlio and 12 from Lago di Muzzano were dated by AMS-techniques. The age-depth curves of both study sites were smoothed by locally weighted regression (lowess), calibrated as AD/BC cal. by the program Calib

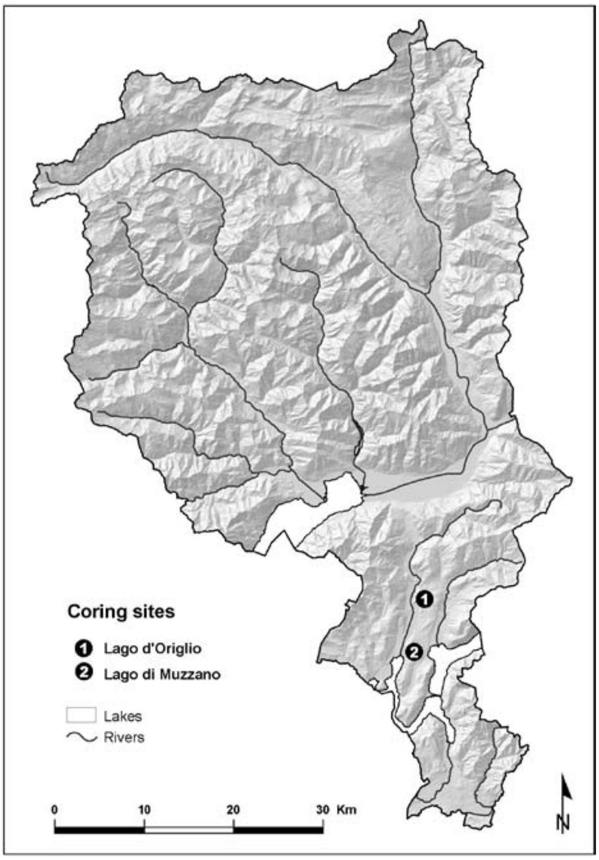

Fig. 4.1. Coring sites in the study area for the reconstruction of the long term fire history.

Version 3.03c (STUIVER & REIMER 1993), and then used for the calculation of charcoal area influx (mm^2 cm^{-2} yr^{-1}) (for details see TINNER et al. 1999).

b) Written documents related to fire
We performed an archive research looking for documentary records possibly related to fire such as the medieval bylaws of the local communities, earlier agronomic literature, correspondence related to forest fire lawsuits, official reports of the cantonal authorities since their publication around 1870, and the official cantonal and federal legislation on forest fires and on the organization of the fire brigades.

c) Local names related to burning activities
The systematic collection of the place names in Canton Ticino (Archivio dei nomi di luogo) was searched for all place names referring to the basic terms *brüsà* [to burn] and *brüsáda* [burn]. Care was taken not to exclude possible phonetically similar dialect options (CONEDERA et al. 2007a). All localised and geo-referenced toponyms were databased in a Geographical Information System (GIS). This enabled us to calculate topographic parameters

such as elevation, slope and aspect by assigning to each toponym the values of the next grid point of the digital elevation model with a resolution of 25 x 25 m (DEM25).

d) Historical documented forest- and wildfires
Fire data information has been collected in Ticino by the Forest Service since 1900. Protocol of fire data changed with time as illustrated in Table 4.1. Some basic data such as the date, time, and cause of ignition, fire duration, area burnt, fire type, and forest type exists for the whole period, allowing us to organise the fire data in a relational database (CONEDERA et al. 1996; PEZZATTI et al. 2005).

e) Data reliability
The reliability and significance of charcoal particles as proxy for past forest fires was then verified by comparing the charcoal concentrations in recent (1920–1990) sediments from Lago di Origlio with the corresponding records in the forest fire data base (TINNER et al. 1998).

4.2 Long-term fire history

Figure 4.2 shows the pattern of charcoal influx for five major zones which describe the fire history of southern Switzerland. Zones FZ-1 to FZ-5 can be identified in the profiles at Lago di Origlio and Lago di Muzzano and influx values are similar at the two sites.
FZ-1 (16000 BP – 8300 BP cal.) represents the very low and basic charcoal influx level of the early post-glacial period. The level of the charcoal influx rises suddenly at the beginning of FZ-2 (around 8300 BP cal.) during a continental temperate climate phase and remains stable when the climate develops into a more oceanic condition at about 7300 BC cal. (TINNER et al. 1999; CONEDERA & TINNER 2000a). This confirms the major role exerted by natural fires in the study area as already outlined by other authors on the subalpine forests of the Alps (STÄHLI et al. 2006).
The start of the phase FZ-3 coincides with the transition to the Neolithic as confirmed by the continuous presence of anthropogenic indicators such as pollen of *Plantago lanceolata* or Cerealia

Table 4.1. Information on forest fires collected by the forest service of Canton Ticino since 1900.

Parameter	Period				
	1900–1938	1939–1968	1969–1983	1984–2004	2005–
Start date and time (first announce)	•	•	•	•	•
End date and time	•	•	•	•	•
Community	•	•	•	•	•
Local name	•	•	•	•	•
Forest service picket				•	•
Helicopter picket					•
Coordinate of ignition point				•	•
Reliability (precision) of coordinates					•
Vegetation at the starting point					•
Altitude			•	•	•
Aspect			•	•	•
Slope			•	•	•
Burnt perimeter (GIS)			•	•	•
Burnt area according to land cover and forest type	•	•	•	•	•
Burnt area according to forest type			•	•	•
Dominant tree species				•	•
Litter cover					•
Herb layer cover (<50 cm)					•
Shrub layer cover (>50 cm)					•
Fire type			•	•	•
Forest damage		•	•	•	•
Height of fire signs on trees				•	•
Soil damage		(•)	•	•	•
Forest function			•	•	•
Ignition cause	•	•	•	•	•
Reliability of ignition cause				•	•
Data source				•	•
General data reliability				•	•

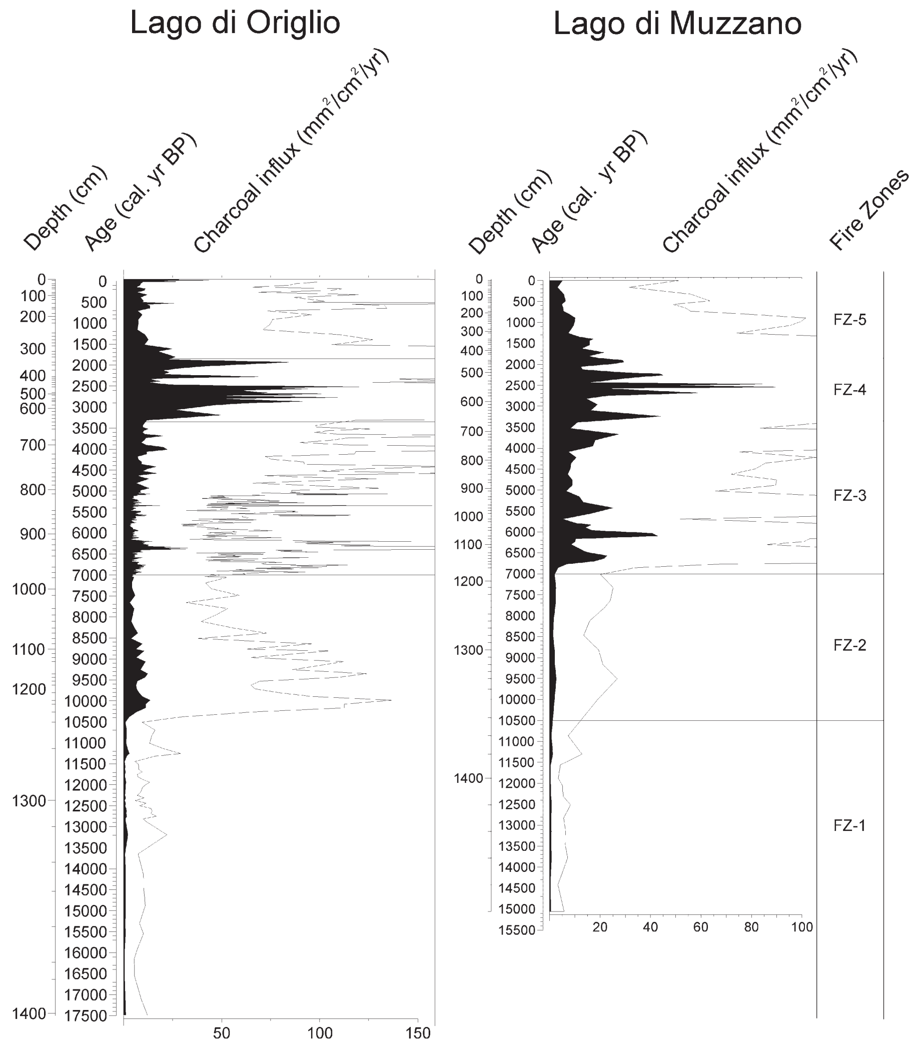

Fig. 4.2. Long-term fire history in Sottoceneri (Ticino): charcoal influx of Lago di Origlio and in Lago di Muzzano (source: TINNER et al. 1999).

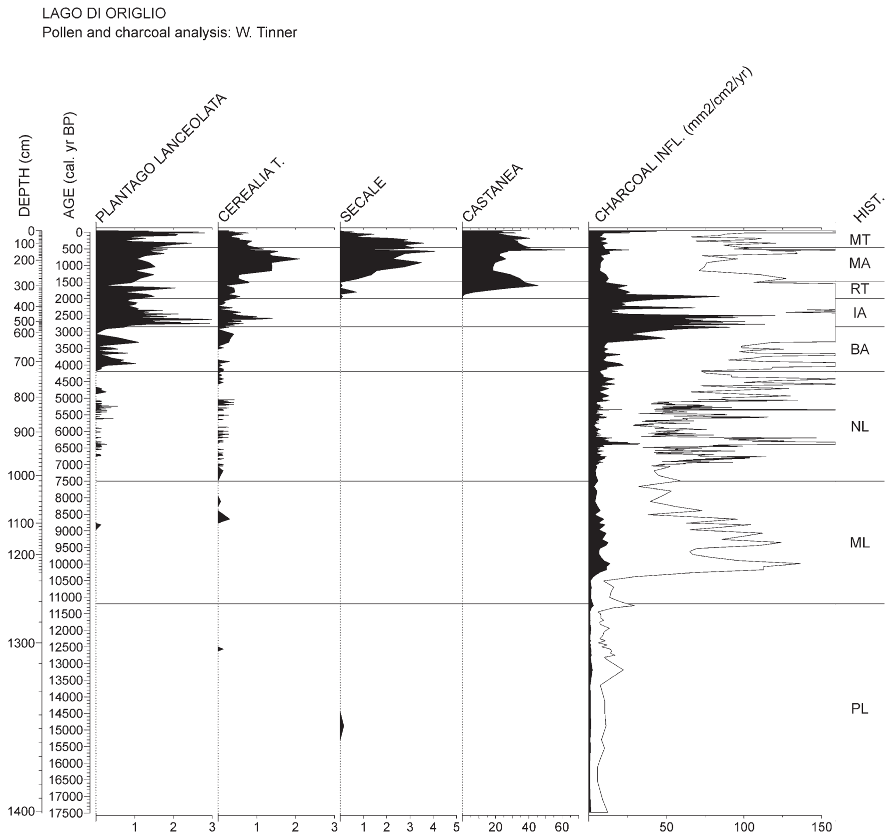

Fig. 4.3. Selected anthropogenic indicators *(Plantago lanceolata, Cerealia t., Secale, Castanea)* and long term fire history at Lago di Origlio (source: TINNER et al. 1999).

(Fig. 4.3). The correspondence of anthropogenic indicators with pronounced peaks in charcoal influx level suggests the human origin of most fires. Phase FZ-4 (corresponding to the Late Bronze and Iron Ages) represents the absolute highest charcoal levels in the fire history of the Canton Ticino. During this phase Arboreal Pollen (AP) is low and pollen of open pasture, agricultural land, and heathlands are dominant (CONEDERA & TINNER 2000a).

Charcoal values drop at the transition from FZ-4 to FZ-5 (0–100 AD) in coincidence with the introduction of chestnut (*Castanea sativa*) cultivation by the Romans (Fig. 4.3), suggesting a final, large-scale use of fire to clear the land before the chestnut woods were planted and the subsequent abandonment of the systematic slash and burn technique once the woodlands were cultivated (TINNER & CONEDERA 1995, CONEDERA et al. 2004a).

4.3 From the Middle Age to the modern times

Although characterized by low charcoal levels, phase FZ-5 displays low AP pollen values, indicating intensive land management by the reduced use of fires during the Middle Ages and the Modern Period. In this phase, the high values of the indicators for anthropogenic activity no longer coincide with high fire frequencies, and striking and persistent peaks in charcoal influx cannot be detected anymore (CONEDERA & TINNER 2000b).

In the study area, the first written documents related to forest or pasture fires can be found in the medieval bylaws of the local communities starting from the 13th century (CONEDERA et al. 2007a). Generally speaking, it was forbidden to start fires arbitrarily in the forests. In fact, most of the local bylaws explicitly prohibited the use of fire on one's own or someone else's land. In the village communities close to the edge of the Alps, there were special fire-guards whose job it was to prevent and to provide early warnings of fires. Although pasture maintenance mostly consisted of the mechanical elimination of brushwood, the use of fire for suppressing blackberries (*Vaccinium* spp.) and brushwood is mentioned. In particular cases, however, prescribed burning was used in selected common pastures or pastured woods to improve their quality (for example, through clearing and fertilization). This may explain the general low charcoal values of both lakes during the late Middle Ages and the first centuries of the Modern Times.

This approach to forest and pasture fires changed at the beginning of the 19th century when the Canton Ticino joined the Swiss Confederation (1803) and the institutionalized system of the local communities became looser and began to disintegrate. At the same time, the adjacent area of Lombardy was booming economically and industrially. The increasing need for timber to feed Lombardy's industry caused a progressive deregulation of the use of the forest resources in the Canton Ticino. As a result the forest stands were overly exploited by entrepreneurs for timber production and by local people for grazing. Annual reports of the forest services, the local agricultural literature, and the cantonal legislation document the illicit use of fire to clear pasture land and eliminate trees and brushwood (Fig. 4.4). In fact, farmers tended to ignore the new Cantonal (1870) and Federal (1876) forest legislation that aimed to increase the forested area and to protect the woods from the damage caused by fire and grazing, among other things. Many local communities felt that the new forest legislation was interfering with their authority and with their freedom to use land in a traditional manner.

Nevertheless, fires were still frequently used illicitly to clear pasture land until the second half of the 19th century, when the practice of setting fire to pastures "extinguished" itself because of the decrease in the number of cattle and improvements in breeding techniques (CONEDERA et al. 2007a).

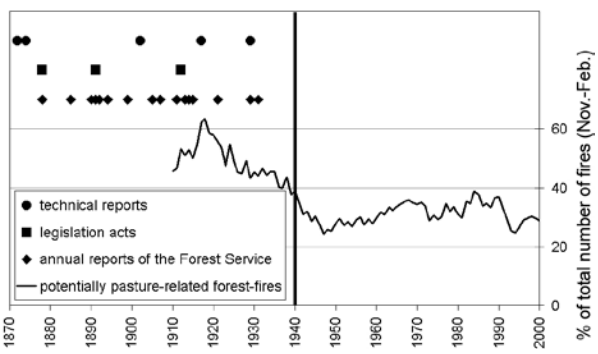

Fig. 4.4. Evidence of pasture fires for the period 1870–2000 in Canton Ticino: technical reports, legislation acts and annual reports referring to pasture fires and the percentage of fires potentially related to pasture fires (ignition cause = negligence and arson) in the period November to December (running mean over 9 years).

Unfortunately, besides a few critical reports in the agronomic local journals (TOGNI 1872; CEREGHETTI 1874; GALGIANI 1902), no inventory or detailed description of the controlled or prescribed pasture fires exists for this period. Only when such a fire got out of control, the foresters could well have registered it as a wildfire arising from negligence or arson. The annual proportion of forest fires registered in the months November to February since 1900 provide an indirect evidence of this as shown in Figure 4.4. In fact, according to CESCHI (1975/76), the late autumn and early winter months (November to February) were considered the most favourable periods for burning pastures because of the dry weather with low relative humidity, the thermic inversion on the mountain slopes, and the low moisture content of the necromass and the undergrowth. Figure 4.4 shows how, in the decades before 1940, such fires systematically represented more then 40 % of the registered events in the period from November to February, whereas they dropped to 30 % when the practice of illegally set pasture fires extinguished. As stated by CONEDERA et al. (2007a), most of the generic place names which referred to "*burn*" (*brüsada*, *schwändi*, etc., Fig. 4.5) represent the ethno-historical inheritance of this practice during both the regulated medieval times of local authority and the deregulated times of the early cantonal and federal authority.

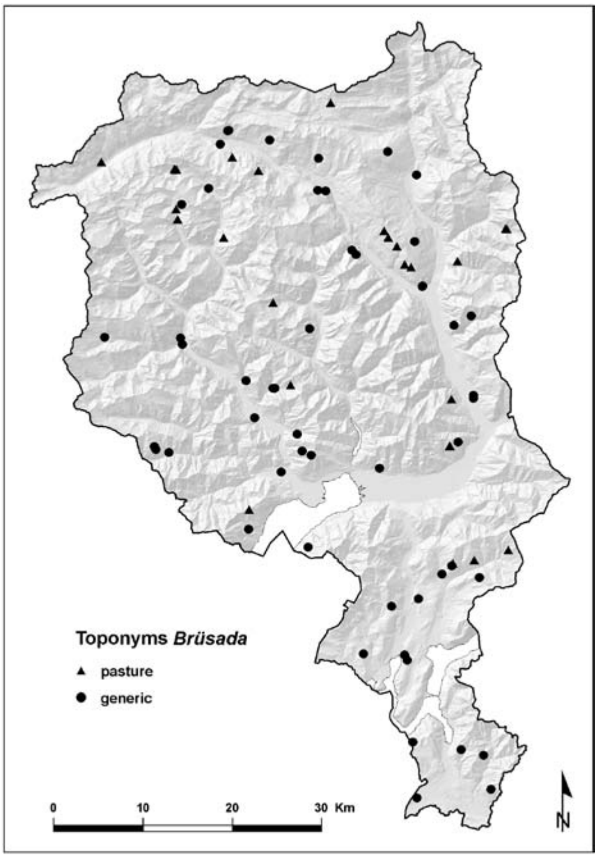

Fig. 4.5. Place names referring to pasture fires *(brüsada, Schwändi)* (source: CONEDERA et al. 2007a).

4.4 Wildland fires in the last century

Figure 4.6 reports the general trend in forest fire frequency and burnt area of the last 100 years in Canton Ticino as registered in the forest fire database (PEZZATTI et al. 2005) with respect to the trend in mean annual precipitation and the charcoal

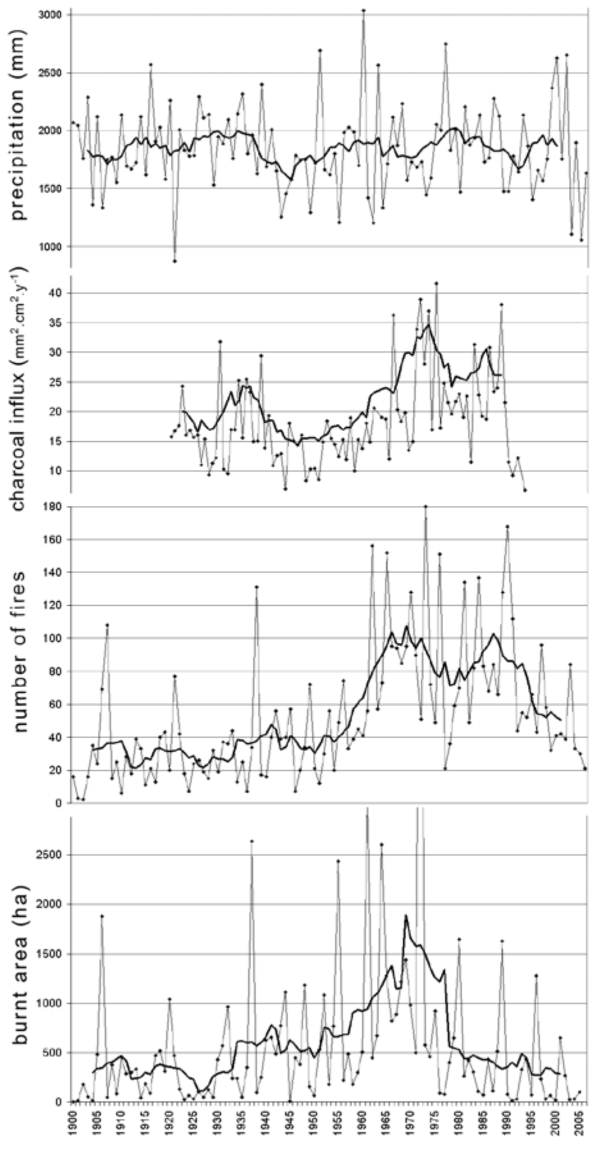

Fig. 4.6. Annual precipitation (Locarno-Monti), charcoal influx Origlio (1920–1995), number of fires and burnt area in Canton Ticino for the period 1900–2006 (source: TINNER et al. 1998; forest fire data base WSL Bellinzona; MeteoSwiss Locarno-Monti).

values as analysed in the sediments of the Lago di Origlio. As already noticed by TINNER et al. (1998), the general trend of the charcoal influx curve in lake sediments best correlates with the fire frequency and not with the burnt area. As expected, there is a general negative correlation between precipitation and the number of fires. The two curves diverge in the period 1955–1965, during a shift towards a consistently high level of fire frequency, and after 1990, when low precipitation values do not promote a proportional increase in the number of fires. The curves of the burnt area and fire frequency run synchronously until the late 1970s. After this date, the burnt area drops to very low levels, with the exceptions of particular years such as 1981, 1990, and 1997.

The comparison between the number of fires registered in the forest fire database and the charcoal particles in the lake sediments confirm the existence of an overestimation in fire frequency from the charcoal level for the period before 1940: the ratio between the number of forest fires and the charcoal influx, which fluctuates between 0.7 and 1.0 in the period 1940–1990, rises to 1.4 on average for the two decades 1920–1940. This very likely originates from the activities of controlled burning pastures that still existed before 1940 and that were not registered as wildfires by the foresters (Fig. 4.4; CONEDERA et al. 2007a).

On the other hand, the sudden increase in anthropogenic fire frequency in the late 1950s is reported in both the charcoal and the forest fire data curves. The slight time displacement between the two curves is probably due to potential dating imprecision of the sediments as well as the time lag caused by the deposition processes of the charcoal particles in the deepest lake parts (TINNER et al. 1998). As shown in Figure 4.7, this sudden increase may not be explained by changes in climatic conditions. On the contrary, it is mainly related to changes in landscape management as a consequence of the rapid socio-economic development after the Second World War. The general abandonment of the rural (i.e. mowing and pasture activities, litter utilisation) and forest (i.e. timber harvesting) activities temporarily turned the abandoned agricultural lands into a succession of fuel-rich fallows and forests. Fuel accumulated also in the existing forests and resulted in an increased danger of outbreaks of severe wildfires starting in the late 1950s (CONEDERA et al. 1996; CONEDERA & PEZZATTI 2005). A similar effect with a time lag of

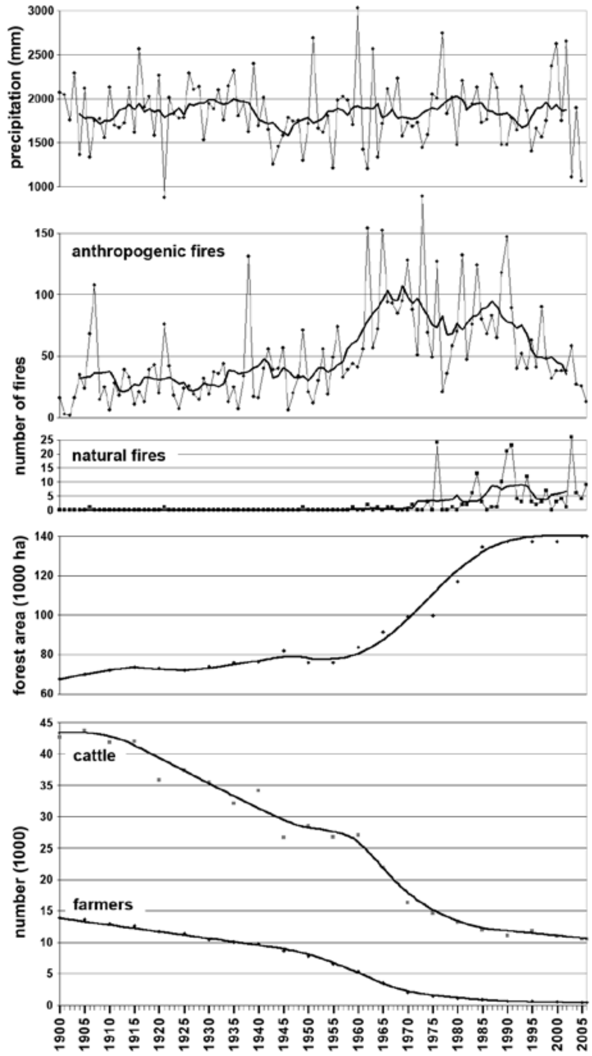

Fig. 4.7. Annual precipitation (Locarno-Monti), number of fires (anthropogenic, natural), forest area, cattle, and number of farmers in Canton Ticino for the period 1900–2006 (source: forest fire data base WSL Bellinzona, Annuario statistico del Canton Ticino, Meteoswiss Locarno-Monti).

20 years may be observed for the natural (lightning-induced) fires (Fig. 4.7), even if in this case one cannot exclude methodological artefacts from the database and changing meteorological conditions that may have overlapped the effect of changes in landscape management (CONEDERA et al. 1996; CONEDERA et al. 2005a; CONEDERA et al. 2006).

The decrease in anthropogenic fire frequency starting from the early 1990s and the reduction in burnt area starting from 1979 are not solely linkable to changes in the climatic condition or to changes in land-use (Fig. 4.6 and 4.7). They are much more likely the result of fire prevention and improvement in fire fighting techniques and organization, which will be discussed in chapter 6.

4.5 Present fire regime

The present (1991–2006) mean annual fire activity corresponds to 53.1 events and 227.3 ha of burnt area. This represents a clear reduction with respect to the preceding period (1975–1990), where the mean values were 86.6 events and 505.1 ha respectively. Beside this general trend toward fewer and smaller fires, fire activity fluctuates heavily from year to year with occasional extreme years such as 1981, 1990, 1997 where the burnt area was greater than 1000 ha (Fig. 4.6).

Fire seasonality is characterized by two major peaks, the first in March-April corresponding to the rapid spreading surface fires in the deciduous forest at low elevation and the second in July-August when lightning-induced underground fires are very common in the coniferous forests (Fig. 4.8). Similar to fire frequency and burnt area, fire seasonality also undergoes rapid changes over time. In the period 1991–2006 the summer peak of the number of fires and the spring peak of the area burnt are much more pronounced with respect to the preceding 15 years (Fig. 4.8).

Unfortunately, for about 40 % of the fires the ignition source remains uncertain or is unknown. Among fires of known cause, in the period 1991–2006 an average of 80.9 % of the events and of 91.6 % of the burnt area may be traced to premeditated or negligent human actions. These values rise to 90.2 % of the events and of 93.2 % of the burnt area for the antecedent period (1975–1990), highlighting the existing trend towards an increase of the relative incidence of the lightning-induced fires (CONEDERA et al. 2006). Humans cause forest fires mostly through negligence or arson. In rare cases, fires are caused by sparks from the railway or from an electrical short circuit, and through the impact of projectiles from military exercises. Surprisingly, the proportion of fires originated from negligence only slightly decreased after 1991 in winter time. Among the minor causes of ignition, railways show a declining trend for both number of fires and burnt areas whereas fires caused by electric lines behave just the opposite (Fig. 4.9).

From the geographical point of view, anthropogenic and lightning-induced fires display a very different distribution pattern (Fig. 4.10). Lightning-induced fires tend to be clustered toward higher elevations with steeper slopes. Because of their underground ignition and the relative inaccessibili-

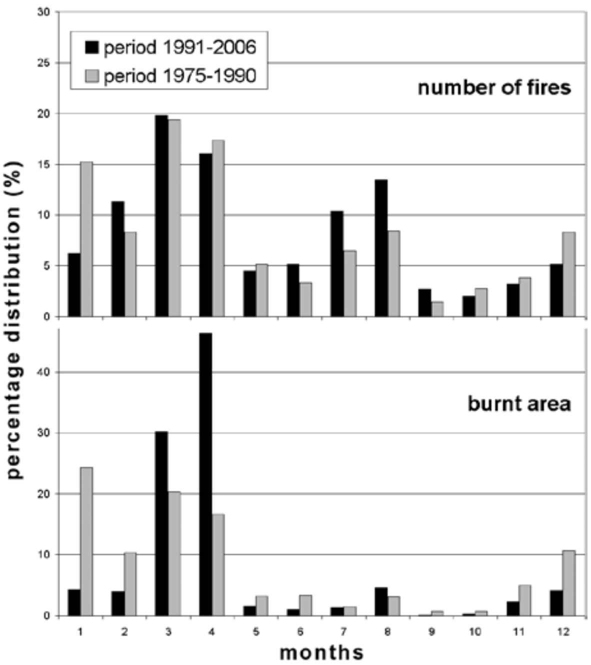

Fig. 4.8. Monthly distribution of forest fires in Canton Ticino (periods 1975–1990 and 1991–2006) (source: forest fire data base WSL Bellinzona).

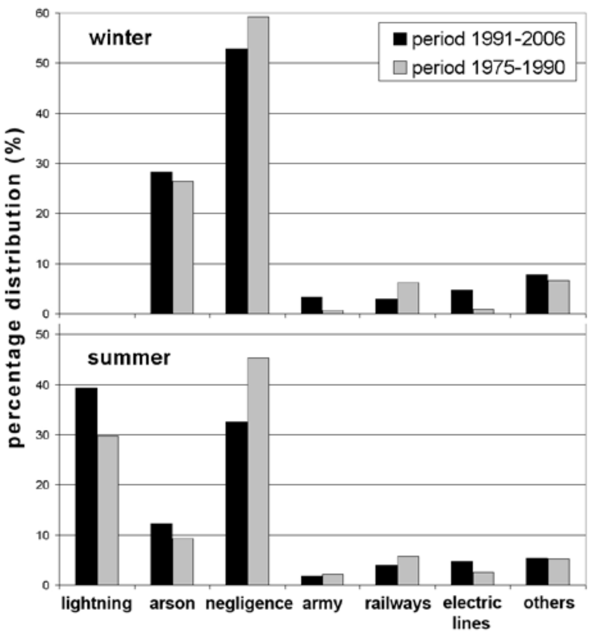

Fig. 4.9. Percentage distribution of the ignition causes according to the fire season (winter; summer) and to the period (1975–1990 / 1991–2006) in Canton Ticino (100 % = number of forest fires for the corresponding season; source: forest fire data base WSL Bellinzona).

