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Characterisation of forest fires in Austria

Charakterisierung von Waldbränden in Österreich

Harald Vacik[a], Natalie Arndt[a]*, Alexander Arpaci[a], Valerie Koch[b], Mortimer Müller[a], Hartmut Gossow[c]

Keywords: database, fire frequency, Ecozones, Alpine region, Austria

Schlagworte: Datenbank, Feuerfrequenz, Ökozonen, Alpenregion, Österreich

Summary

There is an ongoing debate about the increasing number of weather extremes and the associated increased forest fire risk in the temperate mountain forests of Central Europe. In Austria there does not exist something like a real fire regime and therefore a consistent and detailed recording of forest

*Corresponding author (email: natalie.arndt@boku.ac.at)
a University of Natural Resources and Life Sciences, Vienna, Department of Forest- and Soil Sciences, Institute of Silviculture, Peter Jordan Str. 82, 1190 Wien, Tel: +43 (0) 1/47654/4081 Fax: +43 (0) 1/47654/4092
b University of Natural Resources and Life Sciences, Vienna, Department of Landscape, Spatial and Infrastructure Sciences, Institute of Surveying, Remote Sensing and Land Information
c University of Natural Resources and Life Sciences Vienna, Department of Integrative Biology and Biodiversity Research, Institute of Wildlife Biology and Game Management

fires has not taken place so far. A wildfire database has been established for Austria within the projects related to the Austrian Forest Fire Research Initiative (AFFRI) and the Alpine Forest Fire Warning System (ALP FFIRS) at the University of Natural Resources and Life Sciences which covers now 1502 records for the period between 1993 and 2009. A descriptive frequency analysis has been carried out in order to illustrate the characteristics of the recorded forest fires events in Austria. Results indicate that the recordings of forest fires and fire frequency varied throughout the years and across provinces. Anthropogenic and technical causes made up for the major part of forest fires in Austria lightning-caused forest fires have a share of 18% throughout the whole study period. Spring and summer happened to be the main fire seasons for forest fires in Austria. Most of the forest fires took place between 11 am and 7 pm in the evening. In terms of the duration of fires in days, it was found that fires lasting longer than one day accounted for only a small percentage of forest fires. As regards the size of fires, most of the forest fires reached less than 1 hectare, followed by fires with a size ranging between one and five hectares. Only a small number of municipalities experienced more than ten fires within the study period. In relation to the forest area the highest number of forest fires records has been observed within the Eastern and Southern Rim Alps as well as the Summerwarm East. A majority of fire records exists in the submontane and low montane altitudinal zone. Coniferous forests have been affected by forest fires to a great extent followed by mixed forests. Only a small portion of deciduous forests have been affected by forest fires. The major part of fire ignitions has taken place at south-facing exposures. North facing aspects made up for the second-largest group regarding fire ignitions. The reliability of the available forest fire data in the database proved to be heterogeneous but can be seen as satisfactory. Whereas the data regarding the time, coordinates, size of area burned and cause of fire proofed to be relatively reliable the security of information on the localisation of the ignition point and the tree species affected has been rather low. Therefore further investigations are needed to draw more general conclusions.