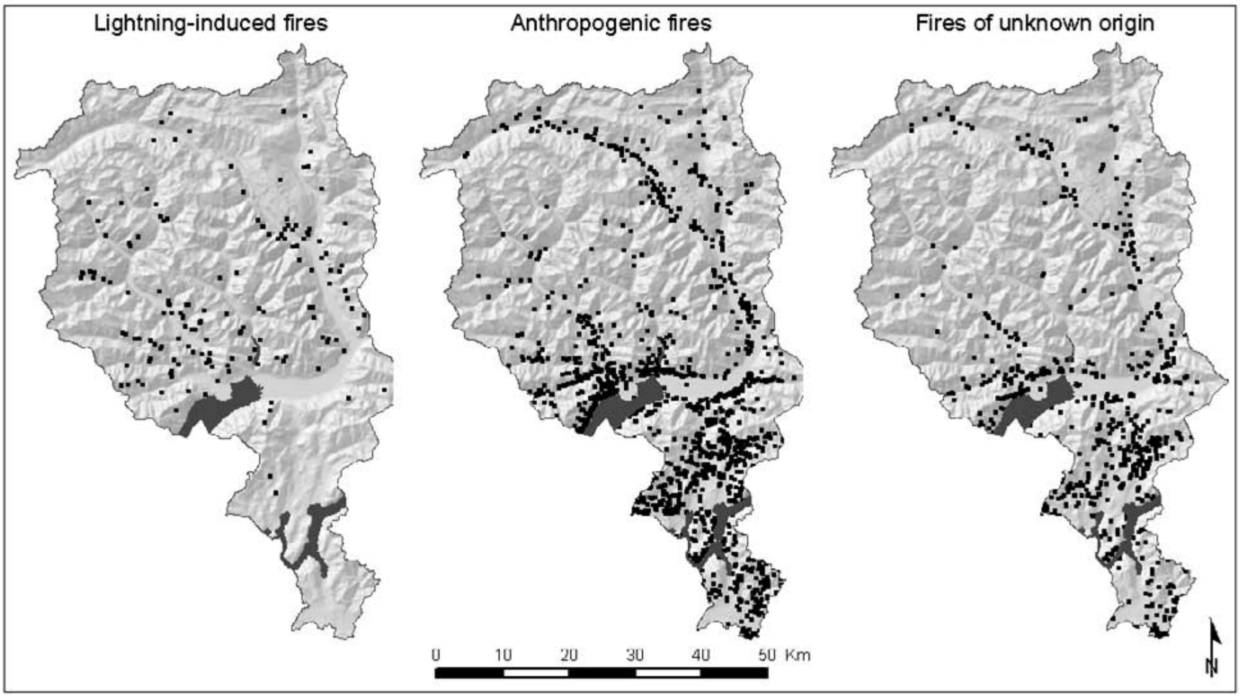

Fig. 4.10. Geographic distribution of the forest fires starting points in Canton Ticino according to the ignition source: lightning-induced fires, anthropogenic fires, fire of unknown origin (period 1969–2006, source: forest fire data base WSL Bellinzona).

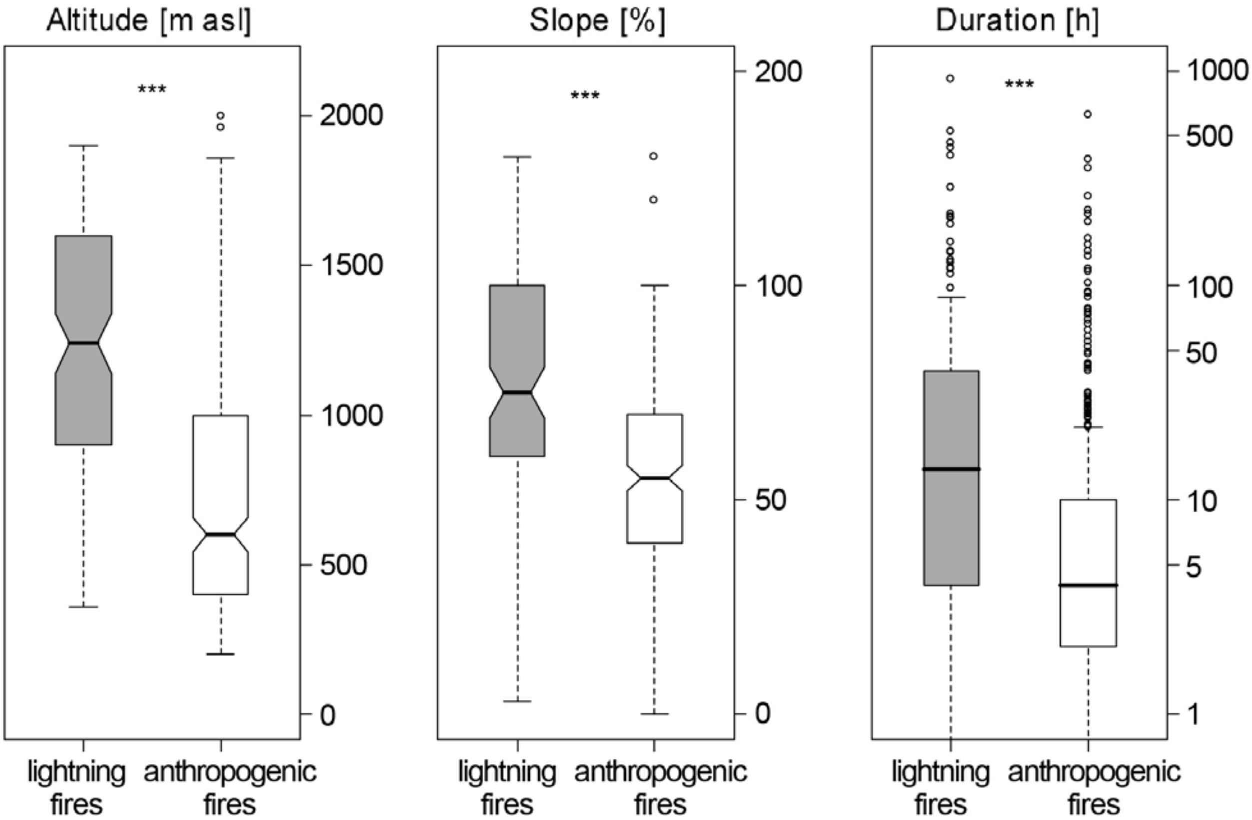

Fig. 4.11. Different elevation, slope, and duration of lightning-ignited and anthropogenic fires in the summer season (May to November) for the period 1981–2006 (source: forest fire data base WSL Bellinzona).

ty of burning sites, lightning-induced fires tend also to last longer before being extinguished than the anthropogenic fires that occur in the same period (Fig. 4.11). The differences are highly significant (non parametric Mann-Whitney U-test) for all the analysed characteristics.

The present fire regime may thus be divided into two main seasons:

– Winter season (December to April) with mostly rapid spreading surface fires (95 % of the events) at low altitude (85 % of the events take place below 1000 m a.s.l.) with a concentration in March-April, the period where the dry foehn wind is particularly frequent and the warming effect of the sunshine starts to be relevant with respect to the previous winter months (CONEDERA & PEZZATTI 2005; SPINEDI & ISOTTA 2004);
– Summer season (May to November) with a peak of lightning-induced fires in July-August that causes an increase in underground fires (18 % of the events) and a shift of the ignition points towards higher elevations (39 % of the events above 1000 m a.s.l.) (CONEDERA & PEZZATTI 2005; CONEDERA et al. 2006).

4.6 Concluding remarks

The Canton Ticino is a fire prone area that has experienced fires since the early late-glacial period. Since the Neolithic human beings have strongly influenced fire activity in the area, virtually continuously masking the natural fire regime. Since it is difficult to define a ‘natural’ fire regime, we refer in the frame of this work to a historical fire regime as defined by HARDY et al. (1998) and MORGAN et al. (2001). The present fire regime is very dynamic and evolves continuously according to general socio-economic patterns and weather conditions. In view of implementing a fire management plan, the detailed analysis of the present fire regime suggests considering two different fire seasons (winter fires from December to April and summer fires from May to November). According to the specific needs of the management plan, summer fires should be additionally split into anthropogenic summer fires and natural (lightning-induced) summer fires.

5 Forest fire selectivity and ecology

5.1 Methodological approach

We analysed the forest fire ecology in Canton Ticino at different biotic scales (fire selectivity of single forest cover classes to fire-susceptibility of single tree and plant species), different time scales (long-term [decades to centuries] forest recovery to short-term [years to decades] post-fire evolution), and different spatial scales (single plots to catchments). We analysed the post-fire reaction patterns of three important components of the forest ecosystem: the vegetation; the invertebrates; and some soil aspects such as runoff, superficial erosion, and soil respiration.

a) Fire selectivity with respect to forest cover

Fire selectivity was tested on the basis of a thematic forest cover map created by combining different existing forest stand maps. The thematic forest cover map consists of 6 classes referring to individual, dominant forest species (*Castanea sativa*, *Fagus sylvatica*, *Picea abies*, *Larix decidua*, *Abies alba*, *Pinus sylvestris*) and three generic forest stand classes (broadleaved forests, mixed broadleaved-coniferous stands; coniferous forests) in cases where a precise information on the main tree species was not available (see Fig. 3.9). In order to account for wildfires originating outside of the forest area, three additional vegetation classes were considered: no forest, a 0 to 50 m and a 50 to 100 m buffer from the forest edge. In total we considered 12 categories of vegetation cover (Table 5.1) covering 91 % (255 481 ha) of the whole territory. The remaining 9 % of the land area is represented by lakes or by land above 2500 m a.s.l. and was cut off from the analysis.

Fire selectivity of each forest vegetation class under consideration was analyzed both in terms of fire frequency and fire size for four different fire assemblages representing the present fire regimes: all fires (period 1990–2007), anthropogenic winter fires (1990–2007), anthropogenic summer fires (1990–2007), and natural summer fires (1980–2007, in order to consider a sufficient number of events for the Monte Carlo simulations). Fires were then randomly reassigned to the forest vegetation categories such that the probability of each fire to be assigned to a given forest cover class was kept equal to the relative extension of that category. The null hypothesis is that forest fires occur randomly across the different wood types such that there is no significant difference between the relative abundance of fires in each forest vegetation categories and the relative extension of each category within the analyzed area. The real number of fires in each forest cover class was then compared with the results of 1000 random simulations for the considered assemblages. For each forest cover class, p-values (two-tailed test) were computed as the proportion of Monte Carlo-derived values that were as low or lower (as high or higher) than the actual values.

At the same time, we tested whether the mean and median fire size in each forest cover class are significantly different from random. First, we com-

Table 5.1. Forest cover classes considered for the fire selectivity analysis.

Forest cover class	Area extent		Description
	[ha]	[%]	
No forest	64’242	25.2	Area outside the forest and the 100 m buffer from the forest edge
Buffer 0–50 m	43’735	17.1	Forest neighboring areas within 50 m of the forest edge
Buffer 50–100 m	19’601	7.5	Forest neighboring areas within 50–100 m of the forest edge
Chestnut stands	13’054	5.1	Forest stands with *Castanea sativa* as the dominant species
Beech stands	15’359	6.0	Forest stands with *Fagus sylvatica* as the dominant species
Spruce stands	13’154	5.2	Forest stands with *Picea abies* as the dominant species
Larch stands	7’092	2.8	Forest stands with *Larix decidua* as the dominant species
Fir stands	3’329	1.3	Forest stands with *Abies alba* as the dominant species
Pine stands	1’076	0.4	Forest stands with *Pinus sylvestris* as the dominant species
Other broadleaved forests	36’392	14.3	Mixed broadleaved stands without any specific dominance by chestnut or beech
Mixed forests (broadleaves-conifers)	23’741	9.3	Mixed stands without any specific dominance by species nor by broadleaves or conifers that always remains under 75 % of total cover
Other coniferous forests	14’706	5.8	Mixed broadleaved stands without any specific dominance by spruce, fir, Scot pine or larch

puted the mean and median fire sizes in each forest vegetation categories. Next, we compared the observed values with a Monte-Carlo simulations for which, by keeping the number of fires in each forest cover class constant, we randomly reassigned the burned surfaces of each fire. In this way we created forests in which the surface burned by each fire is distributed at random with respect to forest types. The p-values (two-tailed test) were obtained as the proportion of 1000 permutations for which the mean and median random fire sizes of each forest vegetation categories are as low or lower (as high or higher) than the actual value (PEZZATTI et al. 2009).

b) Post-fire vegetation response

Vegetation response to fire was studied at two temporal scales. Studies on the long term (decades to centuries) fire ecology were carried out at the Lago di Origlio (for details concerning the coring sites and the methods, see chapter 4 and TINNER et al. 1999). Fire effects on the vegetation were studied using cross correlations for analyzing the lags between charcoal and pollen data (GREEN 1981; DODSON 1990). This method compares the two variables by shifting the value chains one against the other for a specified number of time lags and calculating correlation coefficients at each time lag. Such analysis of palaeoecological time series is based on two general assumptions (GREEN 1981): (1) the time intervals between adjacent samples are equal, and (2) the data are stationary, i.e. the series contain no trend (e.g. population trend, expansion or decline of a species, climatic trend).

Because fires are single events, we applied contiguous sampling for the period from 5100 to 3100 BC. 173 samples corresponding to a nearly constant interval-sample age of 11.6±1.8 calibrated years (span) were used to compute cross-correlation coefficients at ±20 lags. Pollen-percentage values were used since parallel trends in pollen and charcoal influx (e.g. due to changing sedimentation rates) might give spurious correlations. Although linear de-trending and log-transformation would produce higher correlation coefficients, variables were not transformed (de-trended or/and log-transformed). This permitted a direct comparison of the cross-correlations with the pollen and charcoal diagrams. The 95 % confidence interval of the cross-correlation coefficients was estimated by computing ± 2 se (standard error) of the correlation coefficients; this corresponds to a test for a significant correlation between two variables (null hypothesis $r = 0$, $\alpha = 5\%$, two-sided). For further details on the methodology used see TINNER et al. (1999).

Short term (years to decades) vegetation recovery was analyzed using the space-for-time substitution approach. To this purpose, fire history was reconstructed in topographically homogeneous areas using the information provided by the WSL forest fire database (PEZZATTI et al. 2005), and the results were verified in the field using dendrochronological methods. In areas with different fire frequency and time since last fire, species abundance was then surveyed in 100 m^2 (10 x 10 m) plots following the BRAUN-BLANQUET (1964) method. Post-fire effects on the ecosystem were interpreted using species life strategy and indicator values as proposed by LANDOLT (1977). Mean indicator values were calculated on the base of the plant cover composition for each plot (for details see DELARZE et al. 1992; HOFMANN et al. 1998). Total number of plots, forest type, and original references are summarized in Table 5.2.

c) Post fire effect on invertebrates

Post-fire effects of different fire regimes on invertebrate community have been investigated for assessing the influence of fire upon biodiversity and ecosystem functionality. Using a similar space-for-time substitution approach as described for the

Table 5.2. Phytosociological relevés considered for assessing the fire-sensitivity of the vegetation.

Forest type	Relevés	Reference
South-facing chestnut forests on siliceous soils	271	DELARZE et al. (1992)
North-facing chestnut forests on siliceous soils	67	HOFMANN et al. (1998)
South-facing chestnut forests on siliceous soils rich in evergreen species	51	GRUND et al. (2005)
Mixed broadleaves forests on limestone	71	HOFMANN et al. (1998)
Mixed broadleaves forests on siliceous soils	22	HOFMANN et al. (1998)
Beech forests on siliceous soils	68	HOFMANN et al. (1998)

vegetation we selected in a south-facing chestnut area 25 sites with different fire regimes in terms of fire frequency and time since last event. Invertebrates were sampled once a week during the main activity season (March to September) in 1997 using three types of traps: pitfall traps, surface eclectors (emergence traps), and combined window-yellow pan traps (for details see MORETTI et al. 2002; MORETTI et al. 2006b). Seven taxonomic orders (Isopoda, Arenea, Coleoptera, Hemiptera, Neuroptera, Hymenoptera and Diptera) were determined to the species level. For ecological interpretation of the post-fire effects each species was then assigned to one (or two, if larvae and adults belong to different groups) of the following functional groups: ground-litter saprophagous, flying zoophagous, epigaeic zoophagous, phytophagous, pollinophagous, and saprohylophagous species.

d) Post fire effect on soil

Runoff and soil erosion were analyzed using 3 m x 10 m bounded plots and sediment traps for quantifying sediment yield, runoff rates, and nutrient loss. Plots were installed immediately after burning (from both wildfires and an experimental fire), and runoff and sediments were collected after each precipitation event during two years. In total, 8 plots with repeated fires (2 to 5 in the last 35 years), 8 plots with single fires, and 6 control plots were installed (MARXER et al. 1998; MARXER 2003).

5.2 Fire selectivity

The Monte-Carlo simulations highlighted the selective patterning of forest covers both in terms of fire frequency (Tab. 5.3) and fire size (Tab. 5.4 and 5.5).

All fires and winter fire frequency were significantly higher in chestnut stands, mixed forests, other broadleaved forests, and the area next to the forest edge (50 m buffer). Fires were underrepresented in beech, spruce, fir, and larch stands as well as in other coniferous forests. Outside the forests fires are underrepresented in the no forest category and in the 50 to 100 m buffer area from the forest edge. Pine stands were the only vegetation type without

Table 5.3. Results of vegetation cover fire selectivity on fire frequency for all fires, (anthropogenic) winter fires, anthropogenic summer fires and natural summer fires (source: PEZZATTI et al. 2009).

		no forest	other coniferous forests	mixed forests	other boradleaved forests	chestnut stands	beech stands	spruce stands	fir stands	larch stands	pine stands	buffer 0–50 m	buffer 50–100 m
all fires	true value	***102***	***36***	**170**	**320**	**232**	***32***	***37***	***1***	10	6	**389**	89
	upper limit	407	108	171	248	100	114	102	32	59	16	302	141
	lower limit	300	58	99	159	46	55	48	7	22	0	187	79
	significance	***	***	**	***	***	***	***	***	***		***	
winter fires	true value	***39***	***13***	**78**	**136**	**106**	***12***	***4***	***0***	***0***	1	**142**	38
	upper limit	176	54	76	108	51	54	48	18	29	7	128	63
	lower limit	109	17	31	58	14	17	14	1	4	0	69	20
	significance	***	***	***	***	***	***	***	***	***		***	
anthropogenic summer fires	true value	***8***	10	26	33	**27**	***3***	5	***0***	3	1	**66**	15
	upper limit	73	25	32	46	20	24	21	9	14	5	52	28
	lower limit	32	3	7	14	2	2	1	0	0	0	19	5
	significance	***				***	**		***			***	
natural summer fires	true value	***8***	6	**22**	23	4	***4***	**22**	1	5	1	**38**	***4***
	upper limit	51	19	25	35	16	19	18	6	12	5	39	22
	lower limit	21	2	3	8	0	1	2	0	0	0	11	3
	significance	***		*			*	***				**	**

true value: effective number of fires for the period 1982–2005. In **bold** fire frequency significantly greater than random; in ***italic bold*** fire frequency significantly smaller than random;
upper / lower limit: upper and lower limit resulting from the Monte Carlo simulations
significance: p-value (two tailed test). *** = $p < 0.001$; ** = $p < 0.01$; * = $p < 0.05$

Table 5.4. Results of vegetation cover fire selectivity on average fire size (ha) for all fires, (anthropogenic) winter fires, anthropogenic summer fires and natural summer fires (source: PEZZATTI et al. 2009).

		no forest	other coniferous forests	mixed forests	other borad-leaved forests	chestnut stands	beech stands	spruce stands	fir stands	larch stands	pine stands	buffer 0–50 m	buffer 50–100 m
	nr of fires	99	37	143	318	280	35	36	2	8	3	264	50
all fires	true value	10.09	18.44	***3.06***	10.11	5.89	15.22	***0.34***	1.51	0.46	1.04	7.73	***1.48***
	upper limit	367.0	102.0	150.0	220.0	93.0	104.0	90.0	33.0	55.0	14.0	262.0	134.0
	lower limit	2.0	0.7	2.3	3.2	2.6	0.6	0.7	0.0	0.1	0.0	2.7	0.9
	significance			*				***					*
winter fires	true value	8.49	**54.39**	***1.21***	11.52	6.16	9.67	1.63			0.65	10.69	1.31
	upper limit	36.71	84.06	33.59	21.98	21.80	68.18	138.3			550.0	21.06	75.38
	lower limit	1.05	0.18	0.89	1.98	2.50	0.34	0.02			0.01	1.91	0.22
	significance		*	**									
anthropo-genic sum-mer fires	true value	0.89	2.13	3.85	0.33	0.62	0.24	0.15	***0.01***	0.84	***0.01***	2.52	0.55
	upper limit	17.90	14.71	6.45	5.73	6.99	20.16	21.01	94.50	36.84	94.50	4.94	12.26
	lower limit	0.02	0.03	0.16	0.13	0.11	0.01	0.01	0.01	0.01	0.01	0.18	0.05
	significance								***		***		
natural summer fires	true value	2.09	1.44	0.52	1.49	1.00	0.09	***0.12***	3.00	0.24		**10.88**	1.18
	upper limit	29.71	29.83	15.17	13.62	130.0	76.67	14.09	130.0	46.21		10.97	41.29
	lower limit	0.04	0.03	0.12	0.12	0.01	0.01	0.18	0.01	0.01		0.26	0.01
	significance							***				***	

true value: effective average fire size for the period 1982-2005. In **bold** average fire size significantly greater than random; in ***italic bold*** average fire size significantly smaller than random;
upper / lower limit: upper and lower limit resulting from the Monte Carlo simulations
significance: p-value (two tailed test). *** = p < 0.001; ** = p < 0.01; * = p < 0.05

Table 5.5. Results of vegetation cover fire selectivity on median fire size (ha) for all fires, (anthropogenic) winter fires, anthropogenic summer fires and natural summer fires (source: PEZZATTI et al. 2009).

		no forest	other coniferous forests	mixed forests	other borad-leaved forests	chestnut stands	beech stands	spruce stands	fir stands	larch stands	pine stands	buffer 0–50 m	buffer 50–100 m
	nr of fires	99	37	143	318	280	35	36	2	8	3	264	50
all fires	true value	1.00	0.70	***0.10***	0.68	**1.00**	1.00	***0.10***	1.51	0.26	0.65	***0.50***	0.45
	upper limit	1.30	2.00	1.00	1.00	1.00	3.00	2.75	275.0	25.00	61.00	1.00	1.61
	lower limit	0.10	0.06	0.20	0.41	0.40	0.10	0.09	0.01	0.01	0.01	0.40	0.14
	significance			***		*		**				*	
winter fires	true value	**1.50**	1.20	***0.08***	0.46	1.00	2.25	2.00			0.65	0.50	0.13
	upper limit	2.30	10.00	1.50	1.00	1.00	7.00	26.00			550.0	1.50	11.50
	lower limit	0.05	0.02	0.15	0.25	0.20	0.03	0.01			0.01	0.20	0.02
	significance	*		***									
anthropo-genic sum-mer fires	true value	0.03	0.08	0.05	0.10	0.13	0.20	0.03	***0.01***	1.00	***0.01***	0.09	0.08
	upper limit	3.00	1.50	0.50	0.50	0.50	2.00	7.77	94.50	19.00	94.50	0.50	1.00
	lower limit	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01
	significance								***		***		
natural summer fires	true value	0.63	0.50	***0.02***	0.10	1.00	***0.01***	0.06	3.00	***0.01***		0.50	1.10
	upper limit	5.00	4.00	1.00	1.40	130.0	100.0	1.00	130.0	10.00		0.70	21.50
	lower limit	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01		0.02	0.01
	significance			**			***			***			

true value: effective median fire size for the period 1982–2005. In **bold** median fire size significantly greater than random; in ***italic bold*** median fire size significantly smaller than random;
upper / lower limit: upper and lower limit resulting from the Monte Carlo simulations
significance: p-value (two tailed test). *** = p < 0.001; ** = p < 0.01; * = p < 0.05

Table 5.6. Overall fire susceptibility and fire survival strategies of selected forest species in Canton Ticino (Source: DELARZE et al. 1992; HOFMANN et al. 1998; TINNER et al. 1998; TINNER et al. 1999; CONEDERA et al. 1999; GRUND et al. 2005).

species	Vegetative survive		Resprouting capacity		Post-fire colonization potential		Overall susceptibility	
	Low intensity surface fire	High intensity surface fire	Low intensity surface fire	High intensity surface fire	Low intensity surface fire	High intensity surface fire	Low fire frequency	High fire frequency
Abies alba	--	---	---	---	---	---	1	1
Acer spp.	--	---	(+)	-	+	--	1	1
Alnus spp.	--	---	(+)	-	-	---	4	2
Betula spp.	++	+	+	+	++	+	4	3
Castanea sativa	++	+	+++	+++	++	+	5	4
Corylus avellana	--	---	+++	++	-	-	4	2
Fagus sylvatica	--	---	(+)	-	++	+	2	2
Frangula alnus	--	---	+	-	+	+	4	3
Fraxinus spp.	-	---	(+)	-	+	-	1	1
Larix decidua	++	+	---	---	+	+	3	3
Picea abies	-	--	---	---	-	-	2	1
Pinus sylvestris	++	+	---	---	+	+	3	2
Populus tremula	--	---	+++	++	++	+	4	3
Quercus spp. (deciduous)	+++	+	++	+	++	+	4	2
Robinia pseudoacacia	++	+	+++	++	+++	+	5	4
Salix caprea	+	-	+++	++	++	+	4	2
Sambucus spp.	-	---	+++	++	+	+	4	2
Tilia spp.	-	---	(+)	--	+	-	1	1
Ulmus spp.	-	---	-	--	-	-	1	1
Domestic evergreens *(Hedera helix, Ilex aquifolium, Taxus baccata)*	--	---	(+)	--	-	---	2	1
Exotic evergreens (*Laurus nobilis, Prunus laurocerasus, Trachicarpus fortunei,* etc.)	--	---	(+)	--	-	---	2	1
Calluna vulgaris	--	---	+++	+++	++	+++	3	5
Cistus salviifolius	-	---	---	---	+++	+++	4	5
Molinia litoralis	--	---	+	++	++	+++	4	5
Pteridium aquilinum	--	---	++	+++	++	+++	3	5

---	very low	1	intolerant / severely damaged
-	low	2	sensitive
+	existing	3	indifferent
+++	very high	4	enhanced
()	in the youth only	5	adapted / favoured

any significant pattern in fire ignition frequency. Anthropogenic summer fires displayed similar patterns in certain cases (preference for buffer area 0–50, chestnut stands; avoidance for beech stands, fir stands and no forest), albeit with a lower statistical significance in some cases. Natural (lightning-induced) summer fires were clearly more prevalent in spruce stands and with less significance in mixed forests. Natural fires tend to be scarce in the 50–100 m buffer area, beech stands, and – of course – in the no forest area (Tab. 5.3).

Selectivity patterns were much more complex with respect to the fire size. Average fire size was greater than a random distribution would predict in other coniferous forests for winter fires and in the 0–50 m buffer for summer fires. Average fire size was smaller than random in fir and pine stands and the 50–100 buffer area for all fires and in beech and larch stands for natural summer fires (Tab. 5.4). Median fire size was lightly greater in chestnut stands for all fires and was smaller than random in mixed forests for all fire categories except summer anthropogenic fires, in spruce stands for all fires, and in beech and larch stands for natural summer fires (Tab. 5.5).

5.3 Post-fire vegetation response

The response of plants to fire depends on fire regime characteristics (especially fire frequency and severity), on the individual's life history, and on the species' survival strategies (i.e. direct vegetative survival, resprouting capacity (bud bank), flowering and seeding capacity, germination (seed bank), etc.; BOND & VAN WILGEN 1996). Table 5.6 summarizes the fire susceptibility and survival capacity of the main forest species in Canton Ticino. As shown by the cross-correlations, generally speaking trees decrease after a fire and shrubs take advantage of their resprouting capacity, showing a maximum positive correlation at lag 1 (a decade after the fire), whereas herbs behave as short term opportunists (Fig. 5.1, summary). Following these patterns, forest vegetation may be divided into different categories according to their response to fire: (a) decreasing taxa, (b) increasing taxa, (c) opportunists. A fourth category, the fire precursors (d), includes the species related also to anthropogenic activities that usually precede fire activities (Fig. 5.1).

Fire displays different selective pressure on vegetation according to the time scale of analysis (TINNER et al. 1999; DELARZE et al. 1992). The short term (few years) reaction of opportunists contribute to keep diversity relatively high immediately after a fire (see also DELARZE et al. 1992; HOFMANN et al. 1998; MORETTI & CONEDERA 2005; WOHLGEMUTH et al. 2005; MORETTI & LEGG 2006). In the long term (decades), however, high fire frequency corresponds to a significant drop in species diversity (DELARZE et al. 1992; TINNER et al. 1999). As suggested by DELARZE et al. (1992) and HOFMANN et al. (1998), the fire return interval and the time since the last fire interact in a complex way with species diversity in forest stands. As schematically reported in Figure 5.2, after a brief increase of opportunist species in the immediate post-fire period, the number of species that manage to survive frequent fires tend to be very reduced in the long run. Using fire sensitivity values as proposed by TINNER et al. (2000), KELLER et al. (2000) demonstrated with a modelling approach the primary role of fire in determining the long term forest successions in the study area and neighbouring regions.

Similar patterns are also found for the mean indicator values such as the reaction-value, the nutrient-value, and the humus-value (Fig. 5.3). According to DELARZE et al. (2002), such development of the mean indicator values R, N, and H reflect the post-fire perturbation in the nutrient cycle. The high values of R and N after the fire result from the temporary post-fire enrichment in minerals and nutrients. With time, the released minerals and nutrient are lost by run-off and leaching and the site is progressively colonized by fire-adapted species able to live in soils that tend to be poor (low N-values) and acid (low R-values). Contrary to the N and R values, the humus content (H-value) of the soil tend to be low immediately after fire (disruption of the humus layer) and to recover with time (Fig. 5.3).

Furthermore, in the short term repeated fires have an impact on forest stand physiognomy, reducing the degree of cover afforded by the tree layer and thereby increasing both the penetration of light and the index of continentality (HOFMANN et al. 1998). Although not specifically analysed, fire seasonality seems to have only a minor impact on the vegetation (HOFMANN et al. 1998).

5.4 Post-fire response of invertebrates

The response of invertebrates to fire is a result both of direct mortality (e.g. individuals that are killed by the flames or the heat) and of post-fire changes in the environmental conditions (changes in the forest stand physiognomy and in the trophic conditions) (MORETTI et al. 2006b). Direct killing results mostly in a short term effect (first year) whereas post-fire succession acts on longer time scales (years to decades), especially in the cases of high fire frequency and significant changes in the stand physiognomy. In addition, the various taxa and functional groups are affected differently by fire according to the fire severity, frequency, and seasonality.

In the case of the winter surface fires in the chestnut stands of Canton Ticino, direct fire impact (in terms of a significant decrease in number of individuals immediately after a fire) is registered by saprophages, epigaeic zoophages, and – to a lesser extent – saproxylophages (MORETTI et al. 2006b). Direct fire impact may vary slightly according to fire season and the corresponding invertebrate activity in the fuel layer. In the mid-term (3–7 years post-fire), overall biodiversity of the invertebrate community increased (especially in terms of the number of species) in areas with high fire frequencies (fire return interval < 10 years)

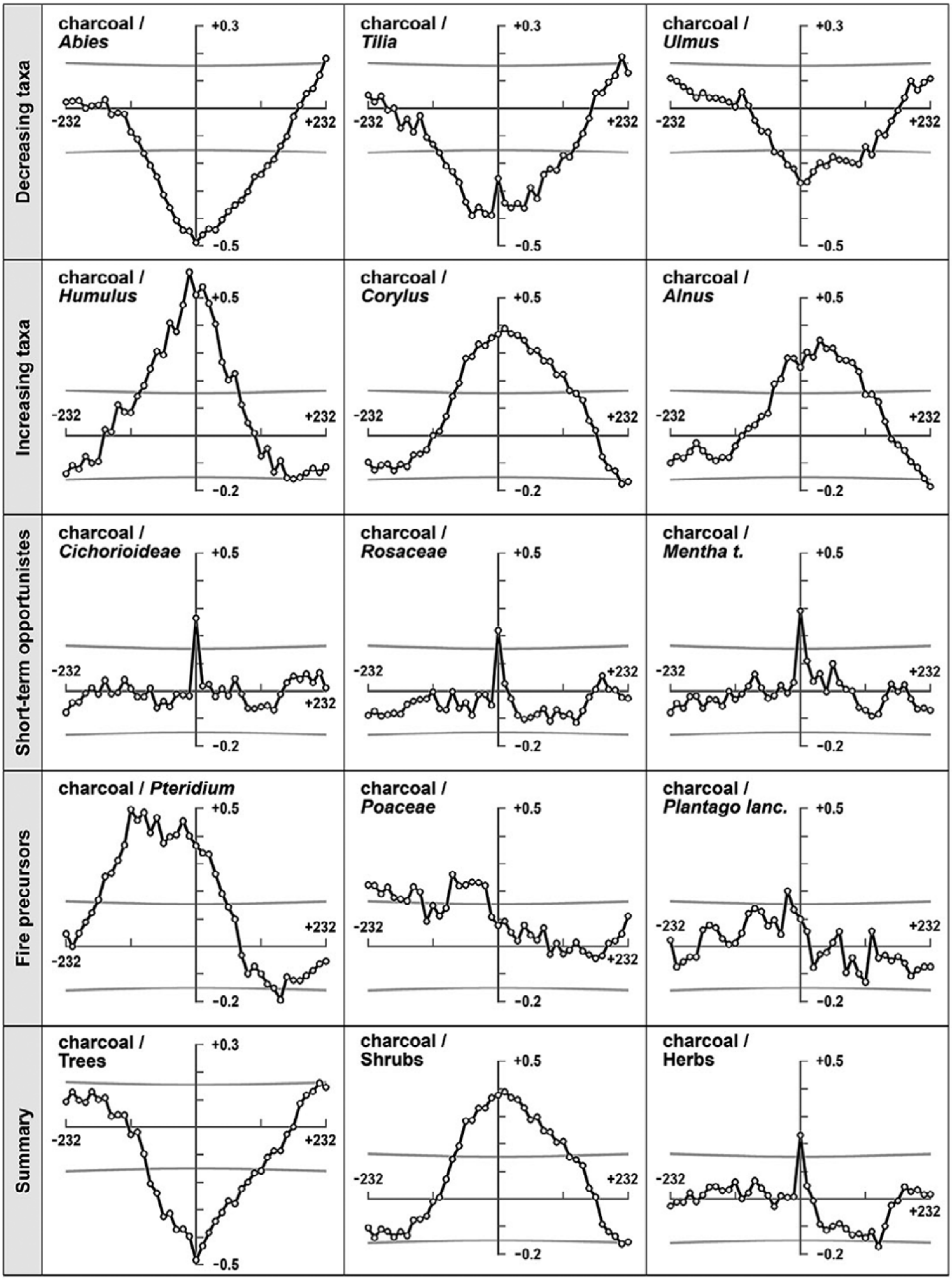

Fig. 5.1. Correlograms of charcoal influx, pollen percentages and diversity from Lago di Origlio (5100–3100 BC cal.). Horizontal axis shows lag in years (one lag = 11.6 years ca.). Vertical axis shows correlation coefficient – those outside the lines are significant at p = 0.05 (Source: TINNER et al. 1999).

and in the 1–3 years immediately following the fires (Fig. 5.4) (MORETTI et al. 2004; MORETTI et al. 2006b). Species richness increased 1–3 years after fire in flying zoophagous, pollinophages and epigaeic zoophages. In addition, after repeated fire there was a shift in dominance from individuals of species that prefer mature forest stands to individuals of species that are usually found at the forest edge or in open forests.
According to MORETTI & LEGG (2006) such shifts in species composition correspond to a shift in the dominant traits of plant and invertebrate communities towards an adaptation to disturbance regimes. In certain cases, such as the bee communities in Canton Ticino, the functional response in terms of shifts in characteristic traits is even stronger than for the taxonomic assemblage (MORETTI et al. 2009). Some of the species and the associated traits established by fire are, however, also present in the control plots, suggesting for Canton Ticino that the forest invertebrates (and to a lesser extent the forest plants) are well adapted to disturbance such as fires or other events affecting forest physiognomy (windthrows, sylvicultural management, etc.) (MORETTI et al. 2004; MORETTI & LEGG 2006).

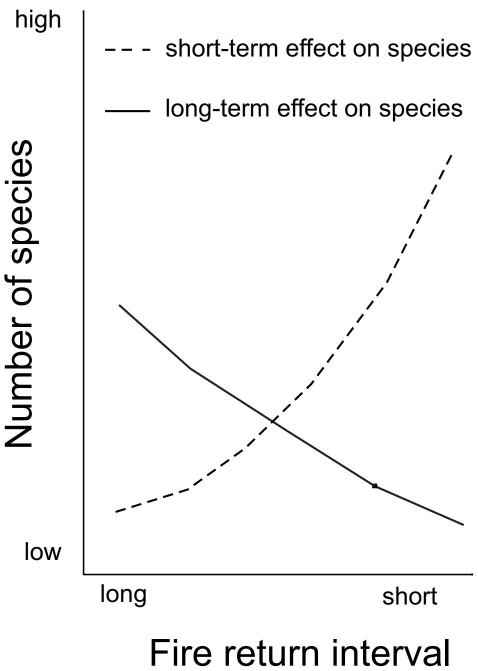

Fig. 5.2. Schematic representation of the short and long term effects of different fire frequencies on the species diversity in Canton Ticino (redrawn after DELARZE et al. 1992).

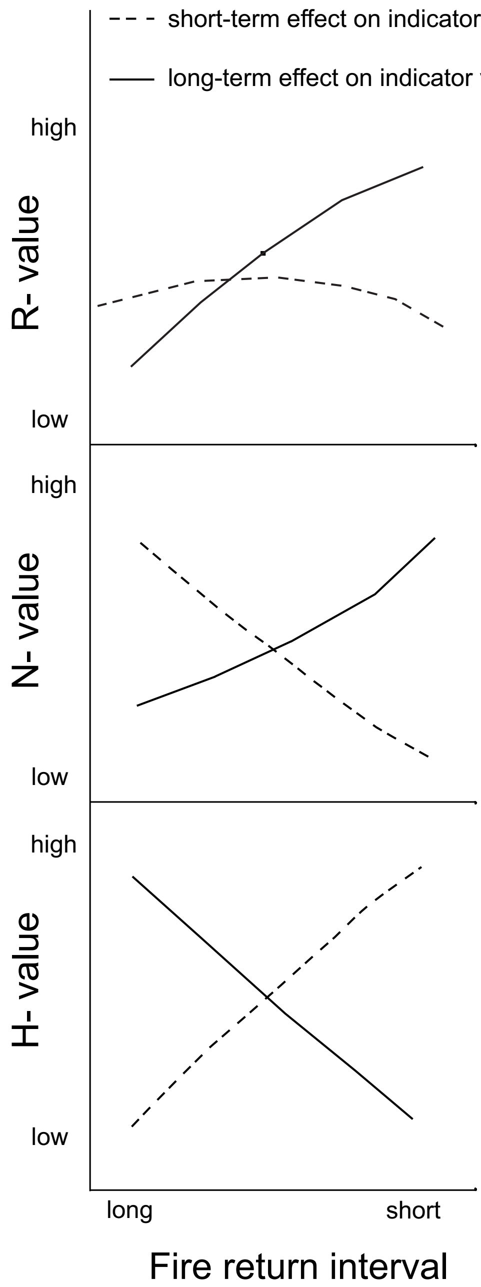

Fig. 5.3. Schematic representation of the short and long term effects of different fire frequencies on R-, N- and H-values in Canton Ticino. R-Values go from 1 (plants occurring chiefly on very acid soils) to 5 (plants found practically only on alkaline soils); N-values go from 1 (plants occurring chiefly on very poor soils) to 5 (plants found on soils with over-rich supply of nutrient); H-values go from 1 (plants occurring chiefly on raw soils) to 5 (plants rooting almost solely in soils rich in humus) (redrawn after DELARZE et al. 1992).

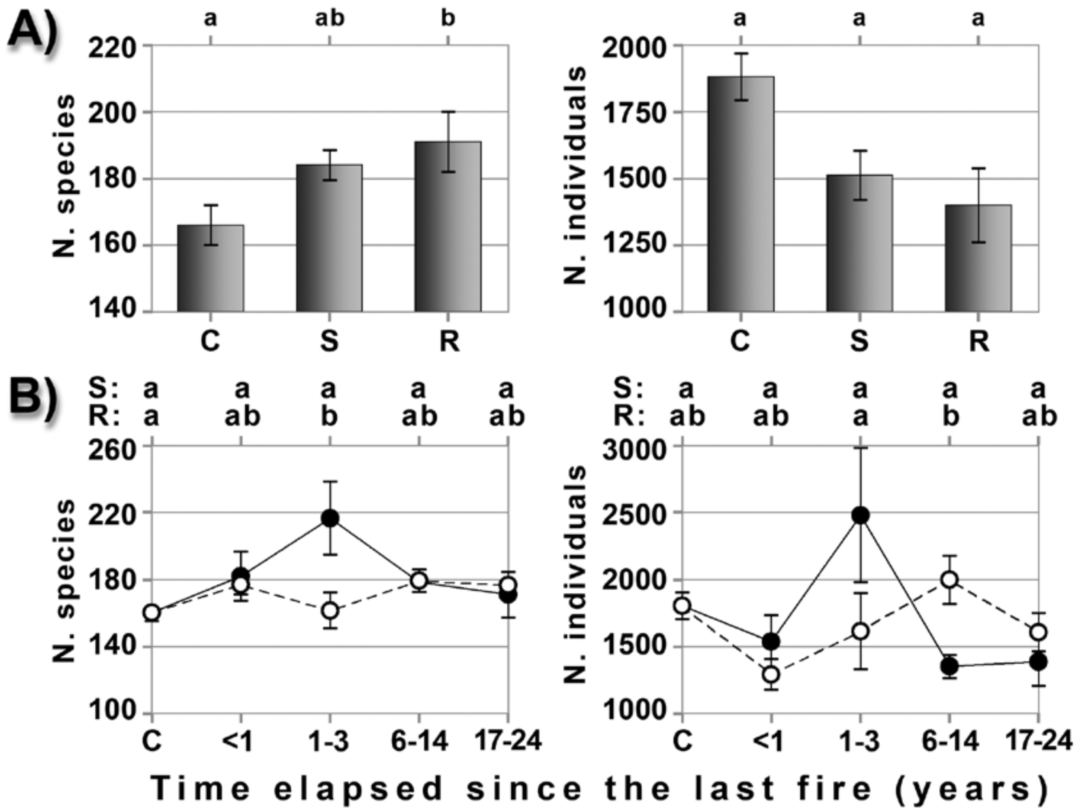

Fig. 5.4 Overall biodiversity in terms of number of species and number of individuals trapped in differently burned chestnut stands in Canton Ticino.
a) with respect to the fire frequency: C = control (no fire in the last 30 years), S = single fire (one fire in the last 30 years; R = repeated fires (3–5 fires in the last 30 years).
b) with respect to different times elapsed since last fire: single fire = open circles; repeated fires = filled circles. Data points with different letters are significantly different (ANOVA, $p < 0.05$).
(source: MORETTI et al. 2004; MORETTI et al. 2006b).

5.5 Fire adapted species

Some of the species favored by forest fires display a remarkable adaptation to fire and may be considered fire adapted species. One such species is the Sageleaf Rockrose *(Cistus salviifolius),* an Eumediterranean plant distributed on acid soils across the whole Mediterranean area in Europe, which displays an obligatory seeding reproductive strategy that makes it particularly well-adapted to disturbances such as recurrent fires (TROUMBIS & TRABAUD 1986; TRABAUD 1995). In Canton Ticino the species has colonised a few spots on steep and extremely south-exposed slopes that have recently burned or where other resprouting pioneer herbaceous and shrub species are scarce (Fig. 5.5). According to GRECO (1998), the distribution area of *C. salviifolius* has decreased dramatically in recent decades. In certain cases, the population is locally fragmented, having been reduced to very

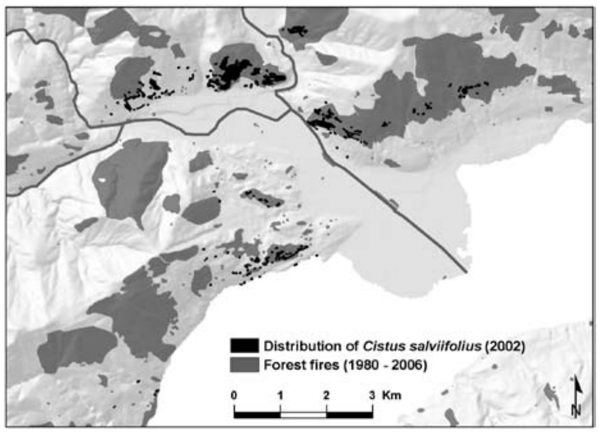

Fig. 5.5. Distribution area of *Cistus salviifolius* in Canton Ticino and its relationship with burnt area in the last decades (source: MORETTI et al. 2006a).

scant patches, jeopardizing population fitness in terms of genetic diversity, seed production, and fertility (CARETTI 2005). A modelling approach performed by MORETTI et al. (2006a) demonstrates how the occurrence of *C. salviifolius* on the southern slopes of the Swiss Alps is strongly related to the availability of competition-free sites, which in turn are mostly determined by topography and/or fire events. Under competition-free conditions, *C. salviifolius* displays a germination capacity similar to that in post-fire areas. On forest-compatible sites (e.g. enough soil depth, no predominance of emerging rocks), however, the absence of disturbance (fire or other) leads to an increase in species diversity, cover, and competition for resources, causing a regression in the vigour and density of the *C. salviifolius* population (BEFFA 2006). According to MORETTI et al. (2006a), the core distribution area of *C. salviifolius* in Ticino is closely related to the availability of competition-free sites, such as emerging bedrock, ridge locations, or steep slopes. The regression in the area of distribution registered by GRECO (1998) is thus probably due to the general decrease in disturbances such as fires and traditional land use (e.g. pasture) in the last decades. In this view, fire plays an important role by increasing germination rates and temporarily reducing the competition from the surrounding vegetation. thereby promoting the establishment of new, vigorous generations and allowing *C. salviifolius* to temporarily extend its range into freshly burnt forest sites.

Among invertebrates, four fire adapted species were detected in the study area so far: the fly *Microsania pallipes* (also known as smoky fly), the drosophila *Amiota alboguttata*, the beetle *Sericoda quadripunxtatum*, and the true bug *Aradus lugubris* (MORETTI et al. 2005; WYNIGER et al. 2002). As demonstrated by the highly documented case of *Aradus lugubris*, fire adapted flying invertebrates are able to remotely detect burning sites or freshly burnt areas and to immediately colonize them in order take advantage of feeding (e.g. fungi growing on charcoal) or breeding opportunities on the new substrates created by the fire. *Aradus lugubris*'s ability to respond rapidly to fire was proved in the frame of a fire experiment executed in the study area in 1998 (Marxer & CONEDERA 1999). During the monitoring of the invertebrate fauna before the experiment, no specimens of the species were captured. Starting from the very next day after the fire, 27 specimens of *Aradus lugubris* were sampled in the burnt area (11 by combined window-yellow pan traps; 16 by pitfall traps), while none were found in the adjacent control plot (Fig. 5.6). Sampling was alternated with periods without catches due to wet and cold weather phases. The predominance of combined window-yellow pan catches in the first post-fire phase indicates the flying approach of the bug. In the following days most specimens were collected in the pitfall traps on the ground, likely as the bugs actively looked for suitable feeding and/or breeding habitats (WYNIGER et al. 2002).

Last but not least, a number of fungal species (up to 35 species identified in the study region so far) exhibited adaptations to fire in the form of enhanced (thermo-induced) post-fire fructification or with a

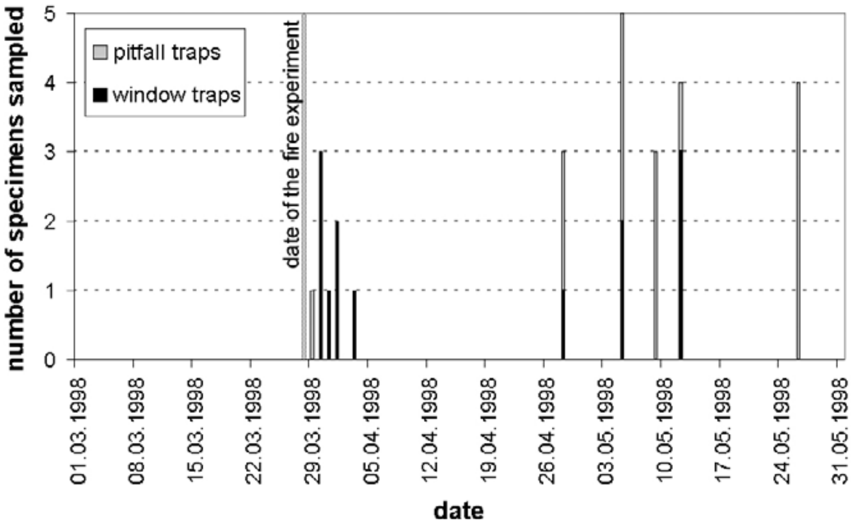

Fig. 5.6. Specimens of *Aradus lugubris* FALLEN 1807 collected in the frame of the fire experiment of March 28th 1998 in S. Antonino (Canton Ticino). No specimen was collected in the control plots (source: WYNIGER et al. 2002).

preference for charcoal as a growing substrate (anthracophilous behaviour) (RIVA 2006). Other fungi, including *Stereum hirsutum*, *Irpex lacteus*, *Schizophyllum commune*, *Daldinia* spp., and *Cryphonectria parasitica*, took advantage of the post-fire stress induced in the trees to attack different tree species, displaying abundant sporulation and accelerating the die back of the trees (CONEDERA et al. 2007b).

5.6 Post-fire effects on soil

Fire consumes the fuel, disrupts the interceptive action of the forest cover (canopy, litter, duff and organic debris), and causes biotic, chemical and physical changes in the soil properties (GIOVANNINI 1994; MARTIN & MOODY 2001). Concerning the study area, moderate to intense surface fires may release a large amount of nutrients and a large pool of easily decomposable compounds from dead plant cells as demonstrated by the increased soil respiration rates that may last for months (WÜTHRICH et al. 2001; WÜTHRICH et al. 2002). Despite nutrient availability and increased rate of respiration, no additional biomass is produced after a fire, which makes available nutrients particularly prone to leaching (WÜTHRICH et al. 2002). The results from MARXER (2003) on nutrient wash-out during precipitation events on burnt surfaces confirm this hypothesis. Leaching of nutrients such as K, Ca, Mg, PO_4 increases in the burnt areas with respect to the control plots by a factor ranging from 1.7 to 17.0 according to the nutrient considered and the fire intensity. This results in a decrease in soil fertility as already indicated by the N-values of the post-fire vegetation in areas with high fire frequency (see Fig. 5.3 and DELARZE et al. 1992; HOFMANN et al. 1998).

Changes in soil chemical and physical properties induced by fires usually also imply an alteration in soil hydrophobicity and in soil infiltration properties (DEBANO 2000a, 2000b; LETEY 2001; MARTIN & MOODY 2001). As reported in Figure 5.7, fast spreading surface fires in the chestnut stands of the study area may cause a decrease in water infiltration rate by a factor of 2.5 (MARXER 2003). For regions such as Canton Ticino, which is highly susceptible to precipitation-induced erosion (mean R-factor of 734 with peak values of 1200, BAIER 1997; MARXER 2003), this results in increased runoff (Fig. 5.8) and soil erosion (Fig. 5.9). As a rule, most erosion (up to 90 %) derives from only 1 or 2 intense and erosive precipitation events, as is reflected in the very high standard deviation of observed values (Fig. 5.9, MARXER 2003). Runoff and erosion rates are especially high in the first post-fire year and in the cases of high fire intensity (due to increased water repellence of the soil, GIOVANNINI 1994) and low fire frequency (due to a lack of fire adapted vegetation able to rapidly cover the bare soil, MARXER et al. 1998; MARXER 2003).

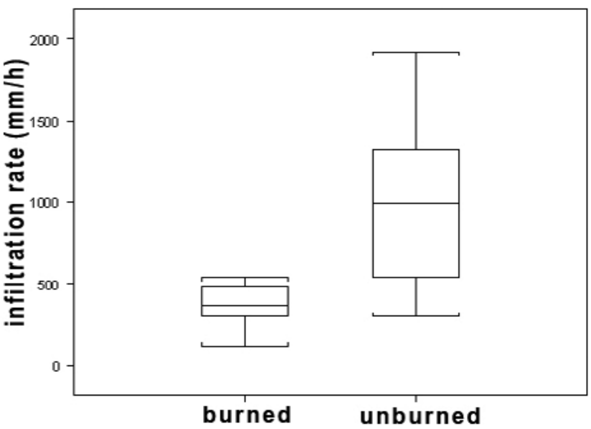

Fig. 5.7. Rate of water infiltration in burned and unburned soil in Ronco s./Ascona. Vertical lines represent standard deviation (source: MARXER 2003).

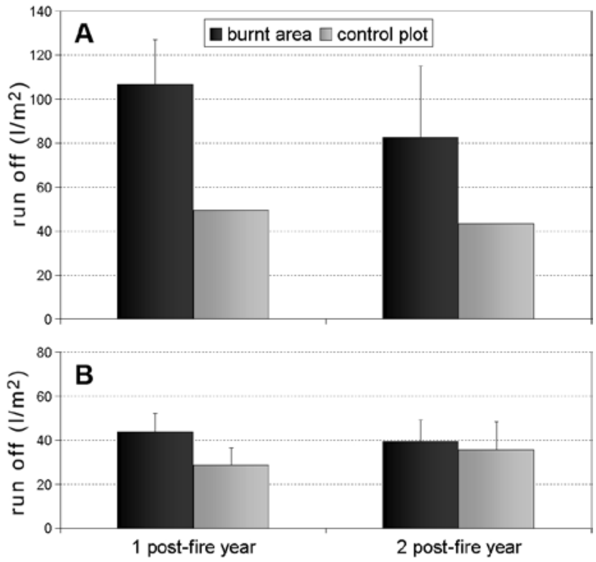

Fig. 5.8. Runoff in burned and unburned areas.
A) Ronco s./Ascona (medium fire intensity, high fire frequency);
B) S. Antonino (low intensity, low fire frequency).
Vertical lines represent standard deviation (source: MARXER 2003).

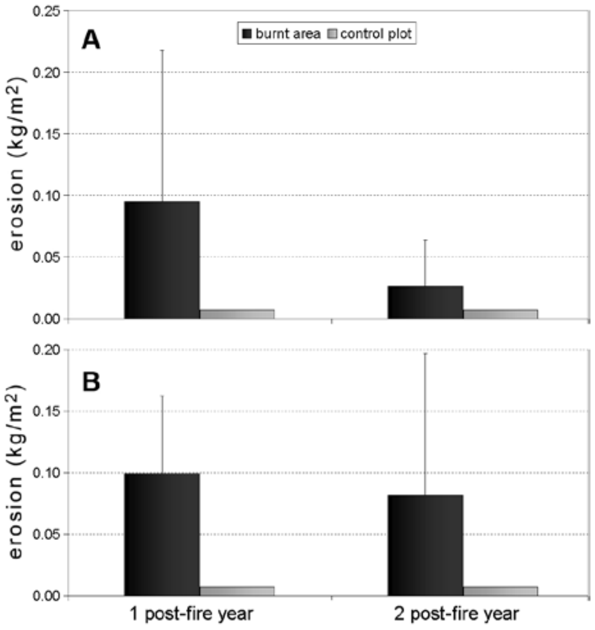

Fig. 5.9. Erosion in burned and unburned areas.
A) Ronco s./Ascona (medium fire intensity, high fire frequency);
B) S. Antonino (low intensity, low fire frequency).
Vertical lines represent standard deviation (source: MARXER 2003).

When a fire affects most or all of an entire catchment, the resulting alterations may trigger a high risk of debris-flows (CANNON 2001). In fact, increased overland flow and runoff-dominated erosion may result in the lowering of the threshold of intensity and amount of precipitation necessary to cause a flood event (CANNON et al. 2008). As demonstrated by CONEDERA et al. 2003, post-fire mudflows and debris flows represent a particularly acute problem in mountainous regions such as Canton Ticino: in 1997 a forest fire affected 80 % of a 35.5 ha mountain catchment in the community of Ronco s/Ascona. This resulted in the following months in a 100- to 200-year flood event as a consequence of a 10-year rainfall event. Unfortunately no sylvicultural or technical measures have proved so far to be efficient in mitigating post-fire erosion and debris flow risk (see for instance PROVIDOLI et al. 2002).

5.7 Concluding remarks

Acquired knowledge of fire selectivity and fire ecology represents very useful information for implementing fire danger and fire risk maps of the study region.

Forest cover classes display clear selectivity patterns in terms of number of fires and – to a less extent – average and median burnt area. In addition, patterns of selectivity suggest a need to consider the origin of the fire (anthropogenic, natural) and the seasonality of the fire (vegetative period, winter rest) separately when implementing management plans.

From an ecological point of view, most post-fire effects depend on fire regime characteristics such as fire intensity, fire frequency and – partially correlated to them – time elapsed since last fire. In this context, fire seasonality may be considered of minor relevance. High fire frequencies reduce soil fertility and plant species diversity in the long run. On the other hand, in areas frequently hit by fire, fire adapted vegetation rapidly covers the bare soil, mitigating post-fire erosion risk and increasing the overall biodiversity due to the entry of forest edge and open forest species. It is important to note that indicators such as the presence of light-demanding and rapidly spreading plants (e.g. *Pteridium aquilinum*) which prevent soil erosion and open structured stands that increase biodiversity are not necessarily specific to areas with a high fire frequency. Similar results can be achieved with targeted sylvicultural management or other disturbance regimes.

Low fire frequencies do not have a significant impact on forest stand structure and functionality in the long run, but may cause high runoff and erosion rates in the early post-fire years, which may end in gully and channel erosion in the case of large fires. High fire intensity acts to magnify these described ecological effects.

In conclusion, the highest risk in terms of runoff and soil erosion exists in areas with a very low fire frequency and a long time elapsed since the last fire, and where unmanaged forest stands have produced an inconsistent herbaceous layer with a lot of dead fuel accumulated on the soil. Highest risk of loss of soil fertility and plant biodiversity exists on the contrary in frequently burnt areas where fires have disrupted the original forest stand structure. In view of the high potential for post-fire erosion and debris flow risk that may be caused by large fires affecting mountain catchments, this type of ecological effect should be considered as a first priority. In this sense, an escaped fire that gets large in size should be considered of high concern in the frame of risk assessment related to fire management (see also FINNEY 2005).

6 Fire management history

6.1 Methodological approach

Information on past fire prevention and fire fighting organization and strategy was provided by searching for documentary records in different archives and written sources such as the medieval bylaws of the local communities, local literature, archives of the Forest Services, official acts of the cantonal administration and of the cantonal parliament, official cantonal and federal legislation on forest fires and on the organization of the fire brigades, archives of the fire brigades and others.
For detecting the effects of the different fire preventive and fighting measures, changes in forest fire data trends were assessed using a simple changing point analysis based on the cumulative difference between the single value and the mean value over the whole considered period (1900–2006):

$$Vt_i = \sum_{i=1900}^{2006} (V_{i-1} + (V_i - V_a))$$

where:
Vt_i = trend values of the year i
V_i = values of the year i
V_a = average value for the whole considered period 1900–2006.

Information on existing water points for fire aerial fire fighting was collected by the Cantonal Forest Service of Ticino by the mean of a survey among foresters in 2005–2006 and was inserted in a GIS-based database.

6.2 Fire prevention

In the study area, existing Medieval fire prescriptions for fire prevention and fire control became looser and obsolete at the beginning of the nineteenth century when the Canton Ticino joined the Swiss Confederation (1803). Starting from this new situation, the Cantonal authorities progressively introduced preventive dispositions aiming to prevent the ignition of anthropogenic wildfires. As reported in Tables 6.1 to 6.3, preventive dispositions are manifold and concern legal acts, information activities, sylvicultural and technical measures.

Fire prevention was long not considered a priority in the newly created Canton of Ticino. The first legal act specifically concerning the prevention of forest fires dates to 1857 – that is more than a half a century after the constitution of the Canton – and failed to be applied. Since then, legal preventative and informational acts on the necessity of avoiding pasture fires were frequently reiterated until the early 1930s, albeit without any efficiency (see chapter Fire history and Fig. 4.4 in particular).
When the problem of illegal pasture fires vanished in the early 1940s, the focus of the preventative measures turned towards the prevention (in the forms of information boards, announcements of fire danger by the Meteorological Service, prohibition of burning garden debris in the open, etc.) of fire ignition through negligence and towards early fire detection and early fire attack (utilizing fire guards, an alert system, technical measures including hydrant nets, etc.) (see Tab 6.1 and 6.2). This was especially necessary since the fire frequency increased dramatically in the period between 1955 and 1965 (Fig. 6.1) as a consequence of the abandonment of the traditional agricultural and land management activities (see also chapter 3.2 and Fig. 3.3).
Unfortunately, the overall efficiency of some long-term and general measures is very difficult to assess. Much easier is the assessment of single and timely, precisely identifiable measures. According to Figure 6.1, the most efficient preventative legal acts in terms of reducing the number of ignited fires seem to be the prohibition of burning garden debris in the open (Cantonal decree approved on October 21, 1987, but operational with the corresponding penalties since January 1, 1989) and the prohibition against fire works and celebration fires during the Swiss National Day of August 1st in case of fire danger (Cantonal decrees of July 11, 1990) (see also chapter 4 and Fig. 4.7 and CONEDERA et al. 2005b). This is confirmed by comparing the evolution of the fire frequency in Canton Ticino with the neighbouring Canton of Grisons in the decades prior to and after the introduction of the legal measures in Ticino (Fig. 6.2). Also evident are the effects of technical and organizational preventative measures concerning single ignition causes. The number of fires caused by the railway dropped a first time after the electrification of the Gotthard line (1913) and a second time after the construction of barriers against sparks along the steepest sectors of the

Gotthard line was co mpleted (1975–1990, Fig. 6.3). Similarly, the severe preventative measures introduced by the army starting in 1974 (see Table 6.3) displayed an immediate effect in terms of reduction of the number of fire caused by military activities (Fig. 6.4).

Important preventative measures for improving reaction times and coordination for an initial attack have been taken starting in 2001 with the organization of a helicopter standby service in case of fire danger that guarantees rapid intervention and enough machines according to the specific needs for aerial fire-fighting. Since 2002 the Forest Service has also provided a standby organization in order to assure that the fire brigade service has access to advice and support after the early initial attack phase (see also Tab. 6.5).

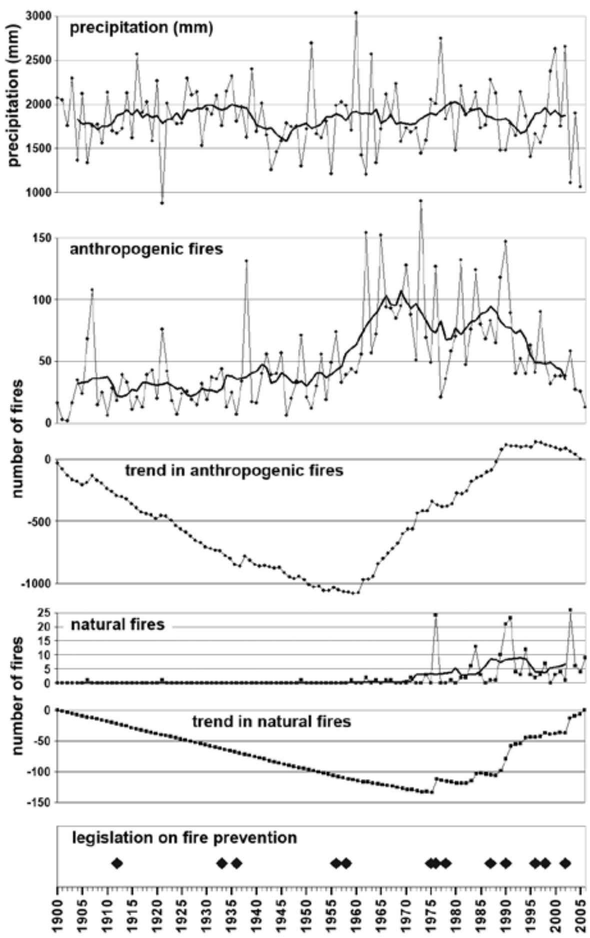

Fig. 6.1. Annual precipitation (Locarno-Monti), number of fires (anthropogenic, natural), trend (cumulative differences to the periodic mean), and legislation related to fire prevention in Canton Ticino for the period 1900–2006 (source: forest fire data base WSL Bellinzona; MeteoSwiss Locarno-Monti; CONEDERA et al. 2004b).

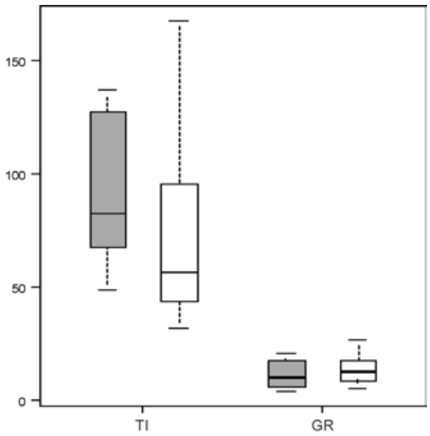

Fig. 6.2. Box-plot distribution of the number of forest fires in the periods 1980–1989 (dark grey boxes) and 1990–1999 (white boxes) in Canton Ticino and in Canton of Grisons.

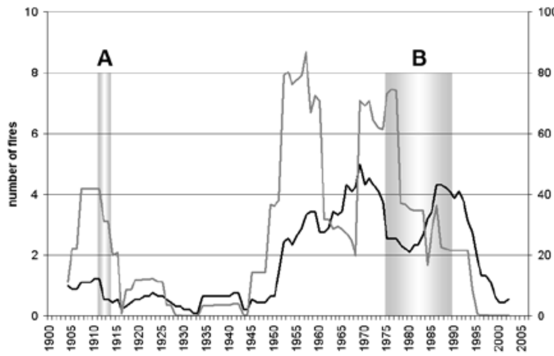

Fig. 6.3. Effect of pre-suppression measures on number of fires (running mean over 9 years, black line) and burnt area (running mean over 9 years, grey line) ignited by the railways in Canton Ticino for the period 1900–2006. A = electrification of the Gotthard line; B = construction of barriers against sparks (source: forest fire data base WSL Bellinzona).

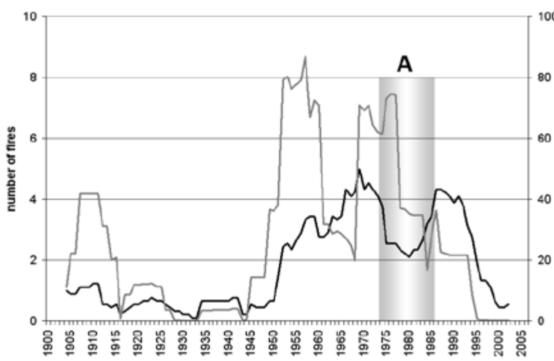

Fig. 6.4. Effect of pre-suppression measures on number of fires (running mean over 9 years, black line) and burnt area (running mean over 9 years, grey line) ignited by the army in Canton Ticino for the period 1900–2006. A = period of implementing active prevention measures (source: forest fire data base WSL Bellinzona).

The Cantonal Forest Service is also responsible for planning and constructing technical facilities for improving fire fighting activities such as forest roads and trails, hydrant nets, water reservoirs, and water points (CORTI 2005). All existing technical facilities are now registered and documented in a GIS-based database of the Cantonal Forest Service that provides foresters and fire brigades with all the information necessary for planning fire attacks (Fig. 6.5, Tab. 6.6).

Since the sylvicultural measures related to fire prevention in Canton Ticino are very poor and discontinuous (Table 6.3), we can conclude that forest fires have so far never assumed a central role in the planning of sylvicultural activities. In spite of this, fire fighting infrastructures such as hydrant nets have been constructed in order to protect forest plantations (Table 6.4). Nevertheless, information on existing plantations and forests of a particularly high value or protection function has also been inserted in the GIS-based database of the forest service (Fig. 6.6).

Table 6.1. Legislative acts related to fire prevention in Canton Ticino since 1803.

Date	Legislative act	Article	Preventive measures	Remarks
9.4.1857	Regolamento forestale	art. 85	Prohibition against making fire in the neighbourhood of the forest without an official permission and without taking the necessary precautions.	This act failed to be applied.
4.5.1870	Legge Forestale Cantonale	Chap. IX /art. 72	Prohibition against making fire in the forests without the permission of the forest service and prohibition against leaving the fire place without extinguishing the fire.	Difficult application because of the lack of people in the Forest Service.
		Chap. IX /art. 73	Limekilns and charcoal places in the forest are prohibited without the permission of the Forest and communal authorities.	
		Chap. X/ art. 84	Infractions to the articles 72 and 73 will be punished with fees from 4 to 100 Swiss francs.	
13.2.1878	Decreto concernente gli incendi di boschi e di pascoli	art. 3	Pasture is prohibited in freshly burned areas.	
23.4.1891	Risoluzione governativa		Extension of the prohibition against using freshly burnt areas for pasture or for accessory products (e.g. mushrooms, herbs, berries).	
26.6.1912	Legge Forestale Cantonale	art. 48–51	Prohibition of making fire in the forests, in the forest neighbourhood and in pastures without taking the necessary precautions. Limekilns and charcoal places in the forest are prohibited without the permission of the Forest authorities and have to be thoroughly controlled. Pasture is prohibited in freshly burned areas. Forest service may order the forestation of burnt areas.	
8.11.1933	Decreto Legge di modifica della legge Forestale Cantonale	art. 48 bis	The cantonal authorities may constrain the community in fire prone areas to organize a fire-alert service.	
14.4.1936	Decreto esecutivo concernente la creazione di squadre di spegnitori degli incendi di boschi e di pascoli		The fire-alert service is extended to the whole Canton.	
13.10.1949	Legge sulla polizia del fuoco	art. 3b	Prohibition of making fire in the urban area, in the open areas and in the forests during drought or wind periods.	
21.12.1956	Decreto federale concernente la partecipazione della Confederazione alla ricostituzione delle foreste affette da cancro della corteccia del castagno	art. 2	Costs for technical prevention measures may be financed by the Swiss Confederation up to 70 % of the total costs	The Federal contribution is proportional to the Cantonal one.

Table 6.1. Continued.

Date	Legislative act	Article	Preventive measures	Remarks
16.5.1958	Decreto esecutivo concernente la creazione di squadre di spegnimento degli incendi di boschi e di pascoli	art. 4	The cantonal authorities may also financially support fire prevention measures such as fire-guards, alarm-service, exercitation of the fire brigades, and information boards on fire danger.	
21.7.1958	Decreto legislativo cantonale concernente il risanamento della zona pedemontana ticinese in seguito alla distruzione del castagneto a causa del cancro corticale	art. 3, § 2c	Costs for technical prevention measures in the frame of forest projects may be financed up to 50 % of the total costs.	The Federal contribution is proportional to the Cantonal one.
30.4.1975	Modifica al DE del 16.5.1958	art 5bis	Prohibition to make fire in the open during drought periods or windy days; periods of prohibition are to be decided by the Swiss Meteorological Service in Locarno-Monti and broadcasted by the mass-media.	
13.12.1976	Legge sulla polizia del fuoco	art. 4b	Any activity related to fire danger is prohibited, in particular making fire in the open during drought or windy periods.	
4.7.1978	Regolamento di applicazione della legge sulla polizia del fuoco	art. 4	The rules prohibiting fires in the open are confirmed by the Swiss Meteorological Service in Locarno-Monti.	
21.10.1987	Decreto esecutivo concernente il divieto dei fuochi all'aperto e il compostaggio degli scarti vegetali		Prohibition of burning garden debris in the open.	Fees applied only since 1.1.1989 (art. 8).
11.7.1990	Decreto esecutivo concernente l'uso dei fuochi d'artificio e l'accensione di falò per le celebrazioni commemorative in periodi di siccità	art. 2	The absolute prohibition of making fire in the open is extended to fire works and ceremony fires.	
12.2.1992	Partial revision of the executive decree 21.10.1987		Exceptions to the prohibition of burning garden debris in the open is allowed for phytosanitary reasons.	
28.3.1995	Partial revision of the executive decree 21.10.1987		The application of the decree concerning the prohibition of burning garden debris in the open should be executed by the communal authority.	
5.2.1996	Legge sull'organizzazione della lotta contro gli incendi, gli inquinamenti e i danni della natura	art. 4b	Any activity related to fire danger is prohibited, in particular making fire in the open during drought or windy periods.	See former law (13.12.1976).
4.3.1998	Partial revision of the executive decree 21.10.1987		Authorization of burning dry garden debris in the open in the regions above 600 m a.s.l.	
7.4.1998	Regolamento di applicazione della legge sull'organizzazione della lotta contro gli incendi, gli inquinamenti e i danni della natura	art. 4	Prohibition to make fire in the open during drought periods or windy days; period of prohibition are decided by the Swiss Meteorological Service in Locarno-Monti and broadcasted by the mass-media.	See former decrees and regulations (30.4.1975 / 4.7.1978).
21.4.1998	Legge Cantonale sulle Foreste	Chap. III, art. 1c	Wildfires are for the first time included in the list of natural hazards to be prevented in order to preserve the territory.	
		art. 16	Promotion of general preventive measures against natural hazards.	
		art. 30b and 31b	Financial support for the fire prevention.	
22.10.2002	Regolamento di applicazione della legge Cantonale sulle Foreste	art. 1d	Forest Service is in charge for fire prevention.	The role of the Forest Service in the frame of the fire fighting activities is precisely defined.
		art. 28	Forest Service collaborates with MeteoSwiss in deciding the periods of absolute prohibition of making fire in the open and organizes a stand-by service.	

Grey background: legislative acts still in force.

Table 6.2. Information activities related to fire prevention in Canton Ticino since 1803.

Date	Information activity	Remarks
1907– ?	Information about the problems related to wildfires in the Sottoceneri becomes available by means of newspapers and with the collaboration of the schools and the church.	POMETTA (1929)
1921–1924	The Forest Service publishes instructions on fire prevention.	CRCS 1929
1912 (?)–	Bilingual boards raising the attention to fire danger are placed in different strategic (e.g. tourist) parts of the area.	CRCS 1929
1912 (?)–	During fire danger, the fire danger alert is published in the official bulletin and in the newspapers.	CRCS 1929
1953	208 additional boards raising the attention of fire danger.	CRCS 1954
1960	284 additional boards raising the attention of fire danger.	CRCS 1961
1965 (?)–	Announcements of fire danger are radio broadcasted. Additional boards raising the attention of fire danger.	CRCS 1961, POHL (1967)
1968	Additional boards raising the attention of fire danger.	CRCS 1968

Table 6.3. Sylvicultural, technical and organizational measures related to fire prevention in Canton Ticino since 1803.

Date	Sylvicultural measures	Remarks
1900	Plantations in fire prone areas should mostly include resprouting broadleaved tree species.	FREULER (1900)
? –1913	Electrification of the Gotthard railway.	
1929–1968	Creation of fire breaks around plantations and in the coppice forests (first mention of executed fire breaks in 1966 because of the existing financial support of the Confederation).	Measure never realized throughout (POMETTA 1929; POHL 1938, 1958; CRCS 1966, 1967, 1968)
1974	The army introduces several fire prevention rules concerning the use of war munitions during exercises.	CRCS 1974
1974–1990 (?)	Construction of barriers against sparks along the Gotthard railway.	CRCS 1974
1990–	Restoring and managing chestnut orchards contribute to the creation of fire breaks.	

Table 6.4. Technical and infrastructural measures related to fire fighting in Canton Ticino since 1803.

Date	Technical measures	Remarks
1920 (?)–	New forest roads and trails are planned also for fire managing purposes (firebreaks, access for fire brigades).	POMETTA (1929); ANTONIETTI (1974)
1958–	A hydrant-net is usually combined with the construction of a new forest road. Civil fire brigade facilities (e.g. water tank vehicles, mobile water reservoirs, etc.) may also be used for controlling forest fires.	Decree 16.5.1958
(1961)–1967–	Progressive introduction of radio equipments for internal communication during fire fighting	CRCS 1961, 1968, 1969, 1972
1962–	Progressive introduction of aerial craft for transport of fire brigades and direct fire fighting.	POHL (1965; 1967); MEYER (1967); CRCS 1968
1967–	Hydrant-nets and water reservoirs are possible also for new plantations.	POHL (1967)
1974–	Swiss army helicopters may be used for fire fighting.	CRCS 1974
1975–	Introduction of automatic rechargeable water tanks for helicopters.	CRCS 1975, CORTI (1990)
1987–	Introduction of new and lighter fire fighting tools (tubes, mobile water reservoir, etc).	CORTI (1990)
1987–	High capacity helicopters (Superpuma with 3000–3500 litres of water capacity) are introduced in fire fighting.	CORTI (1990)

Table 6.5. Organizational aspects related to fire fighting in Canton Ticino since 1803.

Date	Organizational measures	Remarks
1878	Forest Service, Bourgois – and Political Municipalities are obliged to organize wildfire fighting and extinction.	Cantonal decree (13.2.1878)
1912	Municipalities are obliged to organize wildfire fighting and extinction. Forest Service should persecute the authors.	Cantonal Forest Law (26.6.1912)
1926	Confusion still exists between Bourgois - and Political Municipalities concerning the competence in fire fighting.	POMETTA (1926)
1929	Political Municipalities are asked to organize in advance fire fighting teams and to collaborate with neighbouring communities for fighting border-crossing fires.	CRCS 1929; POMETTA (1929)
1933–40	Political Municipalities are asked to organize in advance fire fighting teams and fire fighting tools (blades, palms, rakes) and to collaborate with neighbouring communities for fighting border-crossing fires. For the first time fire fighting brigades reap the benefit of causality insurance.	Cantonal decrees (8.11.1933; 14.4.1936) adding art. 48bis to the Cantonal Forest law; Official Bulletin (8.3.1940)
1940	The two existing fire brigade associations are merged in the new Cantonal Federation of Fire Brigades that represents all fire brigades units of the Canton.	CORTI (1990)
1945	A forest fire commission was created with the aim of involving existing civil fire brigades in forest fire fighting.	CORTI (1990)
1958	Fire-guard and fire alarm service, fighting costs and purchase of fire fighting tools will be financed by the cantonal authority. Civil fire brigades and their facilities (e.g. water tank vehicles, mobile water reservoirs, etc.) may also be used for controlling forest fires.	Cantonal decrees (16.5.1958)
1968	Organization of three fire watching points.	CRCS 1968
1975	Preparation of a fire fighting field book for the heads of the fire brigades and of a map with flying obstacles for helicopters	CRCS 1976
1978	Creation of official forest fire brigades (corpi pompieri di montagna) in addition to urban fire brigades.	Fire law (13.12.1976) and executive regulation (4.7.1978); Corti (1996)
1982	Coordination of the fire fighting operations (and especially of the use of helicopters) is assumed by the 6 urban fire brigades of first category.	Governmental decision (21.9.1982)
1982	Organisation of a helicopter stand-by service in case of fire danger during the week-ends.	CORTI (1990)
1998	Forest fire brigades (corpi pompieri di montagna) are better integrated in the fire brigade organization. Collaboration rules with army and civil protection in case of fire fighting is defined.	Fire law (5.2.1996) and executive regulation (7.4.1998)
2001–	A convention with private and army helicopters is concluded for a permanent stand-by service in case of fire danger (last update: 26.10.2004).	CORTI (2001); ZAMBONI (2001)
2002–	Permanent stand-by service of the Foresters in case of fire danger.	Cantonal Forest Law (21.4.1998) and executive regulation (22.10.2002)

Table 6.6. Fire Fighting organization in Canton Ticino 1981–2010 (source: RYSER 2005).

Fire brigades		1981		1990		2003		aimed organization (2010)		
Type	Category	Nr. Brigades	Nr. Fighters	Nr. Brigades	Nr. Fighters	Nr. Brigades	Nr. Fighters	Cat.	Nr. Brigades	Nr. Fighters
Urban	A	6	340	6	396	6	441	A	6	500
Urban	B	23	591	23	582	23	625	B	15	600
Urban	C	28	352	27	369	20	276	C	6	125
Forest		29	557	58	1100	50	966	C Mont	11	400
Total		86	1840	114	2447	99	2308		38	1625

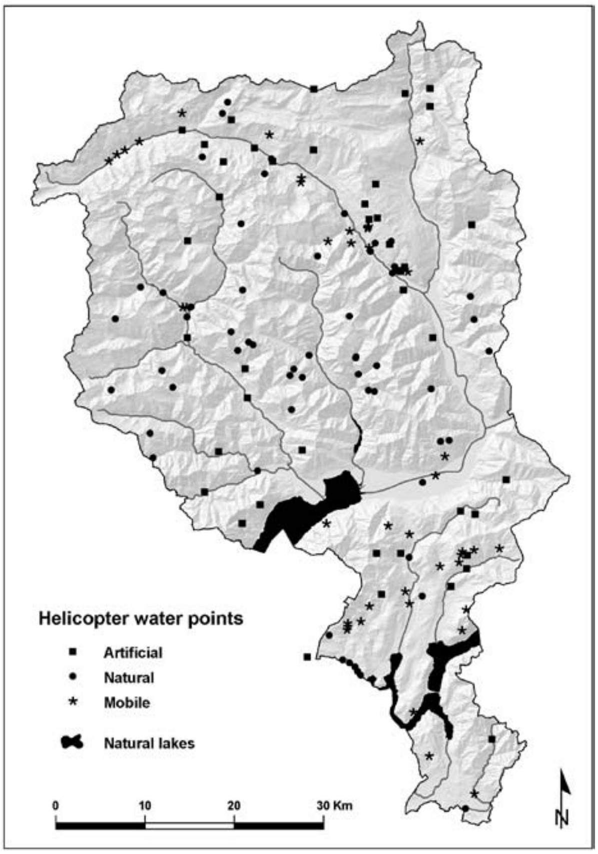

Fig. 6.5. Water points available for water supply during aerial fire fighting (source: Cantonal Forest Service Bellinzona, MeteoSwiss Locarno-Monti).

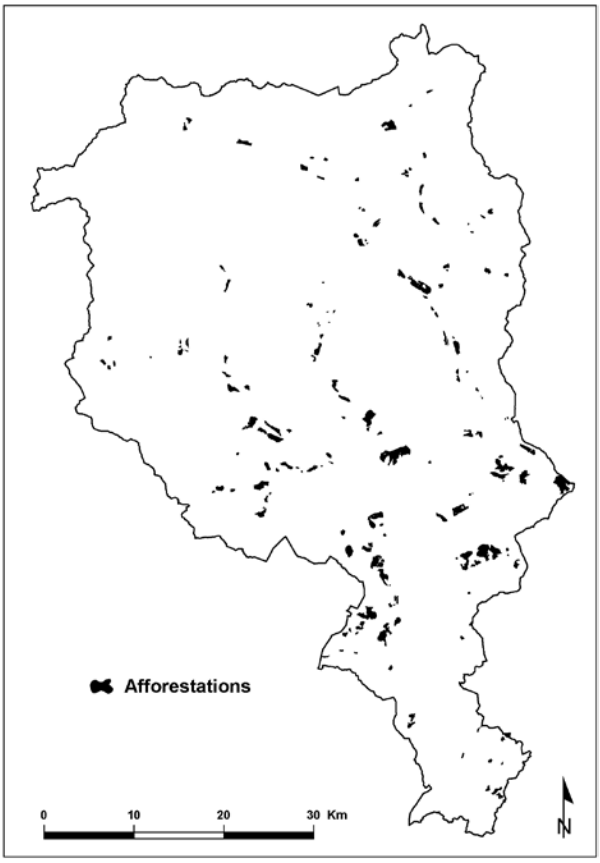

Fig. 6.6. Stands originated from plantations in Canton Ticino (source: CESCHI 2006).

6.3 Fire fighting organization

As shown in Table 6.5, improvements to the fire fighting organization took place throughout the whole last 130 years. The constant trend towards an increase in the proportion of small fires and the reduction of the mean fire size throughout the last century (Fig. 6.7) may be the expression of such efforts for improving the fire fighting organization and techniques. The most significant milestone in the organization of the fire brigades has been, however, the law of 1976 and the related executive regulation (1978) that called for the creation of specific forest fire brigades (corpi pompieri di montagna) and the transfer of the responsibility of the civil fire brigades from the community level to the cantonal level and also introduced a hierarchical structure to the fire brigades (see also Table 6.5). This rapidly improved the coordination and the technical and tactical capabilities of the fire brigades and – as final result – their efficiency in controlling the burnt area. In fact, improvements in fire fighting have particularly influenced the mean fire size of single events and the total amount of burnt area as opposed to the total number of fires. As shown in Figure 6.8, there is a significant changing point in the trend of the anthropogenic burnt area starting from early 1980s that coincides with the first effects of the cited major reorganisation of the fire brigades, combined with the concomitant start of the systematic use of helicopters for both transporting the fire fighters and aerial fire fighting (CONEDERA et al. 2004b). In the case of lightning fires there is no overall trend, yet summers with high fire frequency have a strong influence on the total amount of burnt area. As already discussed in chapter 4, despite the modern and very efficient fire fighting organization, in cases of particular meteorological situations and high fire danger, the total burnt area (Fig. 6.8) and maximal fire size of the events (Fig. 6.9) may still get out of range and reach high numbers. In exceptional fire years (such as 1981, 1990, 1997), extreme weather conditions that drastically increase the number of ignitions can overwhelm existing suppression resources and cause large fires due to the failure of initial attack, resulting in a large total area burnt (Fig. 6.8). As a consequence very few events are responsible for most of the total burnt area: for the period 1990–2007, 10 % of the events were the cause of 87 % (winter fires) to 89 % (summer fires) of the burnt area (Fig. 6.10). In recent times fire fighters have tried to face these problems by increasing the efficiency of aerial intervention (through the organization of a stand by service, see Table 6.5) and by improving the tactical and technical instructions of the fire brigades (see also www.pompiericiticino.ch).

Presently, the forest fire organization in Canton Ticino is under reorganization (RYSER 2005; CALABRESI 2005). The principle of the hierarchical organization will be maintained (Fig. 6.11), although forest fire brigades will be reduced in number and fully integrated in the urban fire brigades (Table 6.6). Coordination, supervision and control functions also will be operated in the future by some

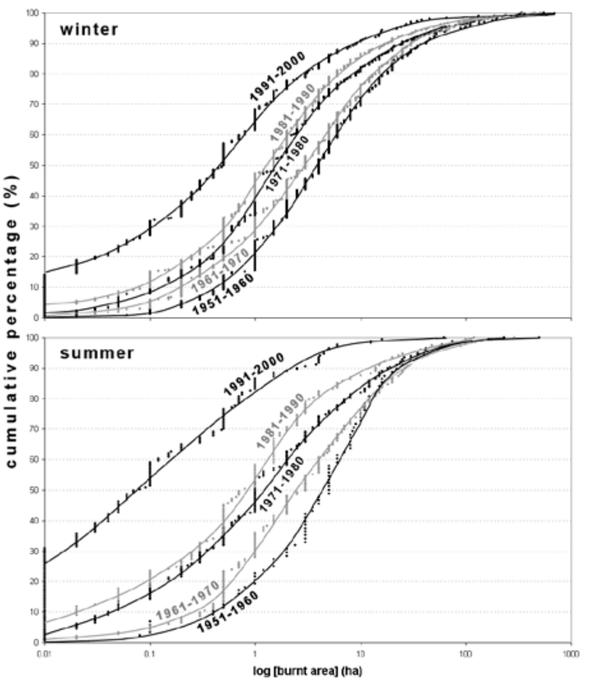

Fig. 6.7. Cumulative percentage of the forest fire events according to their size and to different periods: winter season (December to April), summer season (May to November) (source: forest fire data base WSL Bellinzona).

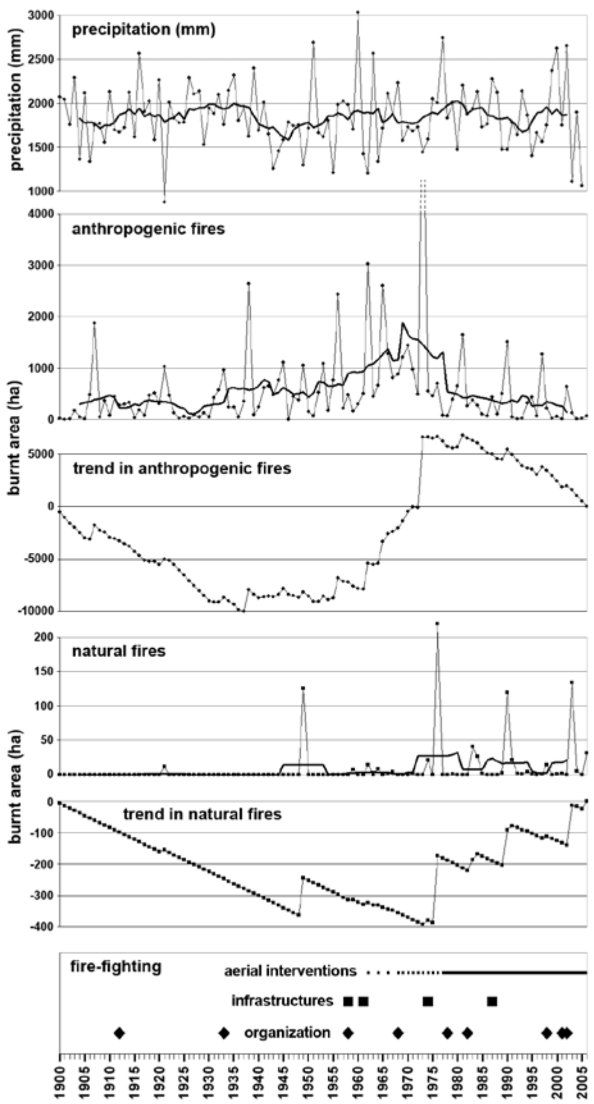

Fig. 6.8. Annual precipitation (Locarno-Monti), burnt area (anthropogenic, natural), trend (cumulative differences to the periodic mean), fire brigades reorganisations, technical improvements, and aerial fire fighting in Canton Ticino for the period 1900–2006 (source: forest fire data base WSL Bellinzona; MeteoSwiss Locarno-Monti; CONEDERA et al. 2004b).

key actors such as the Cantonal Fire Commission (Commissione Cantonale degli Incendi, existing since 1975 with advising and supervision functions), the Cantonal Fire Brigades Federation (Federazione Cantonale Ticinese dei Corpi Pompieri – FCTCP, existing since 1940 and responsible among other things for the instruction of the fire brigades and for technical advises, GUERINI 2005), and the Cantonal Fire Office (Ufficio Cantonale Difesa contro gli Incendi, existing since 1978 and responsible for the financial control) (Fig. 6.12).

The annual costs of the whole fire organization are about 12 million Swiss Francs per year (CALABRESI 2005). Half of the sum is provided by the cantonal fire funds (Fondo cantonale incendi, which is in turn alimented by the insurance companies, the Confederation, and the refunding of the fire fighting costs by the authors of the fires), and the other half is provided by the single communities. Effective forest fire fighting costs are on average 1.4 Million Swiss Francs per year with peak amounts of 4.2 Million Swiss Francs in extreme fire years (e.g. 1990) (Fig. 6.13). On average, aerial fighting accounts for 60 % of the total forest fire fighting costs, whereas fire brigades for the remaining 40 % (RYSER 2005).

Operational fire suppression is headed by Officers of the A categories fire brigades. They decide and coordinate in particular the deployment of the fire fighters and the employment of helicopters. The forest service acts as adviser, providing all information about local forest conditions and technical facilities (CORTI 2005).

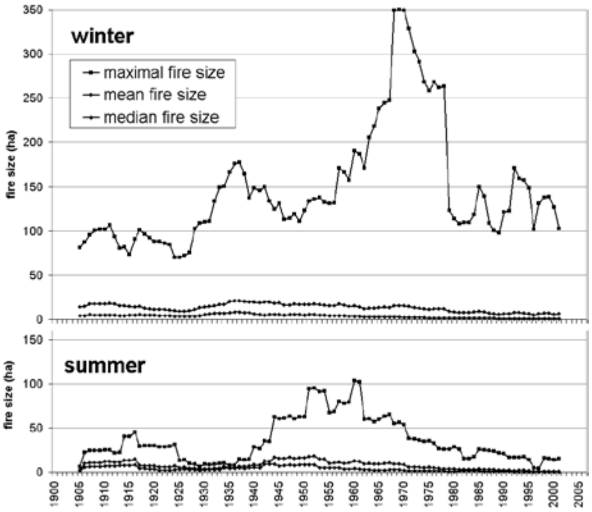

Fig. 6.9. Running means over 11 years of mean, median and maximal annual fire sizes of winter (December to April) and summer (May to November) forest fires in Canton Ticino for the period 1900–2006 (source: forest fire data base WSL Bellinzona).

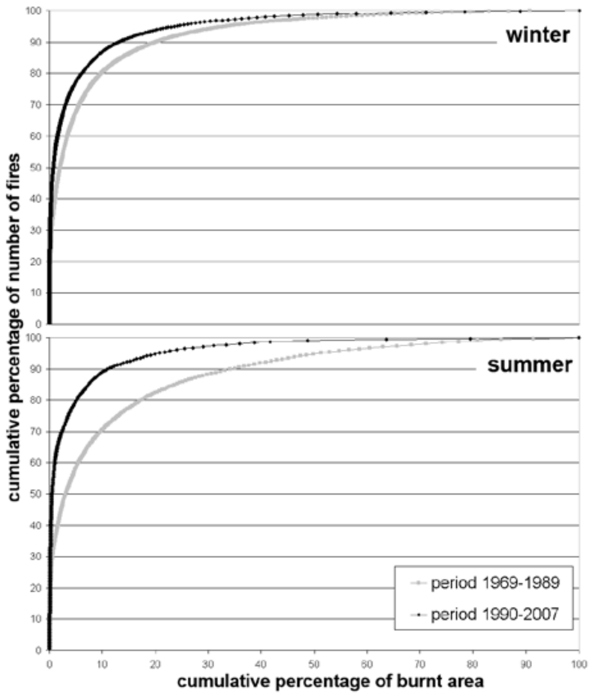

Fig. 6.10. Cumulative percentage of number of fire and burnt area for the periods 1969–1989 and 1990–2007 and for winter and summer fires (source: forest fire data base WSL Bellinzona).

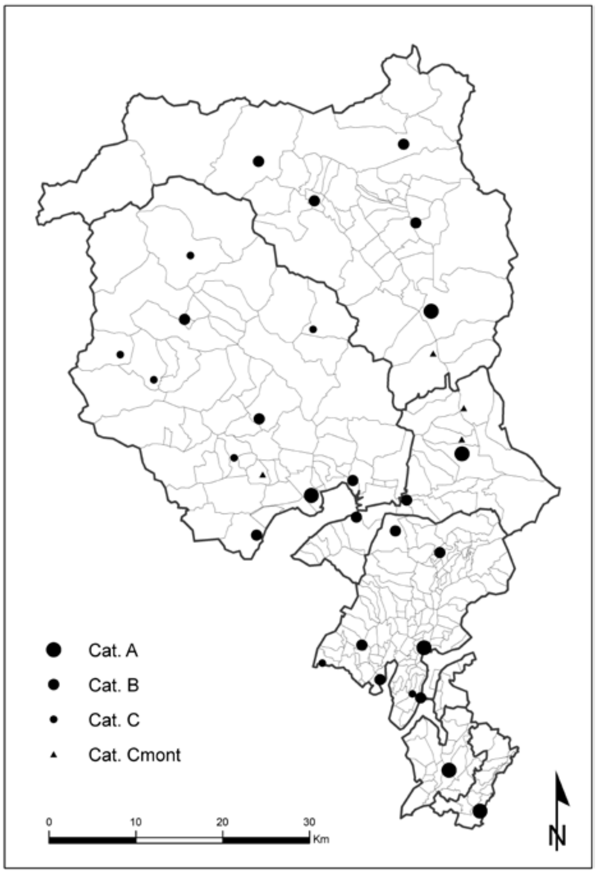

Fig. 6.11. Present geographic distribution of fire brigades in Canton Ticino (source: GUERINI 2005).

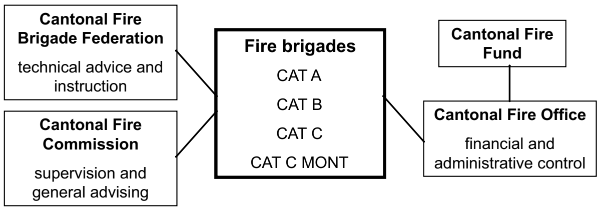

Fig. 6.12. Schematic representation of the fire brigade organization in Canton Ticino (source: CALABRESI 2005; RYSER 2005).

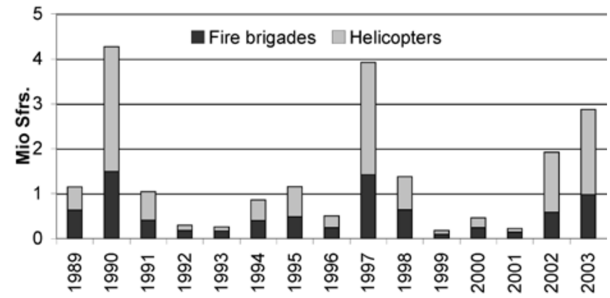

Fig. 6.13. Forest fires fighting costs in Canton Ticino in the period 1989–2003 (source: RYSER 2005).

6.4 Concluding remarks

Human behaviour can alter fire activity both indirectly by changing land-use and fuel build-up patterns in an area (see chapter 4), but also directly by controlling ignition sources and by effectively (or ineffectively) fighting the fires. As a general rule, preventative measures primarily reduce the number of fires, whereas fire fighting measures primarily reduce fire size and total burnt areas. Some measures such as fuel management (restoring chestnut orchards, cleaning road talus, creating fuel breaks) may however avoid both fire ignition and further propagation of existing fires.

Fire being an irregular phenomenon, significant improvement in fire legislation and fire organization are usually stimulated by extreme and catastrophic fire years and by the subsequent favourable political context (Fig. 6.8). In the Eighteenth and in the first half of the nineteenth century it took very long (years to decades), however, to implement new ideas rising from a catastrophic fire year. It took for instance 20 years for translating the input of the catastrophic 1938 fire-year into the executive decree of May 16, 1958. With time, the general awareness of the problem increased and the political authority reacted faster: so it took only 3 to 5 years to set up the fire policy law of December 13, 1976 and the executive regulation of December 5, 1978 after the 1973 fire year and just one year after the catastrophic National Day of August 1, 1989 (19 wildfires due to fire works) to implement the executive decree of July 11, 1990.

Despite the very efficient fire fighting organization, extreme fire years with large and severe fires (see for instance CONEDERA et al. 2003) are still recurrent in the area. This may raise the question as to whether in Canton Ticino the phenomenon of the fire paradox (that is, the more efficiently fires are fought, the larger and more intense fires become) will also start to fan out, similar to other parts of the world (CASTELLNOU et al. 2002; INGALSBEE 2002; FINNEY 2005). The knowledge acquired so far on fire history, fire ecology and fire control in the area (see chapters 4 to 6) does not support this hypothesis. Increased severity of single fires during exceptional fire years may be caused by both increased drought conditions due to climate change (especially in March-April during the main winter fire peak, REINHARD et al. 2005) and fuel build up as a consequence of reduced traditional agricultural and forestry activities (CONEDERA & TINNER 2000b). In addition, no fire-adapted forest ecosystems exist in Canton Ticino where preventative controlled fires would help to reduce wildfire severity or the risk of crown fires.

It is of course impossible to dimension the whole fire fighting system on the basis of exceptional years. Successful fire management may thus be obtained through the traditional legislative and organizational measures. For the future, however, sylvicultural measures and traditional agriculture practices related to fire prevention and reduction of potential fire severity and fire impact on ecosystems should be increasingly taken into consideration in the frame of the fire management activities.

7 Assessing relative fire danger

7.1 Methodological approach

Methods for assessing fire danger have to be adapted to the desired temporal and spatial scale. In particular, the degree of knowledge and control (data grain and information resolution) has to be adapted to the aims and the strategic decisions of the final user (HARDY et al. 2001). In our study area, analysis of fire statistics clearly revealed the existence of a mixed fire regime (MORGAN et al. 2001) represented by three different and very dynamic fire regimes: anthropogenic winter fires, anthropogenic summer fires, and natural summer fires. As a consequence, a reliable assessment may be performed only when considering a homogeneous data set for each of the three fire regimes. Homogenous data is only available for the period 1990–2007 for both winter and summer anthropogenic fire regimes and 1980–2007 for the natural summer fires. Expanding the period of natural forest fires back to 1980 represents a compromise between the consistency (homogeneity) and the representativeness (quantity) of the data. Using this criterion of selection we ended up with 569 anthropogenic winter fires, 197 anthropogenic summer fires, and 138 natural (lightning-induced) summer fires.

The small data set available suggests avoiding the use of sophisticated statistical models such as multiple linear regressions, logistic regressions, geographically weighted regressions, neural networks, classification, and regression tree analysis (for a review on strengthens, gaps and drawbacks of the existing methods, see EUROFIRELAB 2003, AMATULLI et al. 2006). In addition we looked for relative indications of fire danger distribution in the study area that suggest adopting an experts' knowledge-based approach (GOUMA and CHRONOPOULUS-SERELI 1998; THOMPSON et al. 2000). We therefore propose implementing and synthesizing thematic maps (elementary topics) to express the relative fire danger (representing the primary topic as proposed by HESSBURG et al. 2007). Such elementary topics (or layers as we use GIS technology to produce the thematic maps) have to be spatially-explicit, continuous in coverage and homogeneous in terms of resolution of the information (e.g. DEM, Swiss Landscape Model VECTOR25, fire statistics derived from the forest fire data base, etc.).

We decided to consider the whole territory except the lakes, the urban area, and the area above 2500 m a.s.l. and we converted all data layers to a 25 x 25 m raster grid.

In order to make the analysis as objective as possible, the contribution of each category of the elementary topics to the relative fire danger was assessed by testing their fire selectivity for each considered fire regime against the mean of 1000 random Monte Carlo simulations as already illustrated for fire selectivity with respect to vegetation cover (for a detailed description of the method, see chapter 5.1 and BAJOCCO & RICOTTA 2008). Categories displaying significant negative or positive selectivity with respect to fire ignition or average fire size received negative or positive points, respectively, according to the level of significance: 3 points for $p < 0.001$; 2 points for $p < 0.1$, 1 point for $p < 0.05$.

7.2 Outline for evaluating the fire danger

As defined in chapter 2, fire danger (primary topic) represents the chance that a fire will occurr at a given place. It consists of two secondary topics: the probability of ignition (ignition danger, i.e. probability of a fire starting in a given place) and the chance that a fire will spread over an area, regardless of the place of ignition (fire spread danger) (Fig. 2.1 and Table 7.1). Each secondary topic in turn consists of two elements: a theoretical index deriving from the union of the results of the Monte Carlo simulations for each elementary topic considered and an effective number resulting from the frequency of ignition points or fire spreads in a given place for the considered period. In addition, for the anthropogenic fire regimes the forest-urban interface (defined as the overlapping 50 m buffer of both categories) was taken into consideration (Fig. 7.1, NAPOLEONE & JAPPIOT 2008). For anthropogenic fire regimes we compared the results of the theoretical indexes with the effective fire regime in order to detect special cases of increased fire frequency due to particular and recurrent local anthropogenic activities (e.g. army shooting areas) or infrastructures (railway or electricity lines) related to fire. For the fire ignition we used a buffer of 150 m before adding the number of events, and for the fire spread we used the effective fire perimeters. The secondary topics assume the maximum value between the theoretical and effective indexes

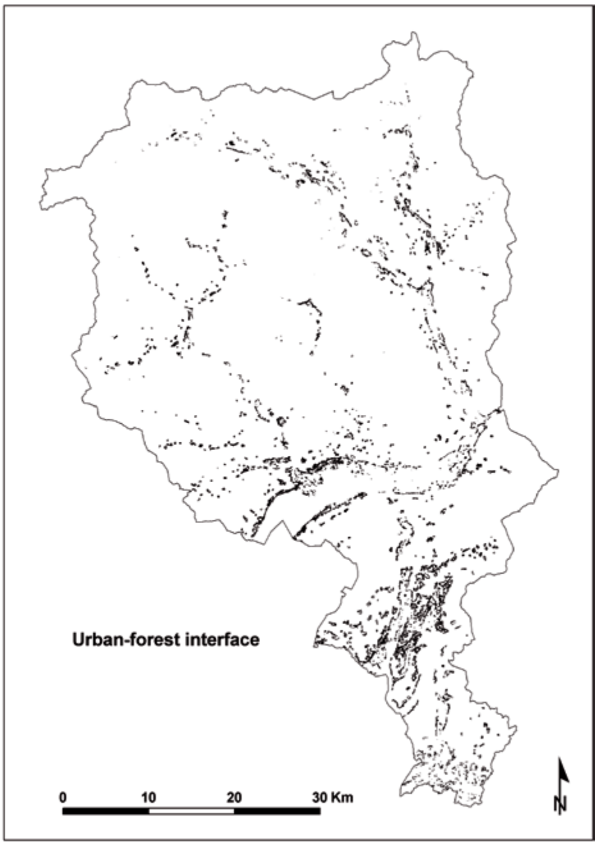

Figure 7.1. Urban-forest interface considered in this study.

(normalized from 0 to 10) (Table 7.1). Finally, the primary topic is expressed as the addition (union) of the two secondary indexes, giving a final potential range of the fire danger between 0 and 20.

7.3 Results of the Monte Carlo simulations

Results of the Monte Carlo simulations for the elementary topic "vegetation cover" are reported in Tables 5.3–5.5. Tables 7.2–7.5 summarize the numbers and the statistical significance resulting from the Monte Carlo simulations for the remaining elementary topics considered when calculating both the theoretical fire ignition (represented by the number of fires) and the fire spread (represented by the average fire size) danger. Figure 7.2 shows a graphic visualization of the results of the Monte Carlo simulations for the ignition danger of the elementary topic "aspect".

Altitudinal distribution of ignition frequency clearly follows two opposite patterns: significant over-representation of the lower altitude (< 1000 m a.s.l.) for both anthropogenic fire regimes and the over-representation of lightning induced fires at altitude between 1000 and 1700 m a.s.l. (Table 7.2). Natural fire distribution is congruent to what CONEDERA et al. (2006) reported for lightning fires in the Alps, whereas the concentration of anthropogenic fires

Table 7.1. Proposed outline for the evaluation of the fire danger.

Primary topic	Secondary topics		Elementary topic	Categories considered	Range
Fire danger **(sum)**	Ignition danger **(max of)**	Theoretical ignition danger **(sum)**	Vegetation cover	12 categories as defined in Table 5.1	–3 to 3 according to the significance of the Monte Carlo simulations
			Elevation class	10 categories of 250 m	
			Aspect	9 categories (N, NE, E, SE, S, SW, W, NW and flat)	
			Slope	10 categories of 8.25°	
			Urban - forest interface*	Overlapping 50 m buffer between the two categories	0–1
		Effective ignition danger*	Effective ignition points	Count of overlapping 150 m buffers around each ignition point	real number
	Spread danger **(max of)**	Theoretical spread danger **(sum)**	Vegetation cover	11 categories as defined in Table 5.1	–3 to 3 according to the significance of the Monte Carlo simulations
			Elevation class	10 categories of 250 m	
			Aspect	9 categories (N, NE, E, SE, S, SW, W, NW and flat)	
			Slope	10 categories of 8.25°	
			Curvature	10 categories according to the function curvature in ARCGIS	
		Effective spread danger*	Effective spread	Count of overlapping fire perimeters	real number

* for winter and summer anthropogenic fire regimes only
logic operator: **union** (=addition of the single values); **max of** (the greater value will be retained)

at lower elevations matches the distribution of the population density. Similarly, summer lightning fires develop mostly on steep slopes (50–66°), whereas anthropogenic winter fires on the gentler slopes (8–33°) usually corresponding to the neighbourhood of the densely populated urban area (Table 7.3). Fire ignitions are clearly overrepresented on south facing slopes during the winter season, but not during the summer. During the summer time no differential drying effect of the sunshine apparently exists among the main expositions with the exception of the NW sector (Table 7.4).

As for the vegetation cover (chapter 5.2 and Table 5.4), the interpretation of the results concerning the average fire size is more difficult. In winter, average fire size tends to be smaller than average at very low elevation (< 500 m a.s.l.) and greater at medium elevation (between 1000 and 1250 m a.s.l.) (Table 7.2). This may be due to the distance needed to cover by the fire brigades (usually located in the urban area at low elevation) and to the presence (at lower elevations) or absence (at higher elevations) of a road system. A similar pattern is displayed by the selectivity of the average fire size with respect to the slope (lower size on gentle slopes, larger size on medium slopes, Table 7.3) which may be connected to the differing heat transfer from the fire front according

Table 7.2. Fire selectivity of the elementary topic “altitude” on ignition frequency and average fire size for anthropogenic winter fires, anthropogenic summer fires and natural summer fires.

Parameter	Fire regime	values	< 250 m	251–500 m	501–750 m	751–1000 m	1001–1250 m	1251–1500 m	1501–1750 m	1751–2000 m	2001–2250 m	2251–2500 m
ignition frequency	anthropogenic winter fires	true value	9	**197**	**175**	**95**	**47**	**26**	***17***	***3***	***0***	***0***
		upper limit	24	74	75	83	89	93	93	97	96	74
		lower limit	3	32	32	40	40	44	48	52	46	31
		significance		+++	+++	+++	-	---	---	---	---	---
	anthropogenic summer fires	true value	7	**67**	**37**	**31**	19	***11***	***13***	***8***	***3***	***1***
		upper limit	11	31	31	36	39	37	38	44	38	31
		lower limit	0	5	3	8	9	9	11	12	11	7
		significance		+++	+++	++		--	--	---	---	---
	natural summer fires	true value	***0***	**7**	18	21	**25**	**29**	**29**	***9***	***0***	***0***
		upper limit	9	26	23	27	27	33	33	32	31	27
		lower limit	0	4	4	5	4	6	6	3	6	3
		significance	---	-			+	++	+	--	---	---
mean burnt area	anthropogenic winter fires	true value	0.3	***1.3***	5.8	12.3	**31.9**	7.2	19.1	13.1		
		upper limit	110.3	20.05	19.01	26.52	31.84	50.64	57.84	145.8		
		lower limit	0.03	2.20	2.57	1.24	1.34	0.36	0.23	0.02		
		significance		---			+++					
	anthropogenic summer fires	true value	0.0	0.4	4.0	1.2	1.7	0.9	2.2	0.9	2.0	
		upper limit	19.44	4.08	5.16	6.37	10.12	13.26	14.84	15.99	49.30	
		lower limit	0.01	0.23	0.17	0.13	0.04	0.04	0.02	0.03	0.01	
		significance										
	natural summer fires	true value		0.3	***0.1***	1.7	3.3	1.6	9.2	0.6		
		upper limit	130.0	33.12	15.97	19.18	12.78	11.60	11.57	26.62		
		lower limit	0.01	0.01	0.09	0.06	0.11	0.22	0.23	0.03		
		significance			--							

true value: effective number of fires for the period 1990-2007 (1980-2007 for natural summer fires). **Bold** fire frequencies are significantly greater than random; ***italic bold*** fire frequencies are significantly smaller than random;
upper / lower limit: upper and lower limit resulting from the Monte Carlo simulations
significance: p-value (two tailed test). +++/--- = $p < 0.001$; ++/-- = $p < 0.01$; +/- = $p < 0.05$

to the different slopes. No effects exist for the average fire size in winter with respect to the aspect (Table 7.4), whereas the curvature displays significant effects only for the extreme situations (positive for convex profiles, negative for concave ones) and also a negative effect of no curvature in the case of summer lightning fires (Table 7.5). Aside from the curvature, selectivity of the analysed elementary topics on the average fire size is very low for both summer fire regimes, probably also because of the generally small size of the fires in summer (Tables 7.2–7.5 and Fig. 6.7–6.8).

Table 7.3. Fire selectivity of the elementary topic “slope” on ignition frequency and average fire size for anthropogenic winter fires, anthropogenic summer fires and natural summer fires.

Parameter	Fire regime	values	< 8.35 °	8.25 – 16.50°	16.50 – 24.75 °	24.75 –33.00 °	33.00 –41.24 °	41.24 – 49.48 °	49.48 – 57.73 °	57.73 – 65.98 °	65.98 – 74.23 °	> 74.23 °
ignition frequency	anthropogenic winter fires	true value	36	**66**	**162**	**183**	***89***	***26***	***5***	***2***	***0***	***0***
		upper limit	63	68	117	166	178	100	50	21	8	2
		lower limit	18	28	61	95	113	51	15	2	0	0
		significance		++	+++	+++	---	---	---	---	---	---
	anthropogenic summer fires	true value	9	23	39	61	42	***12***	8	3	***0***	***0***
		upper limit	24	31	46	63	70	40	21	10	5	2
		lower limit	3	6	16	31	28	11	1	0	0	0
		significance				+		--			---	---
	natural summer fires	true value	***0***	***5***	7	24	44	**28**	**17**	**10**	3	**0**
		upper limit	23	24	35	47	52	33	15	8	4	1
		lower limit	1	2	9	17	21	5	0	0	0	0
		significance	---	--	---			+	+++	+++		---
mean burnt area	anthropogenic winter fires	true value	***0.20***	***0.84***	***1.60***	4.57	**30.60**	7.00	4.75	***0.01***		
		upper limit	55.43	33.05	24.14	18.29	20.92	48.86	195.9	322.3		
		lower limit	0.48	1.07	2.15	2.80	1.86	0.35	0.01	0.01		
		significance	---	---	---		+++			---		
	anthropogenic summer fires	true value	0.0	0.2	***0.3***	1.0	3.4	4.5	4.3	***0.0***		
		upper limit	19.05	7.17	5.34	4.42	5.38	10.98	25.66	50.25		
		lower limit	0.01	0.12	0.20	0.22	0.15	0.03	0.01	0.01		
		significance			-					---		
	natural summer fires	true value		0.3	0.6	0.4	3.9	6.9	1.3	0.5	0.5	
		upper limit		130.0	38.60	15.02	7.60	11.40	19.47	33.22	59.17	
		lower limit		0.01	0.01	0.12	0.30	0.22	0.04	0.02	0.01	
		significance										

true value: effective number of fires for the period 1990-2007 (1980-2007 for natural summer fires). **Bold** fire frequencies are significantly greater than random; ***italic bold*** fire frequencies are significantly smaller than random;
upper / lower limit: upper and lower limit resulting from the Monte Carlo simulations
significance: p-value (two tailed test). +++/--- = p < 0.001; ++/-- = p < 0.01; +/- = p < 0.05

Table 7.4. Fire selectivity of the elementary topic “aspect” on ignition frequency and average fire size for anthropogenic winter fires, anthropogenic summer fires and natural summer fires.

Parameter	Fire regime	values	flat	N (337.5–22.5)	NE (22.5–67.5)	E (67.5–112.5)	SE (112.5–157.5)	S (157.5–202.5)	SW (202.5–247.5)	W (247.5–292.5)	NW (292.5–337.5)
ignition frequency	anthropogenic winter fires	true value	***0***	***47***	***18***	***52***	**112**	**136**	**105**	57	***42***
		upper limit	5	96	96	96	114	108	103	90	84
		lower limit	0	44	45	45	57	59	55	43	39
		significance	---	--	---	-	++	+++	+++		--
	anthropogenic summer fires	true value	***0***	19	17	19	24	36	**40**	26	16
		upper limit	5	41	40	38	46	44	43	36	33
		lower limit	0	10	8	12	12	14	13	7	10
		significance	---						+		
	natural summer fires	true value	***0***	***8***	17	15	16	20	**34**	18	10
		upper limit	3	28	30	30	31	35	33	30	24
		lower limit	0	5	6	8	6	7	7	4	4
		significance	---	--					++		
mean burnt area	anthropogenic winter fires	true value	-	20.7	1.2	15.0	13.7	4.9	10.2	***1.6***	4.2
		upper limit		42.62	87.20	33.41	23.03	21.42	24.59	36.37	37.75
		lower limit		0.45	0.36	1.24	2.25	2.50	2.27	0.97	0.98
		significance								-	
	anthropogenic summer fires	true value	-	0.2	1.4	0.7	2.1	0.3	**4.6**	1.0	0.2
		upper limit		8.78	10.50	8.23	6.68	6.20	5.91	8.20	11.07
		lower limit		0.07	0.04	0.09	0.12	0.12	0.15	0.09	0.06
		significance							+		
	natural summer fires	true value	-	0.4	0.4	0.6	2.5	5.7	6.9	0.9	0.4
		upper limit		26.33	16.21	27.80	17.31	12.32	11.04	20.92	36.76
		lower limit		0.02	0.09	0.03	0.11	0.23	0.17	0.06	0.01
		significance									

true value: effective number of fires for the period 1990-2007 (1980-2007 for natural summer fires). **Bold** fire frequencies are significantly greater than random; ***italic bold*** fire frequencies are significantly smaller than random;
upper / lower limit: upper and lower limit resulting from the Monte Carlo simulations
significance: p-value (two tailed test). +++/--- = p < 0.001; ++/-- = p < 0.01; +/- = p < 0.05

Table 7.5. Fire selectivity of the elementary topic “curvature” on average fire size for anthropogenic winter fires, anthropogenic summer fires and natural summer fires.

Parameter	Fire regime	values	< –2.0	-2.0 – –1.0	–1.0 – –0.5	–0.3 – –0.2	–0.2 – –0.1	–0.1–0.1	0.1–0.3	0.3–0.5	0.5–1.0	> 1.0
mean burnt area	anthropogenic winter fires	true value	**22.69**	4.21	4.60	***0.26***	1.15	3.33	1.93	1.00	**28.47**	***1.71***
		upper limit	27.64	41.95	35.20	132.2	58.59	42.19	57.81	87.59	29.37	17.01
		lower limit	1.56	0.90	0.67	0.08	0.61	0.64	0.54	0.12	1.76	2.81
		significance	+			-					++	---
	anthropogenic summer fires	true value	**9.61**	0.25	4.79	0.03	0.02	0.80	1.64	1.35	2.51	***0.30***
		upper limit	11.09	12.86	12.14	47.35	94.50	16.39	34.50	37.17	9.18	2.51
		lower limit	0.07	0.03	0.04	0.01	0.01	0.02	0.01	0.01	0.07	0.47
		significance	+									---
	natural summer fires	true value	**11.35**	1.72	0.64	0.02	1.12	***0.01***	0.42	0.25	3.45	***0.45***
		upper limit	10.74	30.35	38.66	55.50	42.63	130.0	55.05	48.00	38.64	5.96
		lower limit	0.29	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.39
		significance	+++					---				--

true value: effective number of fires for the period 1990-2007 (1980-2007 for natural summer fires). **Bold** fire frequencies are significantly greater than random; ***italic bold*** fire frequencies are significantly smaller than random;
upper / lower limit: upper and lower limit resulting from the Monte Carlo simulations
significance: p-value (two tailed test). +++/--- = p < 0.001; ++/-- = p < 0.01; +/- = p < 0.05

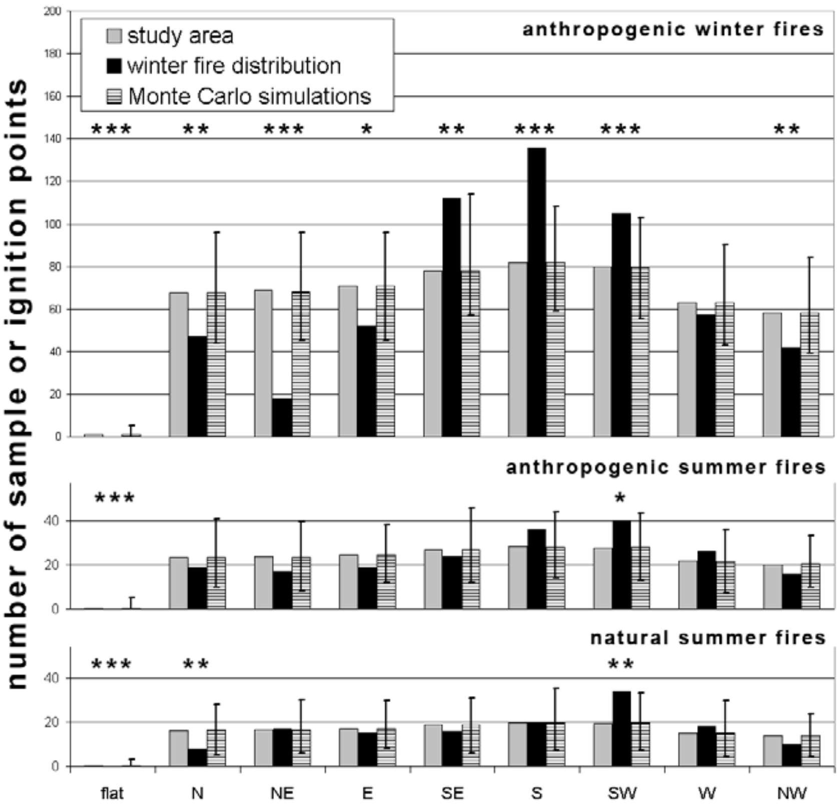

Figure 7.2. Fire ignition selectivity according to the Monte Carlo simulations for the elementary topic "aspect" and the three fire regimes (anthropogenic winter fires, anthropogenic summer fires, natural summer fires). p-value (two tailed test) *** = p < 0.001; ** = p < 0.01; * = p < 0.05.

7.4 Fire danger indexes

Looking for spots of increased effective ignition and spread danger due to anthropogenic activities or infrastructures, we considered only the cases with three or more ignitions or incidences of fire, respectively, during the considered period (1990–2007). Applying these criteria, no spot was retained for the spread danger and for the ignition of anthropogenic summer fires. On the contrary three outlying spots resulted for the ignition danger in winter time, two referring to the steepest sections of the railway line of Gotthard and one in a particular case of the border area to Italy in the very southern part of Canton Ticino (Fig. 7.3). Figures 7.4–7.9 show the map of the ignition and spread dangers resulting from the union of the elementary topics according to the logical outline presented in Table 7.1 for the three fire regimes. The final winter fire danger (Fig. 7.10) resulted from the union of ignition and spread danger (Table 7.1), whereas for the synthetic summer fire danger, after adding ignition and spread danger, for each pixel only the maximal values between natural or anthropogenic fire regime was retained (Fig. 7.11).

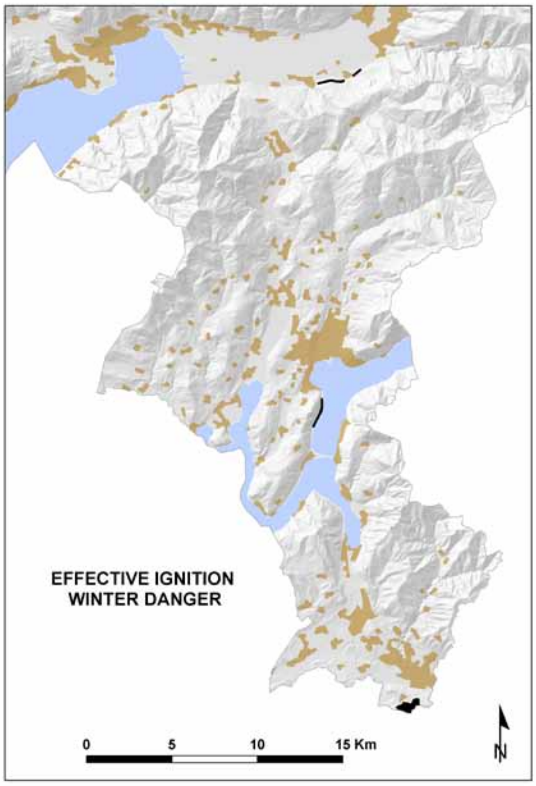

Figure 7.3. Spots of effective ignition danger exceeding the value resulting from the theoretical approach for anthropogenic fires.

We verified the suitability of the obtained indices by randomly selecting points with different fire history and looking for statistical significantly differences in the distribution of the index values by the mean of a non parametric Mann-Withney U-test. Concerning the fire ignition index, starting places of the fires (ignition points) show a significantly higher index value ($p < 0.01$) for both winter and summer fires (Fig. 7.12). Similarly, the fire danger indexes for both winter and summer fires display significantly lower index values ($p < 0.01$) in places without any fire since 1980 with respect to areas that burned at least once. On the contrary, no consistently statistically significant differences exist within places that burned differently (1 to more than 2 times (Fig. 7.13). Generally speaking, however, the proposed fire danger indexes are consistent and offer a suitable reference for detecting the most fire prone sites of the study area.

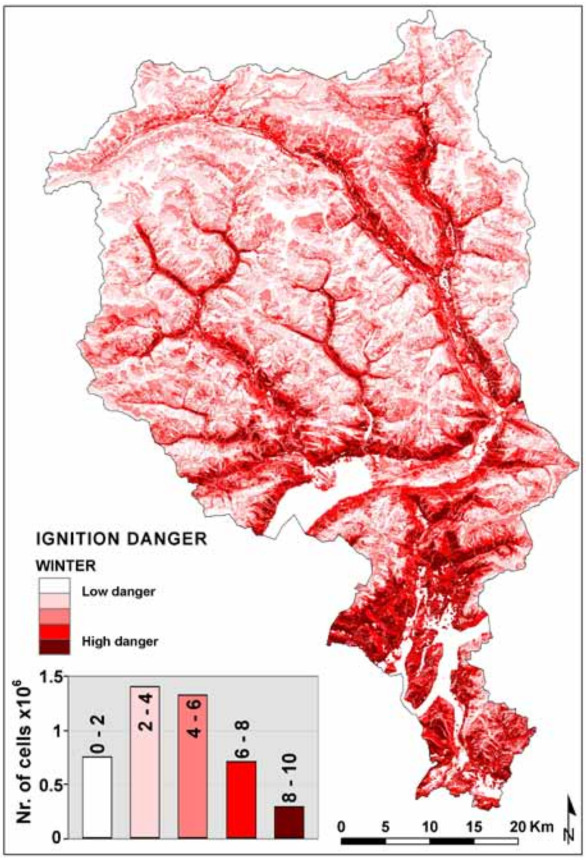

Figure 7.4. Map of the ignition danger for the winter fires in Canton Ticino.

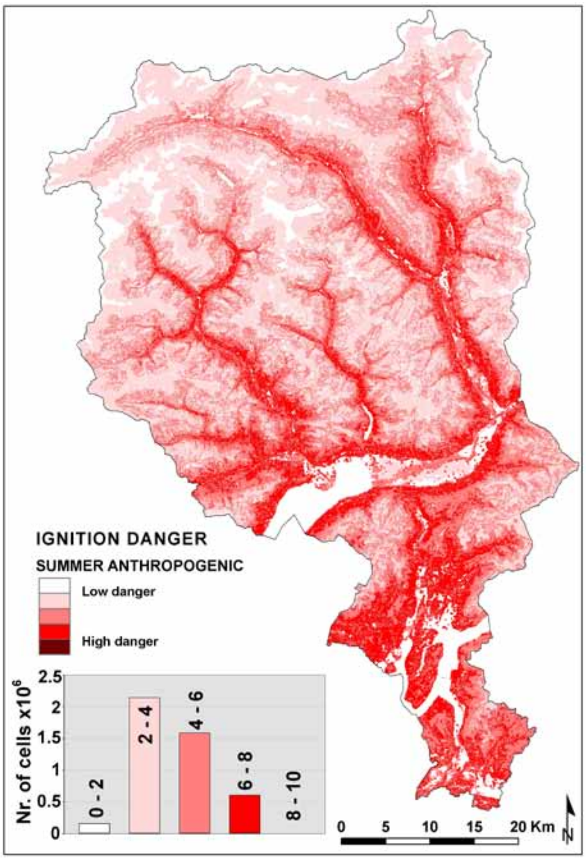

Figure 7.5. Map of the ignition danger for the anthropogenic summer fires in Canton Ticino.

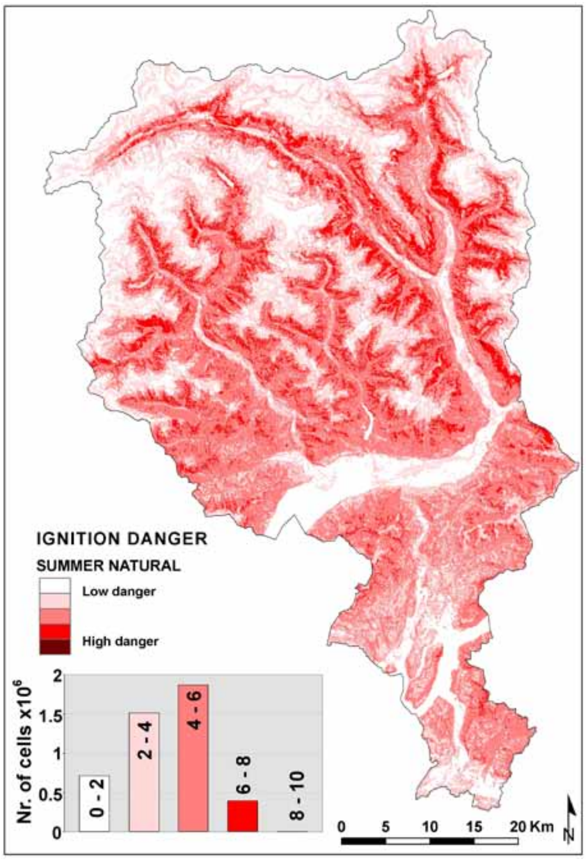

Figure 7.6. Map of the ignition danger for the natural summer fires in Canton Ticino.

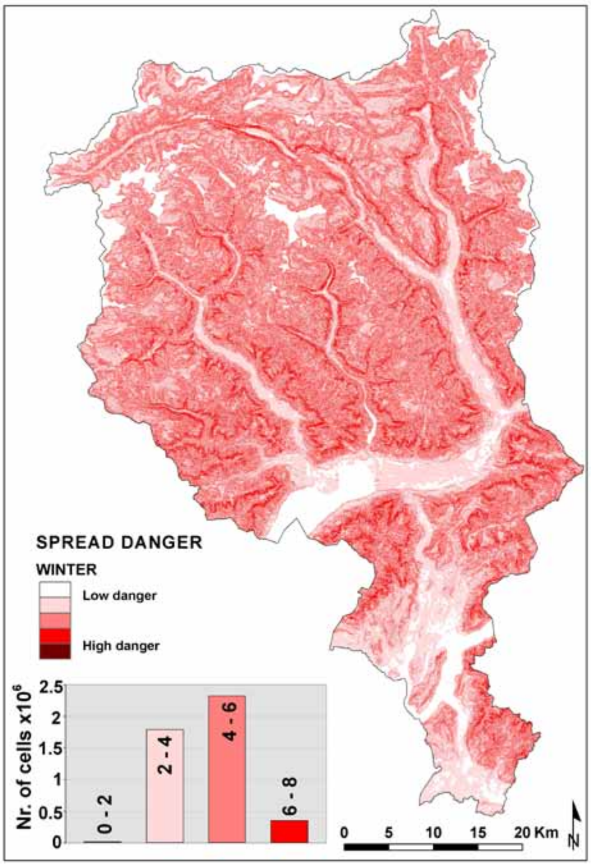

Figure 7.7. Map of the spread danger for the winter fires in Canton Ticino.

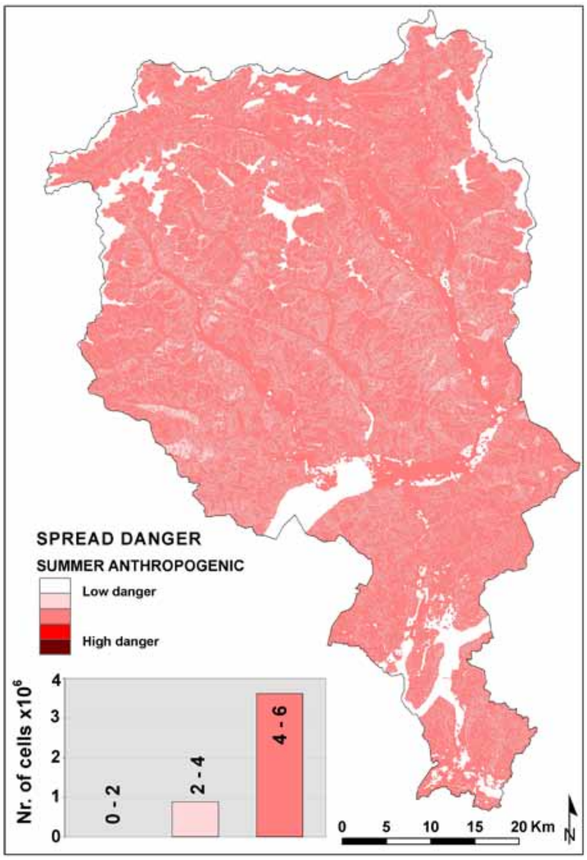

Figure 7.8. Map of the spread danger for the anthropogenic summer fires in Canton Ticino.

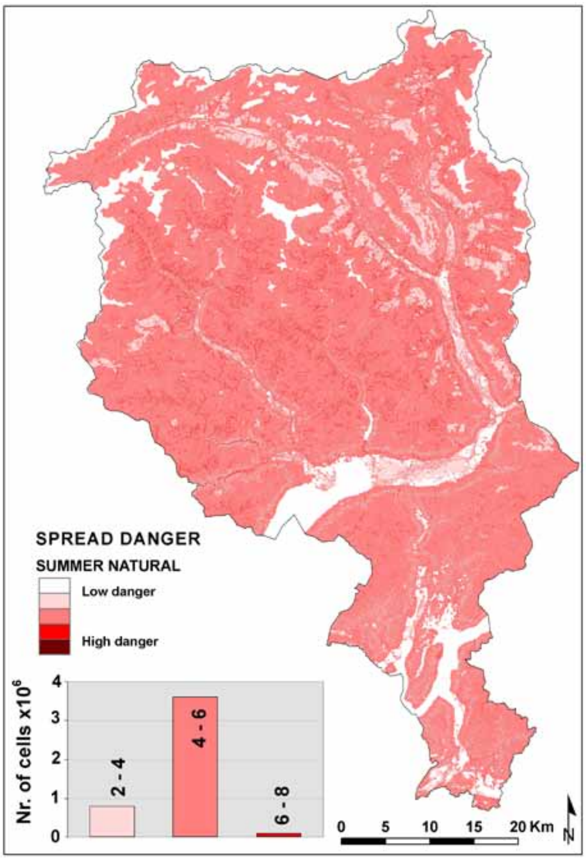

Figure 7.9. Map of the spread danger for the natural summer fires in Canton Ticino.

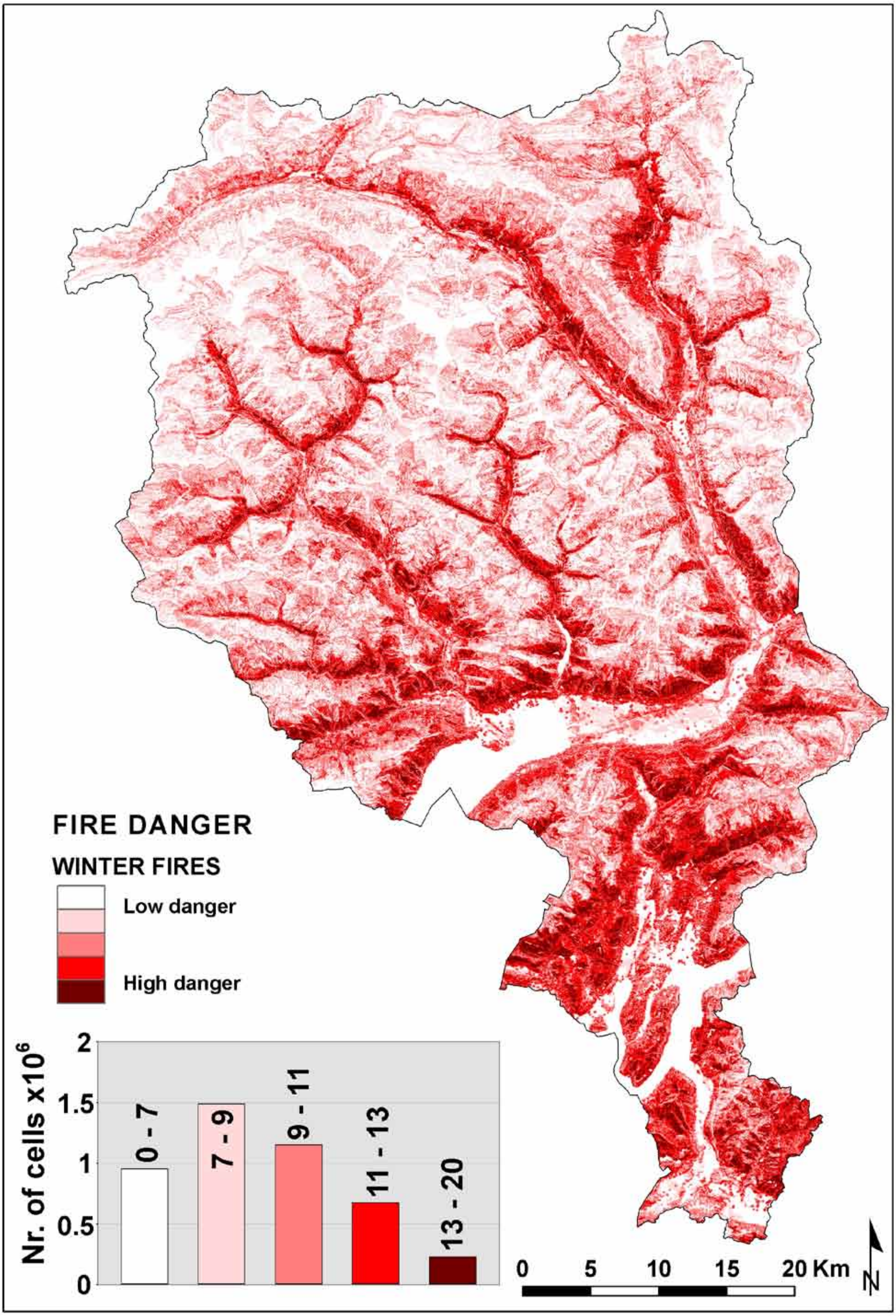

Figure 7.10. Map of the fire danger for the winter fires in Canton Ticino.

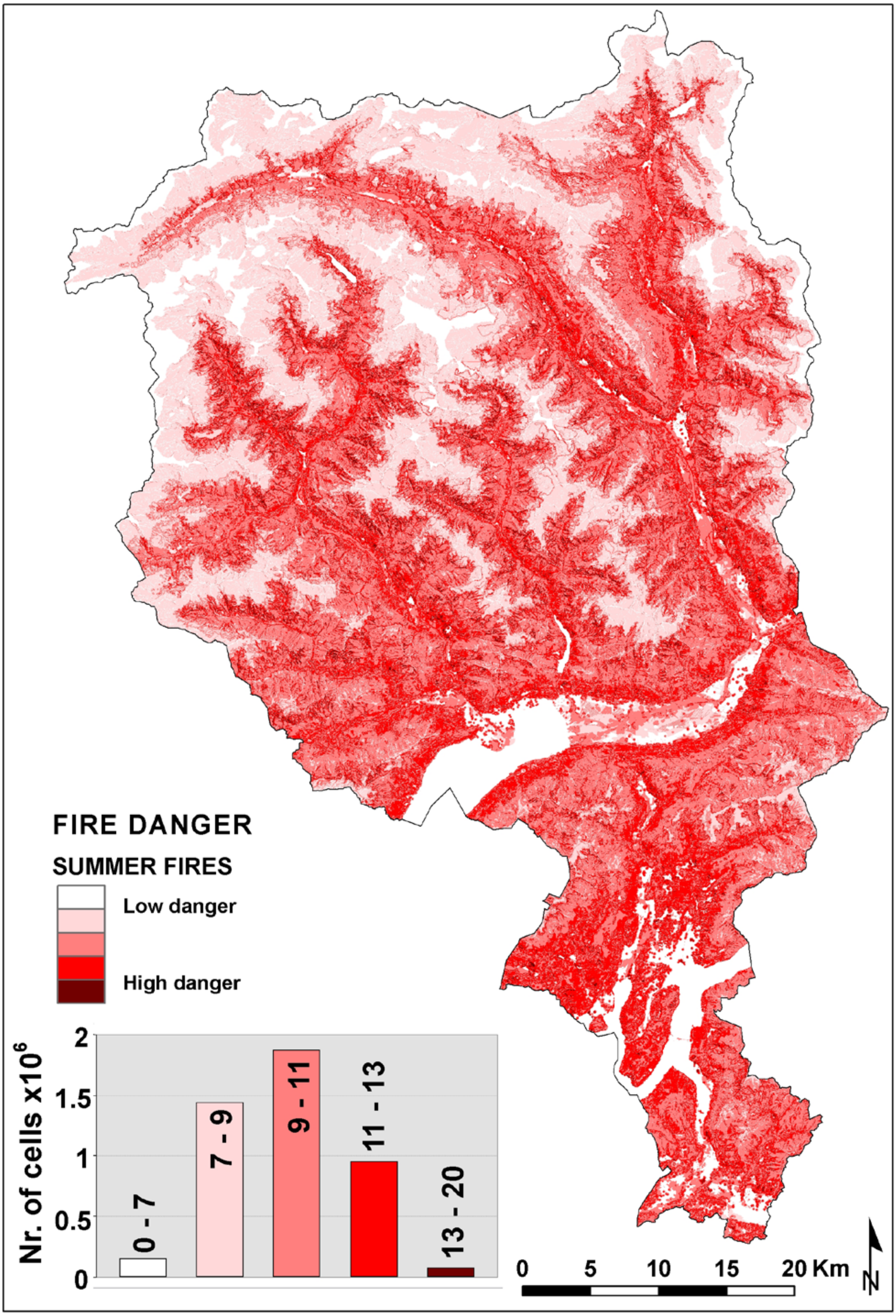

Figure 7.11. Map of the fire danger for the summer fires in Canton Ticino.

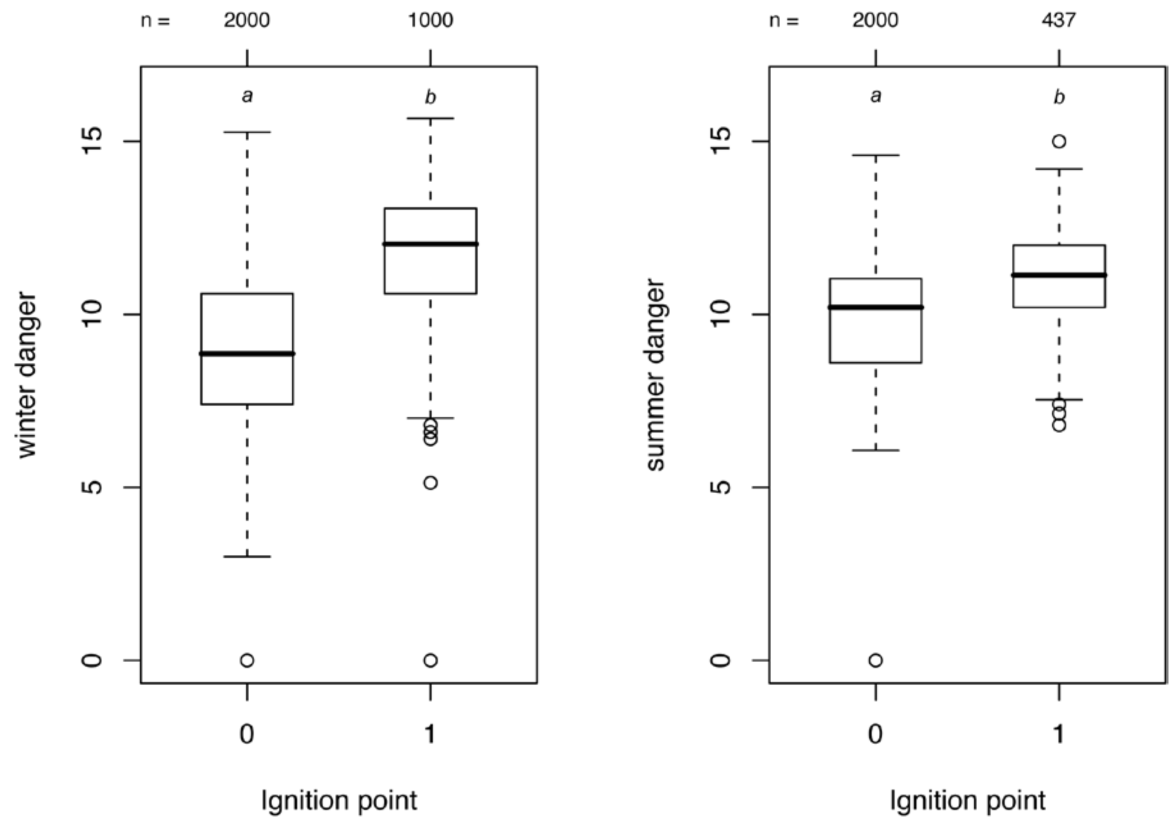

Figure 7.12. Box-plot distributions of winter and summer ignition danger for points with (ignition point = 1) and without (ignition point = 0) any fire start since 1980. Data points with different letters are significantly different (Mann-Withney U-test, $p < 0.01$).

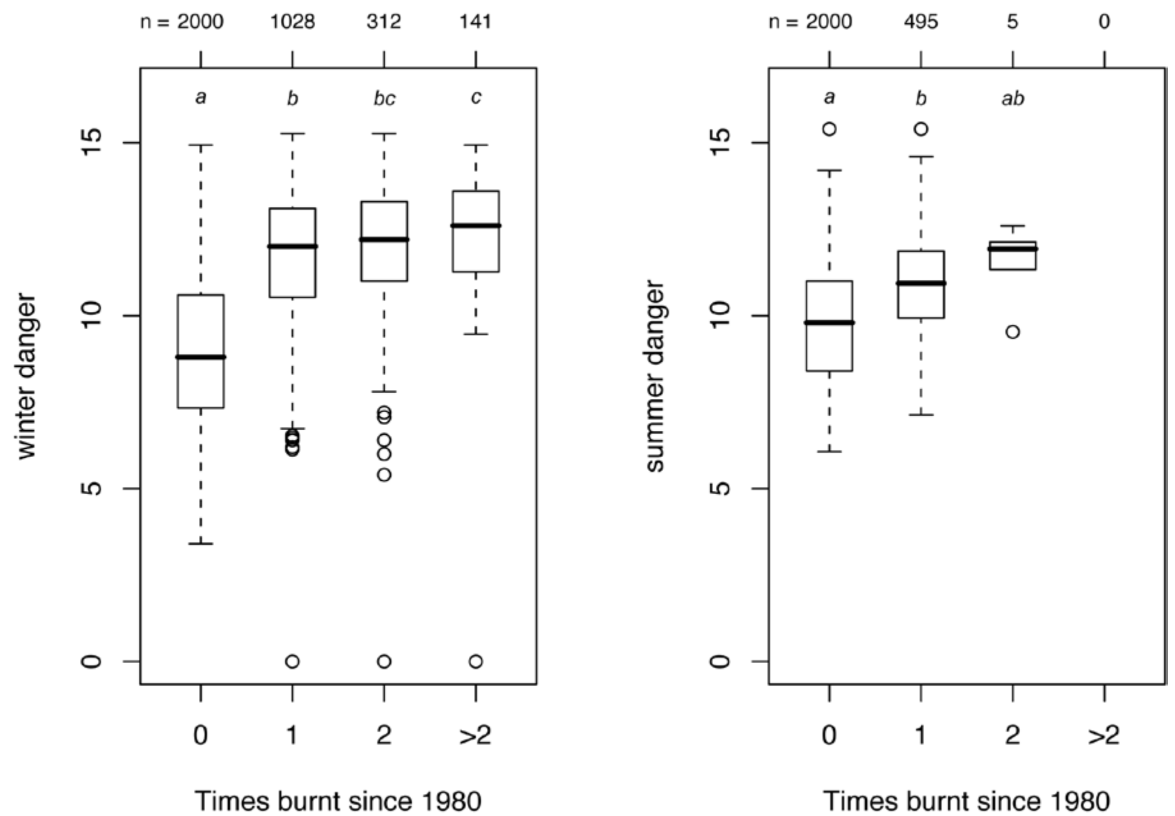

Figure 7.13. Box-plot distributions of winter and summer fire danger for points that experienced a different number of fires since 1980. Data points with different letters are significantly different (Mann-Withney U-test, $p < 0.01$).

8 Assessing relative fire risk

8.1 Methodological approach

Fire risk results from the combination of two primary components: fire danger and vulnerability to fire for a given area (see Fig. 2.1). In turn, vulnerability to fire represents the potential outcome of a fire in terms of ecological effects, damage to infrastructure or properties, and human losses.

As stated by CHANDLER *et al.* (1983) and BACHMANN (2001), rigorous quantitative estimation of fire effects is almost unattainable. A qualitative approach for identifying the potentially dangerous processes may consist of listing post-fire ecological effects such as the resilience of forest ecosystems to fire, the longevity of fire effects, and post-fire erosion and debris-flow risks and ranking them in terms of dangerousness according to a point system based on the acquired fire ecological knowledge. Doing so, the different effects are not quantified, but arranged in an increasing order according to the potential impact of the next fire.

With this approach, the time scale cannot be explicitly addressed, varying according to the fire effect considered: a stand replacing fire in a coniferous forest may have ecological effects over centuries, but the ground vegetation recovery may re-establish the protection against debris flow within a few years to a decade. The time scale of reference varies therefore according to the fire effect considered. Similarly, the spatial scope of the fire effect may vary according to the effect considered (e.g. post fire erosion, debris flow, and rock fall) and the presence of potentially endangered resources and infrastructures (e.g. urban areas, road and rail nets, protection forests, plantations, and intensively managed forests).

The method presents therefore a great flexibility in terms of temporal and spatial scales of reference, but implies the disadvantages of the subjectivity of the assessor and the possibility that the analysis is not exhaustive (VON GADOW 2000). In order to mitigate this downside, we asked a group of local fire experts (see Table 8.1) to critically evaluate the proposed checklist of fire effects and the assigned ranking point system, as well as to give their feedback on the plausibility and usefulness of the resulting fire vulnerability and fire risk maps.

8.2 Assessing the fire ecological effects

Vulnerability to fire in terms of ecological effects was evaluated considering the resistance and the resilience of the most representative species of each vegetation and forest cover category considered (TRABAUD 1976; NEFF 1995). As reported in Table 8.2, open lands (no forest, buffer zones) and resprouting chestnut forests were considered the fastest reacting, most post-fire resilient ecosystems, whereas beech and coniferous forests (with the exception of larch stands) received the highest vulnerability score given their generally limited capacity to survive intense fires, their lack of resprouting capability, and their limited post-fire colonization potential (see also Table 5.6).

Table 8.1. Fire expert group involved in the method assessment

Name		Funtion	Organisation
Ing.	Gabriele Corti	Fire management	Forest Service of Canton Ticino
Ing.	Aron Ghiringhelli	Fire management	Forest Service of Canton Ticino
For.	Pietro Bomio	Fire management	Forest Service of Canton Ticino
Iten	Daniele Ryser	Fire fighting	Cantonal Fire Brigade Organization
Dr.	Paolo Ambrosetti	Weather forecast	Meteoswiss, Locarno-Monti
Col	Tiziano Ponti	Helicopter pilot	Swiss air force

Table 8.2. Potential ecological impact

Parameter	Impact
Impact on vegetation and forest cover	
No forest, Buffer 50, Buffer 50–100, Chestnut stands	1
Other broadleaved forests; adult larch stands	2
Spruce stands, Beech stands, Pine stands, Other coniferous forests, Mixed forests, Fir stands, young stands up to the pole stage	3

8.3 Assessing the fire impact on resources

In Canton Ticino wildfires very seldom have a direct impact on resources such as buildings, roads, and infrastructures, partially because of the particular geomorphology of the territory and partially because of the clear separation between main urban areas in the lowlands and forest areas on the slopes. Much more relevant is the indirect impact of fire in terms rock fall, runoff, and debris flow (CONEDERA et al. 2003; MARXER 2003).

Effects of fire regime on post-fire erosion and runoff potential were estimated considering two parameters: fire frequency in the last 15 years and time since last fire (Table 8.3). As stated in chapter 5, in areas frequently and/or recently hit by fire, disturbance adapted vegetation rapidly covers the bar soil, mitigating negative post-fire effects in terms of erosion and runoff. In our model we consider the frequency of two or more fires within 15 years and a period shorter than 5 years since last fire as the best prerequisites to mitigate the vulnerability to post-fire erosion and runoff. A single fire within 15 years and a time span between 5 and 10 years since last fire are regarded as having an intermediate effect in preventing increased post-fire erosion and runoff (Table 8.3).

Generally speaking, erosive and runoff processes increase with slope. We therefore added the slope parameter to the model considering the slopes above 60 % as very relevant (score = 3), the slopes between 30 and 60 % as intermediate (score = 2), and the slopes below 30 % as the less relevant (score = 1) for erosive processes (Table 8.3).

Potential indirect damage to buildings and other resources due to fire-induced rock fall and debris flows was assessed using the SilvaProtect-CH approach. The aim of the SilvaProtect-CH project is to develop uniform criteria (e.g. harmonized, consistent, and updated input data) for defining protection for forests across all of Switzerland (GIAMBONI & WEHRLI 2007; GIAMBONI 2008). The frame of the SilvaProtect-CH project encompasses different, potentially damage-inducing events such as snow avalanches, rock fall, shallow landslides, debris flows, and drift wood (GIAMBONI & WEHRLI 2008). Among these we retained just rock fall and debris flow as potentially relevant for the vulnerability to fire evaluation. The rock fall model (LINIGER 2000) calculates the paths of rocks and boulders in a digital three-dimensional elevation model (DEM) from starting points generated in a specified density within defined detachment zones. The final model consists of thousands of calculated rock fall paths defining at the end the rock-fall process

Table 8.3. Potential impact on resources.

Parameter	Impact
Fire frequency in last 15 years	
2 or more fires	1
1 fire	2
no fire	3
Time since last fire	
< 5 years	1
5-10 years	2
> 10 years	3
Slope	
Slope < 30%	1
Slope 30-60%	2
Slope > 60%	3
Potential impact on forest protection	
No effect according to SilvaProtect CH	1
Rock fall danger according to SilvaProtect CH	3
Debris flow danger according to SilvaProtect CH	5
Particular forest stands	
Stand with no particular function	1
Intensively managed forests for timber production	2
Plantations, forest reserves, holly forests, etc.	3

space. The debris flow model (GAMMA 2000) combines different components (catchment area size, slope gradient, exposure, flow paths, estimation of the available bedload, and analysis of sediment yield) and simulates the trajectories (spread and range) for all possible debris flow releases. The hazard perimeters for rock fall and debris flow thus obtained are successively intersected with the damage potential (line and point objects such as the main road network, the railway network, permanently and temporarily occupied residential buildings, industrial, commercial, and public buildings and areas, tourism installations, etc.; see Fig. 8.1) in order to obtain the damage-relevant process area (GIAMBONI & WEHRLI 2008). In our model we considered for Canton Ticino the debris flow as the most significant post-fire hazard, giving it a high score (5 points) and considering it a first priority when overlapping with the rock fall hazard (Table 8.3).

Finally we considered forest stands of particular function (forest reserves, holly forests) and plantations (see also Fig. 6.6) as resources of high value (score = 3) and forests with intensive sylvicultural management and investments as resources of intermediate value (score = 2) (Table 8.3).

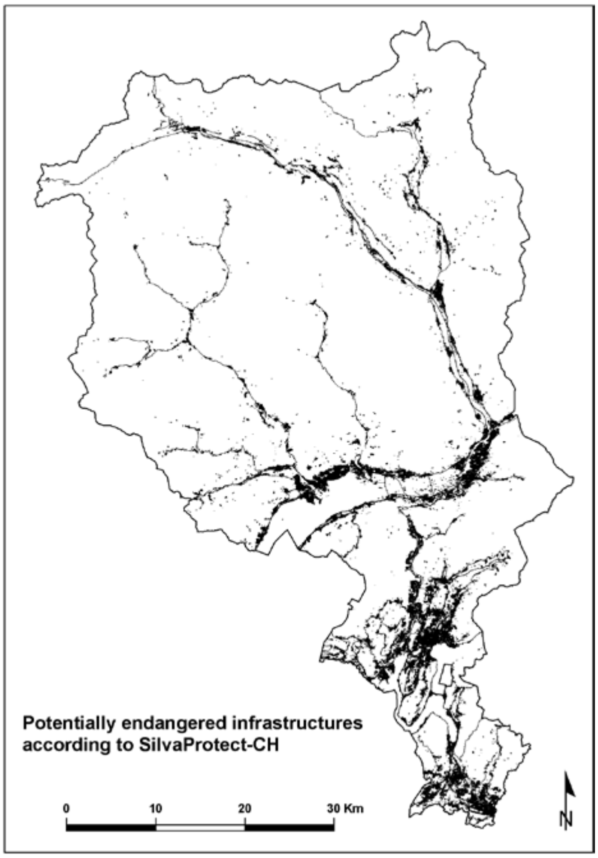

Figure 8.1. Potentially endangered infrastructures in the study area.

8.4 Assessing the vulnerability to fire

Vulnerability to fire as defined in this work results from the combination of the direct and indirect ecological effects and damages due to fire (Fig. 2.1). We therefore generated the fire vulnerability map by adding to each pixel of the grid the scores obtained according to the model proposed in Tables 8.2 and 8.3. The map thus obtained displays values ranging from a minimum score of 6 to a maximum score of 20 (Fig. 8.2).

8.5 Implementing the relative fire risk

Fire risk results from the combination of the fire danger and the vulnerability to fire (Fig. 2.1). As for fire danger we produced two different maps, one for the winter fire regime (Fig. 8.3) and one for the summer fire regime (Fig. 8.4). Fire risk maps as reported in Figures 8.3 and 8.4 display the relative fire risk within the two considered fire regimes (winter; summer) but not between the two regimes. In fact, absolute fire frequency in summer is by far lower than in winter in terms of both number of fire (14.4 % in the period 1990–2007) and burnt area (6.4 % in the period 1990–2007). Correcting the summer ignition danger and the summer spread danger accordingly, the resulting "weighted" summer fire risk displays by far lower scores (Fig. 8.5).

Table 8.4 reports the percentage distribution of the fire risk for the winter season and for both normal and "weighted" summer season. In winter time most of the territory displays a medium fire risk (45.8 %), whereas a minor portion scores with high (17.5 %) or very high (1.0 %) risk. If weighted with respect to the winter fire frequency, the summer season displays a very low to low fire risk (up to 99.4 % of the territory).

Table 8.4. Percentage distribution of the fire risk categories for the considered fire seasons.

score	category	winter	summer normal	summer "weighted"
< 15	very low	0.1	0.0	72.8
15–19	low	35.6	30.1	26.7
20–24	medium	45.8	47.3	0.6
25–29	high	17.5	22.2	0.0
>29	very high	1.0	0.5	0.0
	Total	100	100	100

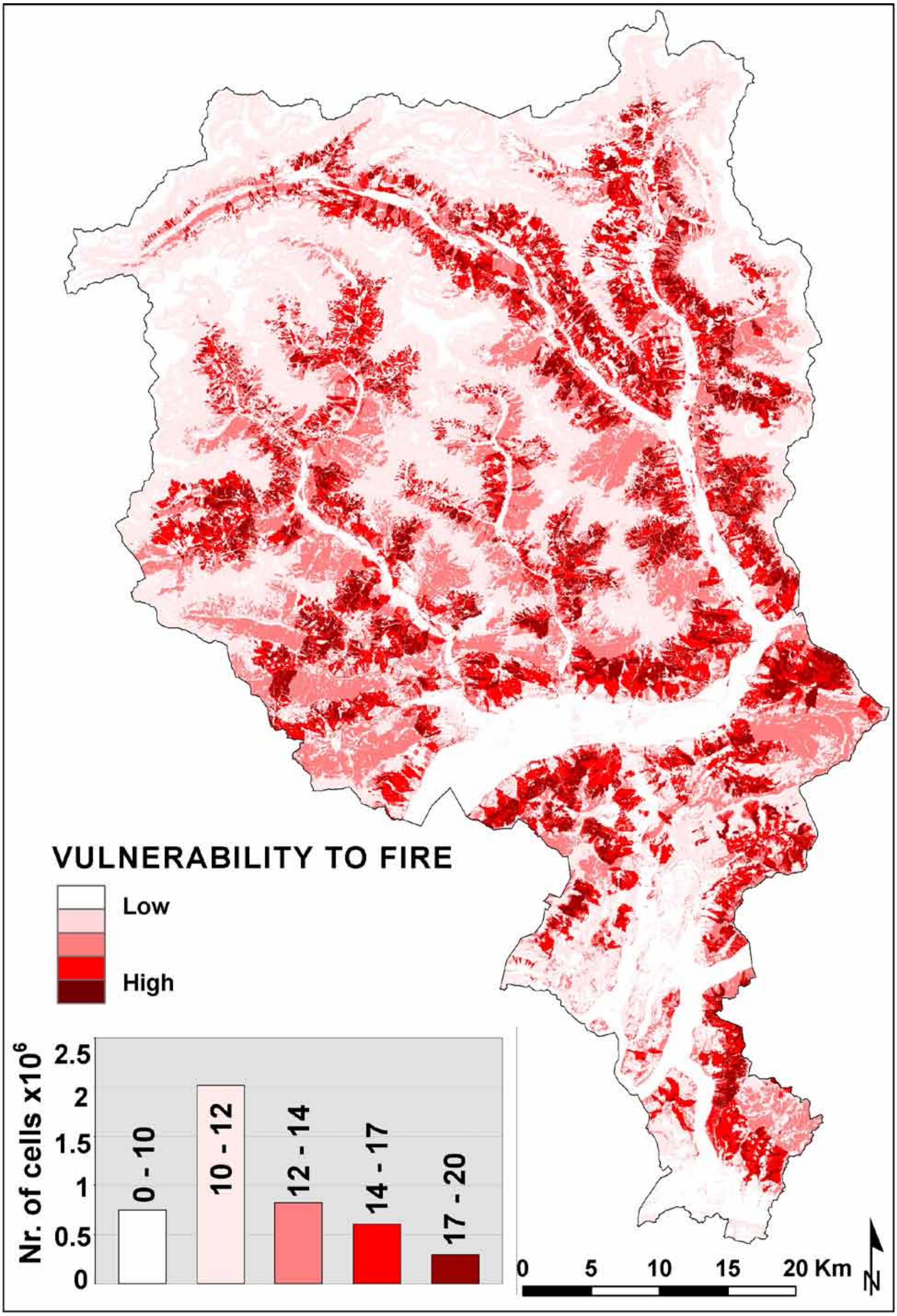

Figure 8.2. Map of the vulnerability to fire in Canton Ticino.

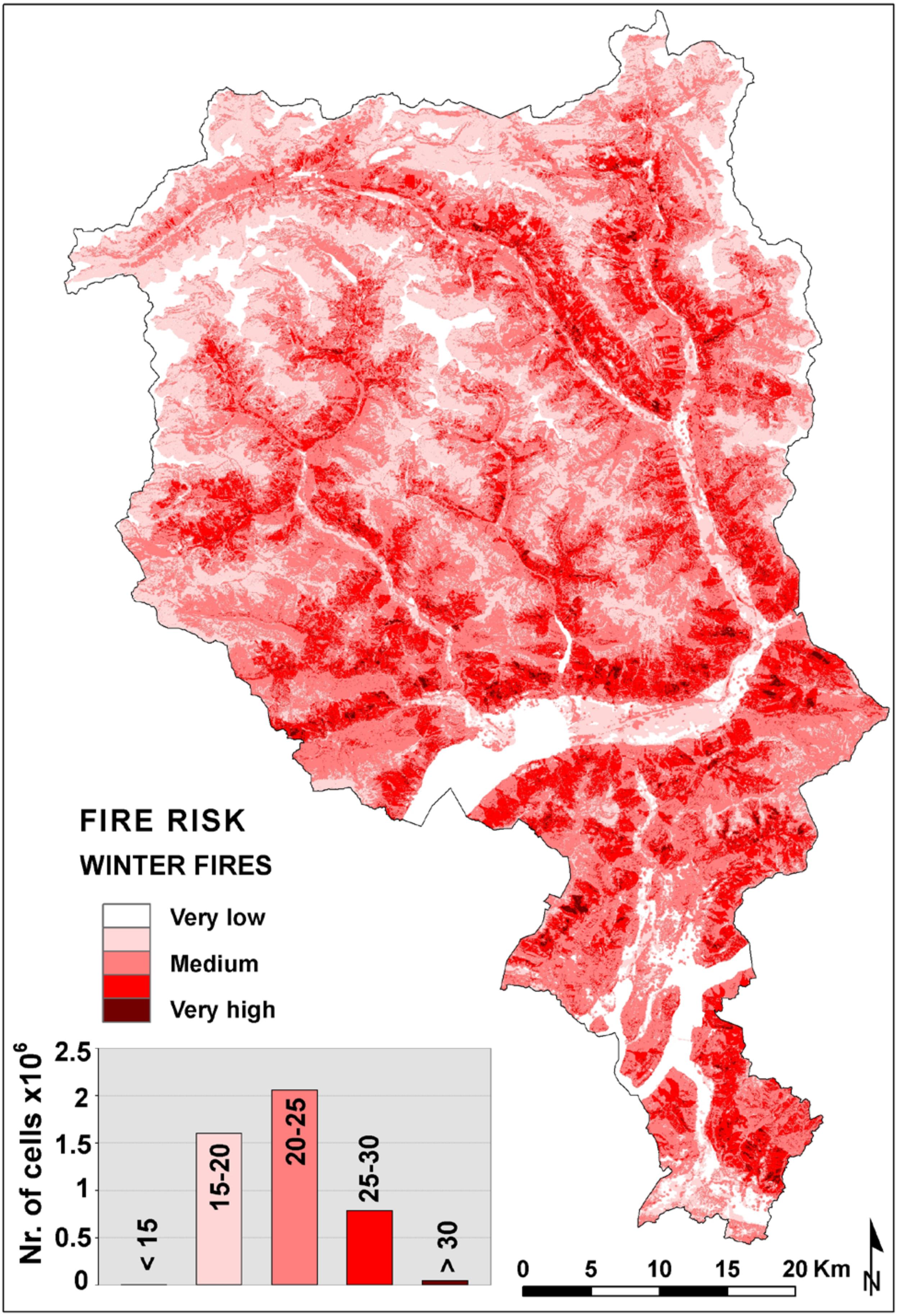

Figure 8.3. Map of the winter fire risk in Canton Ticino.

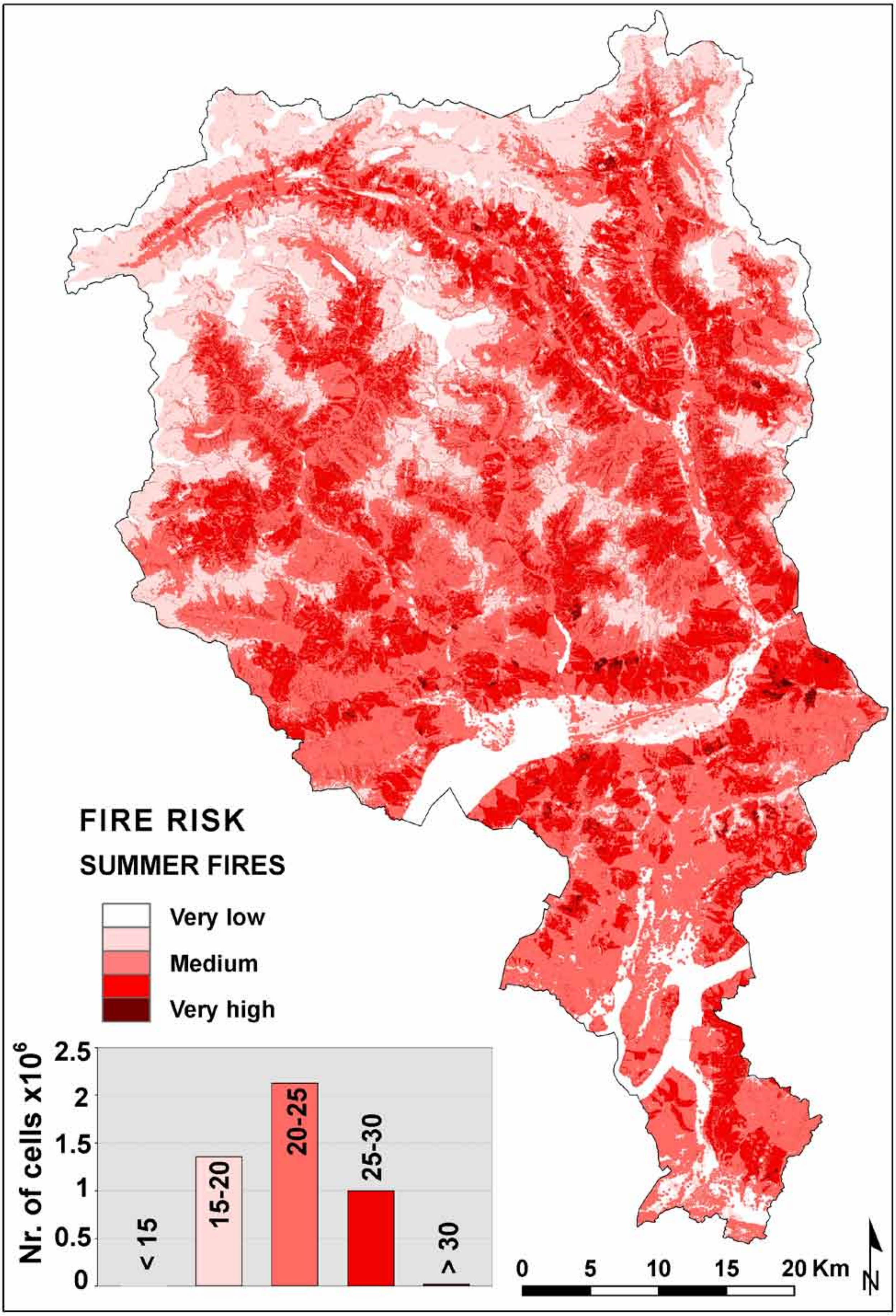

Figure 8.4. Map of the summer fire risk in Canton Ticino.

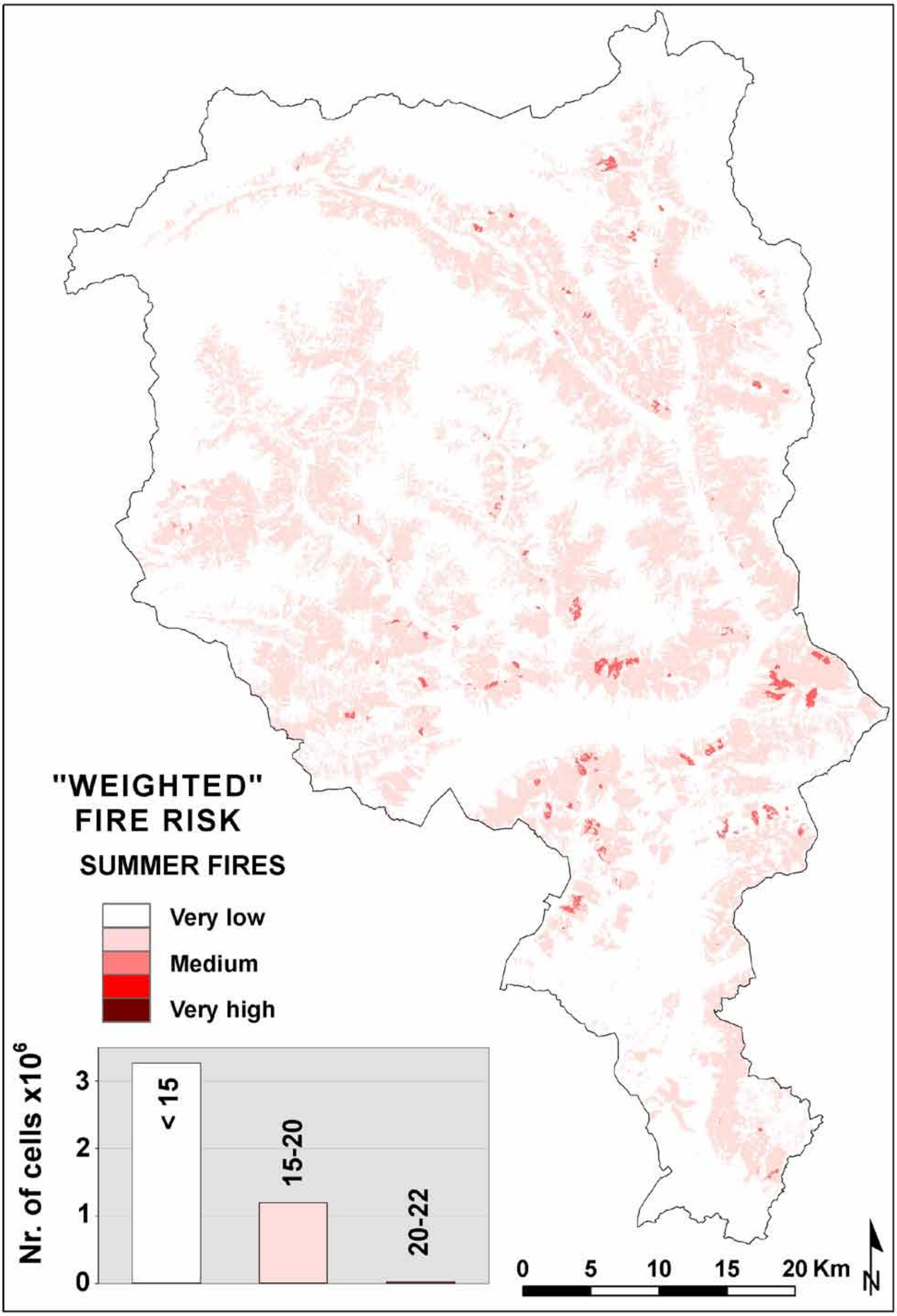

Figure 8.5. Map of the “weighted” summer fire risk in Canton Ticino.

9 Conclusions

This study aims to implement a fire risk analysis approach that incorporates the knowledge gained from reconstructing the fire history and fire ecology in Canton Ticino, an area in southern Switzerland with low to medium fire frequency.

Fire has been part of the forest ecosystems in Canton Ticino since the last post-glacial period, as demonstrated by the charcoal analysis of lake sediments and the presence of a number of fire adapted animal and plant species. Since the Neolithic, humans have strongly modified fire frequency and intensity through active use of fire (slash and burn), fuel management (biomass consumption), and fire suppression. When humans fail to actively prevent fuel build up, fire takes its ecological role as biomass regulator.

Presently the study region experiences a mixed fire regime: anthropogenic fires during the winter season (December through April), and anthropogenic and natural fires during the summer season (May through November). Due to changes in the legislation and fire fighting organization, homogeneous fire regimes have only existed since 1990 for the anthropogenic fires and since 1980 for the natural (lightning-induced) fires. Generally speaking, fire extinction actions are very efficient and most of the forest fires (90 %) do not burnt more then 10 ha during the winter and 2.0 ha during the summer seasons respectively. In particular cases (i.e. dry and windy conditions during the fire season) multiple ignitions and an elevated rate of spread may overburden the capacity of the fire fighting organization and result in an intense and extended fire, as was the case in 1990 and 1997. In such cases, post-fire erosion, superficial runoff and sediment production may increase exponentially, exposing resources and infrastructure to damages.

In this historical and ecological context, fire management should not aim at avoiding any fire, but at preventing intensive and large fires. To meet fire management goals, the limited resources available may be best allocated on the basis of a fire risk analysis (intended as the combination of fire danger and fire impact analysis) allowing prioritization and focus on prevention, pre-suppression and fire fighting activities.

In this study we propose using fire selectivity analysis based on Monte Carlo simulations for a statistically based estimation of the relative fire danger in a given area. Contrarily, the vulnerability of fire (fire impact) was estimated by implementing the knowledge of fire ecology and post-fire reduction of forest protection in a qualitative (point-assignment) assessment of potential fire effects. Statistical verification of the fire danger and expert evaluation of the vulnerability to fire and fire risk highlighted the suitability of the proposed approach for assessing the relative fire risk in a low to intermediate fire-prone region such as Canton Ticino. In addition, the method is open to further improvement such as the integration of information on fire-related fuel and sylvicultural management.

Fire management authorities may now use the developed fire danger and fire risk maps for planning preventive and pre-suppression activities such as helicopter water points, fuel management interventions, and fire-scenario simulations for preparing detailed fire fighting plans for the areas at highest risk.

By changing the relative weight of winter or summer fire risk respectively, it is also possible to simulate shifts in the fire season due to climate change, assuming for instance an increased fire frequency due to lightning-induced fires in summer.

The fire risk maps presented here may, however, rapidly become obsolete due to changing landscape and ecosystem dynamics (e.g. extension of the constructed areas, post-fire recovery of the vegetation, sylvicultural activity, and landscape abandonment). A periodic revision (e.g. every 5 years) is recommended, but the algorithms developed in this study should facilitate the task of re-running the proposed analysis.

10 Abstract

Implementing fire history and fire ecology in fire risk assessment: the study case of Canton Ticino (southern Switzerland)

Biomass burning may be widely considered together with floods, volcanic eruptions, and storms as one of the major disturbances and evolutionary forces patterning vegetation structures and generating disturbance-adapted ecosystems. Since humans have domesticated fire they have contributed essentially to the changing fire regimes of the planet, so that nowadays fire regimes depend not only on climatic and biological factors, but also greatly reflect the cultural background of how people manage ecosystems and fire.

Over time, the systematic use of fire suppression neglected the prominent role of fire in preserving and shaping such ecosystems and brought about the so called "fire paradox": the more efficient and successful the systematic fire suppression is, the more intense and catastrophic the few fires escaping from control will be. This generated a new awareness among scientists and managers about the ecological role of fire and the necessity of a shift from the fire control approach (i.e. concentration of the main effort in suppressing ongoing wildfires) towards the fire management approach, where fire prevention, fire danger rating, fire ecology, fire pre-suppression and suppression strategies are fully integrated in the landscape management. Implementing such a fire management approach is a very difficult task that requires a sound understanding of past forest stand and landscape dynamics and management practices, including fire history and fire ecology. In fact, contemporary forest ecosystems are the result of very complex interactions between past natural and anthropogenic forces. In addition, forest ecosystem services (protection, economic and recreational) and environmental conditions (climate change, pollution, invasive behaviour of alien species) are continuously evolving.

The main objective of this work is to propose a methodological approach for implementing the knowledge derived from studies of fire history, fire ecology, and fire suppression strategies in fire risk analyses at local to regional scales. We define fire risk as the combination of fire danger (the likelihood that an uncontrolled fire will occur in a given place) and vulnerability to fire for a given area (the potential outcome of a fire in terms of ecological effects, damage to infrastructure and properties, and human losses). So defined, fire risk focuses on structural (i.e. topograpical) and static factors that change very slowly (i.e. forest composition, anthropogenic infrastructures) and describes the mean risk level along an average fire season. We selected the Canton Ticino as study area, the most fire prone region of Switzerland.

The long term fire history shows that fire has been part of the forest ecosystems in Canton Ticino since the last post-glacial period. Since the Neolithic, humans have strongly modified the natural fire regime. When humans fail to actively prevent fuel build up, fire takes its ecological role as biomass regulator. Presently the area experiences two main fire seasons: the winter season during the vegetation rest (December through April) when fires are exclusively of anthropogenic origin, and the summer season (May through November) with a mixed regime of anthropogenic and natural fires.

The frequency of anthropogenic fires is primarily regulated through preventative measures (i.e. announcements of fire danger, information campaigns) and legislation (i.e. prohibition of burning garden debris in the open), whereas burnt area mainly depends on fire fighting organization (pre-suppression infrastructures, aerial fighting). The present fire regime is characterized by a prevalence of small size (< ha) fires and an increase of the percentage of lightning-induced summer fires. In case of extreme fire weather conditions (drought combined with dry Föhnwinds), multiple ignitions and an elevated rate of spread may overburden the capacity of the fire fighting organization and result in intense and extended fires. This is the reason why 90 % of the burnt area is caused by only 10 % of the total number of fire events.

From an ecological point of view, the presence of fire adapted species confirms that fire is part of the forest ecosystems in the study area. Large and intense fires may however threaten the protective function of the forests. This is especially the case in undisturbed and unmanaged forest stands that have produced an inconsistent herbaceous layer and a lot of dead fuel. In these stands forest fires may be particularly severe, altering the hydrogeological properties of the soil. This may induce high runoff and erosion rates, and in extreme cases gully and channel erosion or debris flows.

In this historical and ecological context, fire management should not aim at avoiding any fire, but at preventing intensive and large fires. To meet these fire management goals, the limited resources available may be best allocated on the basis of a fire risk analysis allowing prioritization and focus on prevention, pre-suppression and fire fighting activities.

The proposed method for analysing the relative fire risk of the area consists of three different steps.

In the first step we calculate the fire danger. Fire danger results from the combination of the probability of ignition and of fire spreading; that is, the chance of a given place to experience an uncontrolled fire. We used Monte Carlo simulations for testing fire selectivity of single factors such as forest vegetation cover, slope, altitude, aspect and – for the spread danger only – terrain curvature, considering the fire outbreak points for the ignition danger and the mean burnt area for the spread danger. For anthropogenic fires we additionally considered the effect presence of an urban-forest interface and the existence of outliers in fire frequencies due to particular human-related activities (railway and others). We performed the analysis for the three existing fire regimes: anthropogenic winter and summer fires (considered unchanged and with consistent data since 1990) and natural summer fires (considered unchanged and with consistent data since 1980).

In the second step we estimated the vulnerability to fire of the study area. Vulnerability to fire resulted from the combination of the direct and indirect ecological fire effects (ecosystem resilience) and the potential damages to infrastructures and resources as a consequence of increased danger of post-fire runoff, erosion, rock fall, and debris flow.

In the third and last step fire danger and vulnerability to fire are combined in the fire risk calculated separately for the winter and the summer season. The resulting fire risk maps display for the winter time a medium fire risk for almost the half (45.8 %) of the territory and low portions with high (17.5 %) or very high (1.0 %) fire risk. If weighted with respect to the winter fire frequency, the summer season displays a very low to low fire risk (up to 99.4 % of the territory).

Statistical verification of the fire danger and expert evaluation of the vulnerability to fire and fire risk highlighted the suitability of the proposed approach for assessing the relative fire risk in a low to intermediate fire-prone region such as Canton Ticino. In addition, the method is open to further improvement such as the integration of information on fire-related fuel and sylvicultural management.

Fire management authorities may now use the developed fire danger and fire risk maps for planning preventive and pre-suppression activities such as helicopter water points, fuel management interventions, and fire-scenario simulations for preparing detailed fire fighting plans for the areas at highest risk.

11 Zusammenfassung

Analyse des Waldbrandrisikos unter Einbeziehung der Feuerökologie und der Waldbrandgeschichte: Ein methodologischer Ansatz dargestellt am Beispiel des Kantons Tessin (Südschweiz)

In der Natur ist Feuer neben Stürmen, Vulkanausbrüchen, Überflutungen und Erdbeben einer der wichtigsten Störfaktoren, der für Dynamik und Erneuerung in Ökosystemen sorgt.
Seit der Beherrschung des Feuers, hat der Mensch die natürlichen Feuerregime massgeblich beeinflusst, so dass heutzutage das Feuergeschehen nicht nur von klimatischen und biologischen Faktoren, sondern auch vom kulturellen und geschichtlichen Hintergrund abhängt.
Langjährige Anstrengungen, Feuer systematisch zu bekämpfen, ohne deren natürliche Rolle in der Natur zu erkennen und zu respektieren, hat in vielen Fällen zu dem sogenannten Feuer-Paradox geführt: je effizienter die Brandbekämpfung ist, desto verheerender wirken die wenigen Brände, die dem sofortigen Löschen entgehen. Diese Erfahrungen haben die Fachleute inzwischen überzeugt, dass es wichtig ist, den Faktor Feuer aktiv im Landmanagement zu integrieren und vom Feuerlösch-Ansatz zum Feuermanagement-Ansatz überzugehen. So definiert ist Feuermanagement ein Ansatz zur Integration von biologischen, ökologischen, physischen und technischen feuerbezogenen Aspekten in der allgemeinen Landschaftsplanung. Die Implementierung von solchen theoretischen Ansätzen im Feuermanagement ist eine schwierig zu lösende Aufgabe, die ein detailliertes Verständnis der früheren Landschaftsdynamik und insbesondere der natürlichen und anthropogenen Einflussfaktoren, die die aktuellen Ökosysteme geprägt haben, voraussetzt. Hinzu kommen noch die sich ständig ändernden Erwartungen der Gesellschaft an die Ökosystemfunktionen unter den sich ebenfalls im Wandel befindlichen Umweltbedingungen wie z.B. Klimaveränderung, Umweltverschmutzung oder Invasion durch Neobiota.
In dieser Arbeit wird versucht, eine Methode zu entwickeln, um auf regionaler Ebene die Erkenntnisse aus dem Studium der Waldbrandgeschichte, der Feuerökologie und der Löschstrategien bei der Ermittlung des Waldbrandrisikos zu integrieren. Dabei wird das Waldbrandrisiko als Kombination der Feuergefahr (Wahrscheinlichkeit eines Gebietes ein unkontrolliertes Feuer zu haben) und der Anfälligkeit eines Gebietes auf Feuereffekte (z. B. ökologische und funktionale Veränderungen der Ökosysteme, Infrastrukturschäden, Opfer) definiert. Insofern bezieht sich das Feuerrisiko auf strukturelle (Orographie) und relativ statische Faktoren (Waldzusammensetzung, menschliche Infrastrukturen) die sich nur langsam bis mittelfristig verändern. Als Testgebiet für die Fallstudie wurde der Kanton Tessin gewählt, die feueranfälligste Region der Schweiz.
Aus der früheren Feuergeschichte des Untersuchungsgebietes entnimmt man, dass Feuer in diesem Gebiet seit der letzten Eiszeit Bestandteil der Natur ist. Das Feuergeschehen wurde bereits sehr früh im Neolithikum bis in die Gegenwart durch menschlichen Einfluss geprägt.
Das Feuerregime kann heute in zwei unterschiedlichen Feuersaisons unterteilt werden: die Winterbrände während der Vegetationsruhe von Dezember bis April, die ausschliesslich durch Menschen verursacht werden und die Sommerbrände während der Vegetationszeit von Mai bis November, mit sowohl durch Menschen, wie durch Blitzschlag ausgelösten Waldbränden. Was die Waldbrände menschlichen Ursprungs anbelangt, haben vor allem die allgemeine Waldbrandprävention durch Information (z. B. Ankündigung des absoluten Feuerverbotes im Falle von hoher Brandgefahr) sowie die gesetzlichen Vorschriften (Verbot des Verbrennens von Gartenabfällen im Freien) einen Einfluss auf die Waldbrandhäufigkeit gehabt. Die Feuerwehrorganisation, die Vor-Löschaktivitäten (Vorbereitung von Wasserpunkten für Helikopter) und der häufige Einsatz der Feuerbekämpfung aus der Luft haben hingegen einen starken Einfluss auf die Grösse der einzelnen Brände und somit auch auf die gesamte Brandfläche gehabt. Das heutige Feuerregime ist gekennzeichnet durch eine steigende Tendenz der Blitzschlagbrände im Sommer, währenddem die menschlich verursachten Brände sich nach einem Rückgang Anfang der Neunziger Jahre stabilisiert haben. Die meisten Brände sind sehr klein (< 1 ha). Unter besonderen meteorologischen Verhältnissen (andauernde Trockenheit, starker Nordföhn) können aber gleichzeitig viele Brandausbrüche entstehen, die die Löschkapazität der Feuerwehrorganisation sprengen. Unter diesen Umständen können einzelne Brandflächen

sehr gross werden. Heutzutage machen 10 % der Ereignisse ungefähr 90 % der gesamten Brandfläche aus.

Ökologisch gesehen, ist Feuer im Untersuchungsgebiet ein natürlicher Bestandteil der Ökosysteme. Dies wird durch die Präsenz von vielen feuerangepassten Arten bestätigt. Dennoch stellen ausgedehnte und intensive Waldbrände eine grosse Bedrohung für die Schutzfunktion der Wälder dar. In dichten und ungepflegten Wäldern, die seit Jahren ungestört sind (keine Brände und kein Waldbau) und wo sich viel tote Biomasse am Boden akkumuliert hat, können Feuer besonders intensiv werden und erhebliche Veränderungen der hydrologischen Eigenschaften des Gebietes verursachen. Nach Feuer sind der Oberflächenabfluss und die Bodenerosion stark erhöht, was im Falle von intensiven Niederschlägen zu Grabenerosion oder sogar zu Murgängen mit Geschiebetransport führen kann.

Unter diesen feuergeschichtlichen und feuerökologischen Rahmenbedingungen, soll das Ziel des Feuermanagements nicht das absolute Vermeiden jegliches Waldfeuers, sondern das Vorbeugen vor intensiven und grossflächigen Waldbränden sein. Um diese Ziele zu erreichen sollten die begrenzten Ressourcen möglichst effizient und gezielt auf Grund einer umfassenden Waldbrandrisiko-Analyse eingesetzt werden. Die Identifizierung der Risikogebiete ist die beste Voraussetzung, um die präventiven, infrastrukturellen, organisatorischen und strategischen Massnahmen im Rahmen des Feuermanagements zu planen.

Der hier vorgestellte methodologischer Ansatz zur Analyse des Waldbrandrisikos gliedert sich in drei unterschiedliche Module.

In einem ersten Modul wird die Feuergefahr, bestehend aus Ausbruchsgefahr (d.h. die Gefahr, dass ein Feuer ausbricht) und Ausbreitungsgefahr (d.h. die Gefahr, dass ein Feuer über einen beliebigen Punkt des Untersuchungsgebietes durchzieht) ermittelt. Zu diesem Zweck wird mittels Monte Carlo-Simulationen die Feuerselektivität von den Einflussparametern Waldvegetation, Höhe, Neigung, Exposition und – nur für die Feuerausbreitung – Geländebeschaffenheit getestet. Die Selektivitätsanalyse erfolgt aufgrund der Startpunkte für die Ausbruchsgefahr und der mittleren Brandfläche für die Ausbreitungsgefahr. Die Analyse erfolgte für alle drei homogenen Waldbrandregimes des Kantons Tessin: menschlich verursachte Waldbrände seit 1990 für die Wintersaison (Dezember bis April) und Sommersaison (Mai bis November) sowie Blitzschlagbrände seit 1980 für die Sommersaison. Für die Ermittlung der Ausbruchsgefahr von menschlich verursachten Waldbränden wurden zudem auch die Wald-Siedlung-Kontaktzone (forest-urban interface) und allfällige Spezialsituationen mit lokalbedingten überdurchschnittlichen Feuerfrequenzen (steile Bahnstrecken, Waffenplätze usw.) berücksichtigt.

In einem zweiten Modul wird die Anfälligkeit eines Gebietes auf die Feuereffekte ermittelt. Die Feuereffekte werden aus der Kombination der ökologischen Folgen eines Waldbrandes (Resilienz der Waldökosysteme) und dem Schadenspotenzial an den Ressourcen (Oberflächenabfluss, Erosion, Steinschlag, Murgang nach Feuer und daraus folgendes Gefahrenpotential für Infrastrukturen und natürliche Ressourcen) ermittelt.

Im dritten, letzten Modul, werden Feuergefahr und potentielle Feueranfälligkeit zu den Waldbrandrisikokarten (separat für Winter- und Sommersaison) kombiniert. Die so ermittelten Waldbrandrisikokarten weisen für die Wintersaison sehr wenige Gebiete (1.0 %) mit sehr großem Risiko, 17.5 % des Gebietes mit hohem Risiko und fast die Hälfte des untersuchten Gebietes mit mässigem Risiko (45.8 %) aus. Im Vergleich zum Winter ist das Feuerrisiko im Sommer eindeutig kleiner, das ganze Gebiet weist ausschließlich die Kategorien sehr niedriges (72.8 %) bis niedriges (26.7 %) Risiko auf.

Die statistische Analyse der Waldbrandgefahr und die Expertenbeurteilung der resultierenden Feueranfälligkeits- und Waldbrandrisikokarten haben die Eignung der in dieser Studie vorgestellten Methode zur Ermittlung des relativen Waldbrandrisikos für ein wenig bis mässig feueranfälliges Gebiet wie den Kanton Tessin bestätigt.

Die in dieser Studie ermittelten Waldbrandrisikokarten erlauben nun, die zur Verfügung stehenden begrenzten Mittel zur Feuervorbeugung und -bekämpfung gezielt einzusetzen. Feuer-Manager können somit das Planen der Vor-Löscheinrichtungen (wie z.B. die Wasserpunkte für Helikopter), das Durchführen von waldbaulichen Massnahmen zur Brandgutregulierung sowie das Simulieren und Trainieren von Waldbrandszenarien auf diesen Karten abstützen.

12 Riassunto

Un approccio metodologico per integrare le informazioni della storia e dell'ecologia degli incendi nell'analisi del rischio di incendio: l'esempio del Cantone Ticino (Svizzera meridionale)

In natura il fuoco è unitamente alle tempeste, alle eruzioni vulcaniche, alle inondazioni e ai terremoti uno dei principali fattori di disturbo responsabile della dinamica e della rinnovazione degli ecosistemi. Da quando l'essere umano ha imparato a gestire il fuoco ha anche notevolmente influenzato il regime e il ruolo naturale degli incendi, tanto che a partire da allora le caratteristiche pirologiche non dipendono solo da fattori biologici e climatici, ma anche dal substrato storico e culturale del territorio.

La lotta sistematica contro ogni forma di incendio senza cognizione e rispetto per il ruolo ecologico naturale del fuoco ha in molti casi portato al cosiddetto "paradosso del fuoco", vale a dire alla paradossale correlazione positiva tra efficacia della lotta contro gli incendi e intensità dei pochi incendi che riescono a sfuggire a un rapido controllo. Queste esperienze nel campo della lotta contro gli incendi boschivi hanno convinto gli esperti e gli addetti ai lavori a cambiare approccio nella gestione del fenomeno, passando dal semplice controllo del fuoco (fire control) a una gestione attiva del problema (fire management). Alla base della gestione attiva degli incendi vi è l'idea di un'integrazione degli aspetti biologici, ecologici, fisici e tecnici del fuoco nelle attività generali di gestione del paesaggio. La traduzione in pratica di questo approccio teorico presuppone però non solo una conoscenza dettagliata delle dinamiche paesaggistiche pregresse e dei fattori naturali e antropici che hanno contribuito alla creazione degli attuali ecosistemi, ma richiede anche una particolare sensibilità per le esigenze della società nei confronti delle funzioni degli ecosistemi in un contesto ambientale in continua evoluzione (cambiamenti climatici, carico ambientale di inquinanti, comportamento invasivo di alcune specie di nuova introduzione ecc.).

In questo studio abbiamo sviluppato un metodo per la valutazione a livello regionale del rischio di incendio a partire dalle informazioni sulla storia e l'ecologia del fuoco e sulle strategie di lotta contro gli incendi. In questo ambito abbiamo definito il rischio di incendio come la combinazione tra pericolo di incendio (vale a dire la probabilità relativa per un qualsiasi punto del territorio di avere un fuoco fuori controllo) e la vulnerabilità al fuoco (vale a dire le potenziali alterazioni ecologiche e funzionali degli ecosistemi e i danni alle risorse causate dal passaggio di un incendio). Nella nostra definizione, il rischio di incendio si riferisce per lo più a fattori strutturali (per esempio l'orografia) o relativamente statici (composizione del bosco, distribuzione delle infrastrutture) del territorio che mutano lentamente nel tempo e che descrivono quindi il rischio medio durante una stagione di incendi normale. Quale area di studio è stato scelta il Cantone Ticino, la regione della Svizzera più soggetta al problema degli incendi boschivi.

La storia remota degli incendi dell'area di studio ci insegna come il fuoco sia naturalmente presente fin dal tardiglaciale. Da parte sua l'essere umano ha influenzato il regime naturale degli incendi già a partire dal Neolitico. Attualmente esistono due principali stagioni di incendio: la stagione invernale durante la pausa vegetativa (dicembre-aprile) con incendi esclusivamente di origine antropica; la stagione estiva (maggio-novembre), con un regime misto di incendi antropici e naturali. La frequenza degli incendi di origine antropica è stata negli ultimi decenni essenzialmente influenzata dalle attività di prevenzione attraverso l'informazione (annuncio di pericolo incendi, cartellonistica) e dai dispositivi di legge (proibizione di bruciare gli scarti vegetali all'aperto), mentre la superficie percorsa dal fuoco (sia a livello di singoli incendi che totale) ha subito una significativa riduzione grazie a un'adeguata organizzazione antincendio, alla preparazione di infrastrutture antincendio (punti di pescaggio per elicotteri) e al rapido ricorso alla lotta aerea in caso di necessità. Il regime degli incendi attuali è così caratterizzato da incendi di piccole dimensioni (< 1 ha) e da un aumento della frequenza relativa degli incendi estivi originati da fulmine. In caso di condizioni meteorologiche particolari (siccità prolungata accompagnata a vento da nord) possono comunque verificarsi contemporaneamente diversi inneschi di incendi a rapida propagazione che sfuggono all'immediato controllo da parte dell'organizzazione antincendio. In queste condizioni eccezionali singoli incendi possono diventare molto estesi: non a caso il 90 % della superficie bruciata totale è coperta da solo il 10 % degli eventi.

Dal punto di vista ecologico, la presenza di specie adattate al fuoco ribadisce il ruolo naturale del fuoco negli ecosistemi dell'area di studio. Incendi di grande superficie e di forte intensità rappresentano però una minaccia per la funzione protettiva delle foreste, specialmente quando sono colpiti popolamenti densi e maturi da anni cresciuti indisturbati e quindi non pronti a reagire a influenze esterne (incendi o cure selvicolturali). In questi boschi il fuoco può diventare particolarmente intenso a causa della presenza di un accumulo di necromassa e causare notevoli alterazioni delle caratteristiche idrogeologiche del suolo, con un forte aumento del deflusso superficiale delle acque e dell'erosione e, in caso di forti precipitazioni, la creazione di solchi erosivi e l'innesco di colate di fango.

Dato questo quadro pirologico generale, è ragionevole porre come obiettivo ultimo della gestione antincendio non tanto l'eliminazione totale e assoluta di qualsiasi tipo di fuoco, bensì la prevenzione di incendi intensi ed estesi. La miglior premessa per raggiungere questi obiettivi è un impiego finalizzato delle limitate risorse a disposizione in funzione di una analisi globale del rischio di incendio. L'identificazione e la classificazione delle zone a più alto rischio rappresentano infatti un passo fondamentale nell'individuazione delle misure preventive, infrastrutturali ed organizzative prioritarie nell'ambito della pianificazione antincendio.

L'approccio metodologico proposto in questo studio per l'analisi del rischio di incendio si articola in tre moduli. Il primo modulo è rappresentato dal calcolo del pericolo di incendio, vale a dire dalla combinazione del pericolo di innesco e del pericolo di propagazione (probabilità relativa che un fuoco si riveli o percorra un determinato punto dell'area di studio). Allo scopo è analizzata la selettività al fuoco di singoli parametri quali la composizione del bosco, l'acclività, la quota, l'esposizione e – limitatamente al pericolo di propagazione – la conformazione del terreno per mezzo di simulazioni Monte Carlo. L'analisi della selettività all'innesco fa naturalmente riferimento ai punti di origine degli incendi, mentre per la selettività alla propagazione è stata utilizzata la superficie media degli incendi. Per il pericolo di innesco di incendi di origine antropica sono inoltre state considerate sia la presenza di una zona di contatto tra aree abitative e foreste (interfaccia urbano-forestale) sia l'eventuale presenza di particolari situazioni effettive con elevata frequenza di innesco (tratti di ferrovia particolarmente acclivi ecc.). L'analisi ha preso in considerazione separatamente i tre differenti regimi di incendio attualmente presenti nell'area di studio, vale a dire gli incendi di origine antropica (considerati omogenei e consistenti a partire dal 1990) per la stagione invernale e quella estiva e gli incendi da fulmine (considerati omogenei e consistenti a partire dal 1980) per la stagione estiva.

Nel secondo modulo viene stimata la vulnerabilità di un'area al passaggio di un incendio. Gli effetti del fuoco sono stimati combinando le possibili conseguenze ecologiche dell'incendio (resilienza degli ecosistemi forestali) con il potenziale di danno alle infrastrutture e alle risorse naturali dovuto all'accresciuto pericolo di deflusso superficiale, erosione, caduta sassi e colate di fango.

Nel terzo e ultimo modulo il pericolo di incendio e la vulnerabilità potenziale al passaggio di un incendio sono combinati nel rischio di incendio, calcolato separatamente per la stagione invernale e quella estiva. Le carte del rischio di incendio così calcolate hanno indicato per la stagione invernale poche aree a rischio "molto elevato" (1 %), 17.5 % del territorio a rischio "elevato" e quasi la metà dell'area di studio (45.8 %) a rischio "medio". In estate il rischio di incendio è decisamente meno elevato raggiungendo nel 72.8 % del territorio il livello "molto basso" e nel 26.7 % dei casi il livello "basso".

La verifica statistica dei risultati dell'analisi del pericolo e la valutazione di un gruppo di esperti locali delle carte prodotte per la vulnerabilità al fuoco e il rischio di incendio hanno confermato l'idoneità dell'approccio metodologico proposto per la stima del rischio relativo di incendio in un'area a frequenza medio-bassa di incendio come il Canton Ticino. I responsabili della gestione del territorio e delle organizzazioni antincendio hanno ora a disposizione un valido strumento per la pianificazione delle infrastrutture antincendio (per esempio punti di pescaggio per elicotteri), per l'esecuzione di interventi selvicolturali di regolazione del combustibile e per la simulazione e l'esercitazione dei possibili scenari di incendio nelle zone più a rischio.

13 Résumé

Intégration de l'écologie du feu et de l'historique des incendies dans l'analyse du risque d'incendies de forêt: approche méthodologique illustrée par l'exemple du canton du Tessin (sud de la Suisse).

Aux côtés des tempêtes, des éruptions volcaniques, des inondations et des séismes, le feu est, dans la nature, l'un des facteurs clés de perturbation qui contribuent à la dynamique et au renouvellement des écosystèmes. Depuis que l'homme le maîtrise, il a largement marqué de son empreinte les régimes du feu, si bien qu'aujourd'hui ces régimes dépendent non seulement de facteurs climatiques et biologiques, mais aussi des contextes culturels et historiques.

Au fil du temps, on s'est efforcé de lutter systématiquement contre le feu, sans reconnaître ni respecter son rôle de préservation et de façonnage des écosystèmes. Souvent, cela a conduit au „paradoxe du feu": plus la lutte contre les incendies est efficace, plus le faible nombre d'incendies qui échappent à l'extinction immédiate sont dévastateurs. Ces expériences ont entre-temps convaincu les spécialistes qu'il était important d'intégrer le facteur feu de façon active dans la gestion du territoire, et de passer d'une approche privilégiant l'extinction des incendies à une approche centrée sur leur gestion. Définie de la sorte, la gestion des incendies vise à intégrer les aspects biologiques, écologiques, physiques et techniques liés au feu dans la planification générale du paysage. Appliquer une telle approche représente une mission difficile. Elle requiert en effet une compréhension détaillée de l'ancienne dynamique des paysages, et en particulier des facteurs d'influence naturels et anthropiques qui ont marqué les écosystèmes actuels. S'y ajoutent les attentes en perpétuel changement de la société vis-à-vis des fonctions écosystémiques dans des conditions environnementales elles aussi en évolution, comme le changement climatique, la pollution de l'environnement ou l'invasion par les néobiotes.

Le principal objectif de ce travail est de développer une méthode afin d'intégrer dans l'analyse du risque d'incendie au niveau régional, les connaissances de l'historique des incendies, de l'écologie du feu, et des stratégies d'extinction. Le risque d'incendie de forêt est alors défini comme la combinaison du danger d'incendie (probabilité qu'un incendie non contrôlé se déclenche dans une zone donnée) et de la vulnérabilité d'une zone vis-à-vis des incendies (conséquences potentielles d'un incendie en termes de modifications écologiques et fonctionnelles des écosystèmes, dégâts aux infrastructures, nombre de victimes). Défini comme tel, le risque d'incendie porte sur des facteurs structurels (orographie) et relativement statiques (composition de la forêt, infrastructures anthropiques) qui n'évoluent que très lentement. Le canton du Tessin, région de Suisse la plus touchée par les incendies de forêt, a été choisi comme région test pour l'étude de cas.

L'histoire à long terme du feu signale sa présence dans les écosystèmes forestiers de cette région d'étude depuis la dernière période glaciaire. De la période néolithique à nos jours, l'homme a fortement modifié le régime naturel du feu.

Deux saisons différentes caractérisent aujourd'hui le régime du feu: les incendies hivernaux pendant la pause de la végétation, de décembre à avril, incendies exclusivement déclenchés par l'homme; les incendies estivaux pendant la période de végétation, de mai à novembre, incendies de forêt déclenchés par l'homme ainsi que par la foudre. Des mesures de prévention ponctuelles (p. ex. annonce d'interdiction absolue de faire du feu en présence d'un danger élevé d'incendie) et des dispositions légales (interdiction d'incinération en plein air de déchets de jardin) régulent la fréquence des incendies de forêt d'origine anthropique. Quant à la taille des incendies, et par voie de conséquence la surface globale sinistrée, elles dépendent essentiellement des structures de lutte contre l'incendie: organisation des sapeurs pompiers, activités de pré-extinction (préparation de points d'eau pour les hélicoptères) et intervention fréquente des moyens de lutte aérienne. Le régime actuel du feu se caractérise par une tendance à la hausse des incendies estivaux déclenchés par la foudre, tandis que ceux provoqués par l'homme, après avoir baissé au début des années 1990, se sont stabilisés depuis. La plupart des incendies sont de très petite taille (< 1 ha). Mais dans certaines conditions météorologiques extrêmes (sécheresse persistante, foehns secs du nord), nombre de feux peuvent se déclencher simultanément, rendant difficile l'intervention des sapeurs pompiers débordés. Dans de telles circonstances, des incendies de forêt isolés peuvent se propager à grande échelle. C'est pourquoi, à l'heure actuelle,

10 % des événements correspondent à 90 % environ de la surface incendiée totale.

Sur le plan écologique, la présence d'espèces adaptées au feu confirme qu'il est une composante naturelle des écosystèmes forestiers de la zone étudiée. Cependant, de vastes incendies de grande intensité représentent une menace sérieuse pour la fonction protectrice des forêts. Dans des forêts denses non entretenues et épargnées depuis des années par les perturbations (absence de sylviculture et d'incendie), où une grande quantité de biomasse morte s'est accumulée au niveau du sol, les incendies peuvent facilement gagner en intensité et modifier les propriétés hydrogéologiques du sol. Dans leur sillage, le ruissellement de surface et l'érosion au sol se voient largement accrus. De fortes précipitations peuvent alors provoquer une érosion en ravins, voire des laves torrentielles avec transport d'alluvions.

Dans ce contexte à dimension historique et écologique, la gestion des incendies ne doit pas chercher à tout prix à éviter tout incendie, mais à prévenir ceux de grande intensité et à large échelle. Pour atteindre ces objectifs, il convient d'allouer les ressources limitées de la façon la plus efficace et la plus ciblée possible, sur la base d'une analyse exhaustive des risques d'incendies de forêt. Dans le cadre de la gestion des incendies, l'identification des zones à risques constitue la meilleure condition pour planifier les mesures préventives, infrastructurelles, organisationnelles et stratégiques.

L'approche méthodologique de l'analyse du risque d'incendies de forêt a été organisée en trois volets. Dans un premier temps, nous calculons le danger d'incendie. Celui-ci se compose du danger de déclenchement (c'est-à-dire la probabilité qu'un feu se déclenche) et du danger de propagation (c'est-à-dire la probabilité qu'un feu se propage jusqu'à un point donné de la zone d'étude). À cet effet, nous avons réalisé des simulations Monte Carlo pour tester la sélectivité du feu vis-à-vis de paramètres d'influence tels que végétation forestière, altitude, pente, exposition et – uniquement pour la propagation du feu – morphologie du terrain. L'analyse de la sélectivité se déroule sur la base des points de départ de l'incendie pour le danger de déclenchement, et de la surface incendiée moyenne pour le danger de propagation. L'analyse porte sur la totalité des trois régimes homogènes d'incendies de forêt pour le canton du Tessin: incendies d'origine anthropique pendant la saison hivernale (décembre à avril), et pendant la saison estivale (mai à novembre) depuis 1990, incendies déclenchés par la foudre pendant la saison estivale depuis l'année 1980. Pour évaluer le danger de déclenchement d'incendies d'origine anthropique, nous avons aussi pris en compte l'interface habitat – forêt ainsi que quelques situations spécifiques de fréquences d'incendie supérieures à la moyenne liées aux conditions locales (voies ferrées à forte pente, places d'armes, etc.).

Dans un deuxième temps, nous évaluons la vulnérabilité de la zone étudiée vis-à-vis des incendies. Elle résulte de la combinaison des conséquences écologiques d'un incendie de forêt (résilience des écosystèmes forestiers) et des dégâts potentiels infligés aux ressources (ruissellement de surface, érosion, chute de pierres, laves torrentielles après un incendie et danger potentiel pour les infrastructures et les ressources naturelles).

Dans un troisième et dernier temps sont combinés le danger d'incendie et la vulnérabilité vis-à-vis des incendies pour définir le risque d'incendie, les calculs étant séparés pour les saisons hivernale et estivale. Pour la période hivernale, les cartes de risques d'incendie qui en résultent présentent un nombre très réduit de zones à risque très élevé, soit 1.0 %, 17.5 % de zones à risque élevé, et 45.8 % de zones à risque modéré, soit presque la moitié des zones étudiées. L'été, le risque est nettement inférieur: l'ensemble de la zone étudiée présente exclusivement des catégories à risque très faible (72.8 %), ou faible (26.7 %).

La vérification sur base statistique du danger d'incendie calculé, de même que l'évaluation des experts portant sur la vulnérabilité vis-à-vis des incendies et sur le risque d'incendie, ont confirmé la pertinence de la méthode présentée dans cette étude pour évaluer le risque relatif d'incendie de forêt dans une région de vulnérabilité faible à moyenne comme le canton du Tessin.

Les cartes de danger et de risque d'incendie définies dans cette étude peuvent favoriser l'application, de façon ciblée, des moyens limités de prévention et de lutte mis à notre disposition. Les autorités de gestion des incendies peuvent désormais se fonder sur ces cartes lors de la planification des installations de pré-extinction (comme les points d'eau pour les hélicoptères), de l'exécution de mesures sylvicoles pour réglementer la gestion du combustible, et lors de la simulation de scénarios d'incendies en vue de préparer en détail les stratégies de lutte.

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15 Glossar

English	Deutsch
aerial fire fighting	Brandbekämpfung aus der Luft (luftgestütze Brandbekämpfung)
anthropogenic fires	vom Menschen verursachte Feuer
area burnt	gebrannte Fläche
bylaws	Statuten
cantonal decree	kantonaler Beschluss
cattle	Vieh
cause of ignition	Brandursache
charcoal influx	Kohlen-Sedimentationsrate
charcoal particles	Kohlenpartikel
climate change	Klimaveränderung
combined window-yellow pan trap	Kombi-Falle
community	Gemeinde, Gesellschaft
coring sites	Bohrungsstelle
crown fires	Kronenfeuer
distribution pattern	Verbreitungsmuster
epigaeic zoophages	epigäische Prädatoren
fallow	Brachland
fighting techniques	Bekämpfungstechniken
fire adapted species	feuerangepasste Art
fire brigades	Feuerwehr
fire danger	Brandgefahr
fire detection	Brandentdeckung, Brandmeldung
fire duration	Branddauer
fire ecology	Feuerökologie
fire fighters	Feuerwehrleute
fire fighting	Feuerbekämpfung
fire fighting organization	Organisation für Feuerbekämpfung
fire frequency	Brandhäufigkeit
fire hazard	Brandgefahr
fire history	Feuergeschichte
fire management	Feuermanagement
fire paradox	Feuer-Paradox
fire pre-suppression	Feuer-Vorlöschaktionen
fire prevention	Feuerprävention
fire regime	Feuerregime
fire risk analysis	Analyse des Feuerrisikos
fire risk management	Managment des Feuerrisikos
fire seasonality	Jahresverteilung des Brandgeschehens
fire selectivity	Feuerselektivität
fire size	Brandgrösse
fire suppression	Feuer-Löschaktion, Feuerbekämpfung
fire weather conditions	Wetterbedingungen für Feuer

English	Deutsch
Fire Weather Index	Waldbrandwetterindex
fire-guard	Brandwache
fire-susceptibility	Feueranfälligkeit
flood event	Hochwasserereignis
flying zoophagous	fliegende Prädatoren
forest cover classes	Waldbedeckungsklassen
forest cover map	Waldkarte, Forstkarte
forest edge	Waldrand
forest fire	Waldbrand
forest fire database	Waldbranddatenbank
forest function	Waldfunktion
forest physiognomy	Waldphysiognomie
forest plantations	Aufforstung
forest recovery	Erholung des Waldes
fuel	Brandgut
fuel build-up	Anhäufung des Brandgutes
fuel moisture content	Brandgutfeuchtigkeit
germination	Keimung
grazing	Beweidung
helvetic crystalline basement	helvetisches Kristallin-Massiv
historical fire regimes	historische Feuerregime
historical range of variability	historischer Variabilitätsbereich
human-caused forest fires	durch Menschen verursachte Feuer
hydrant nets	Hydrantennetz
Initial Spread Index	Index der Anfangsausbreitung des Feuers
insubric basement	insubrische Grundgebirge
invading alien species	invasive Neobiota
invertebrates	Wirbellose
lake sediments	Seesedimente
land management	Landmanagement
life history	Lebensbiologie (Lebenszyklusgeschichte)
lightning-caused forest fires	durch Blitz verursachte Feuer
limestone	Kalkstein
litter utilisation	Streunutzung
local names	Ortsnamen, Flurnamen
medieval bylaws	mittelalterliche Statuten
natural fires	natürliche Brände
natural range of variability	natürlicher Variabilitätsbereich
necromass	tote Biomasse
nutrient loss	Nährstoffauswaschung
nutrients wash-out	Nährstoffauswaschung
overly exploited	ausgebeutet, übernutzt
penninic nappes	penninische Decken
pitfall traps	Fallgrube