Zusammenfassung

Es gibt derzeit eine kontroverse Diskussion um die steigende Anzahl von auftretenden Wetterextremen und ein damit verbundenes erhöhtes Waldbrandrisiko in den gemäßigten Gebirgswäldern Mitteleuropas. In Österreich gibt es kein wirkliches Waldbrandregime, weshalb bis jetzt auch keine einheitliche und detaillierte Aufzeichnung von Waldbränden durchgeführt worden ist. Im Rahmen der Austrian Forest Fire Research Initiative (AFFRI) sowie des Interreg Projektes Alpine Forest Fire Warning System (ALP FFIRS), die derzeit an der Universität für Bodenkultur Wien durchgeführt werden, wurde deshalb eine Waldbranddatenbank erstellt, die den Zeitraum von 1993 bis 2009 abdeckt und 1660 Fälle umfasst. Darauf aufbauend wurde eine deskriptive Häufigkeitsanalyse zur Charakterisierung von Waldbränden in Österreich durchgeführt. Die Ergebnisse deuten an, dass sich die Aufzeichnung der Waldbrände sowie der Waldbrandhäufigkeit sowohl während der Jahre als auch über die Bundesländer hinweg stark unterscheidet. Menschliche Ursachen waren für einen Großteil der Waldbrände im Untersuchungszeitraum ausschlaggebend; 18% aller Brände waren natürlichen Ursprungs. Die Analyse hat ergeben, dass Frühjahr und Sommer die Hauptsaison für Waldbrände in Österreich waren; ein Großteil der Waldbrände wurde zwischen 11 Uhr vormittags und 19 Uhr abends registriert. Die Waldbranddauer belief sich meist nur auf einen Tag. Die Größe der von Waldbränden betroffenen Fläche lag beim Großteil der Fälle unter einem Hektar. Nur bei einem sehr geringen Prozentsatz war die geschädigte Fläche größer als fünf Hektar. Der Anteil an Gemeinden mit mehr als zehn registrierten Waldbränden ist im Untersuchungszeitraum gering. Die Mehrheit an aufgezeichneten Waldbränden wurde in den Östlichen und Südlichen Randalpen und im Sommerwarmen Osten registriert. Eine Mehrheit der Waldbrände tritt in der sub- und tiefmontanen Höhenzonen auf. Ein Großteil der registrierten Waldbrände ereignete sich in Nadelwäldern, gefolgt von Mischwäldern; in Laubwäldern ereignete sich nur eine kleine Anzahl von Waldbränden. Die Mehrzahl der registrierten Waldbrände wies südliche Expositionen auf gefolgt von nördlichen Expositionen. Die Genauigkeit der Daten kann als ausreichend angesehen werden um Fragen des räumlichen und zeitlichen Auftretens von Waldbränden zu untersuchen. Die Informationen bezüglich der Tageszeit, der geschädigten Fläche und Waldbrandursachen können als relativ verlässlich angesehen werden, während die Qualität der Genauigkeit zur Metainformationen der Verortung und betroffenen Baumart als gering einzustufen sind. Daher sind noch weitere Untersuchungen notwendig, um allgemeine Schlussfolgerungen für die Waldbrandgefahr in Österreich zu ziehen.

1. Introduction

The negative impacts of storm damages, bark beetle infestations and damage by game ungulates on forest ecosystems are often disastrous in Central Europe (Reimoser and Gossow, 1996; Kräuchi et al., 2000; Albrecht et al., 2009). Forest damages caused by natural hazards like avalanches, mudflows or rock fall are an important factor in mountainous areas (Lindner et al. 2010). Particularly in the temperate mountain forests of Central Europe forest fires have played only a minor role so far. Forest fires are a result of complex interactions between ecological factors such as weather, fuel type, forest structure and topography as well as socio-economic factors. Several international studies have identified various factors such as climate change (Flannigan et al., 2000; Reinhard et al., 2005), human factors (Vega-Garcia et al., 1995, Goldammer, 2002) or land use change due to socioeconomic factors (Badia et al., 2002) potentially influencing forest fire hazard. According to the climatic factors European mountain regions may experience somewhat higher increases in temperature compared to non-mountainous regions. In the Alps temperature increases twice the global average were observed over the last century (Auer et al., 2007). Austria is a Central European country largely dominated by the Alps with a forest cover primarily dominated by coniferous tree species. The forests do not fulfil the characteristics of fire prone ecosystems, nor have they seriously been fire-impacted so far. However, two summer seasons (2003 and 2007) have most recently proved quite well how widespread and rapidly forest fires may happen and that they might become an important issue in the case of the occurrence of certain weather extremes such as a prolonged periods of drought or heat waves (Gimmi et al., 2004; Gossow et al., 2008; 2009). On the other hand Wotton et al. (2004) point out a relation between climate change and people-caused forest fires and not only Badia et al. (2002) emphasize that not climate change plays the most significant role in forest fire probability but rather aspects related to socioeconomic parameters. Moreover Conedera et al. (1996), Conedera and Tinner (2000) and Goldammer (2002) point out that forest fires should not only be associated with an increase in drought periods but also with the human influence on forest structure and fuel availability. In this context it needs to be mentioned that in other international studies the aspect of the slope and the herewith associated forest types were found to play a significant role in the spatial distribution of forest fires (Beaty and Taylor, 2001; Gavin et al., 2003, Huyen and Tuan, 2008). This finding is of major relevance within the analysis of forest fire risk for Austria due to its mostly alpine characteristics, since the aspect plays a major role both in terms of fire ignition related to human activities as well as for fire spread.

Research on forest fire management in mountain areas has been initiated in Switzerland (Berli, 1996; Conedera et al., 1996; Gimmi et al., 2004; Weibel et al., 2009), France (Gatheron, 1950; Meyer, 2005; Genries et al., 2009), Italy (Tiller, 1988; Bovio, 1996; Kuntner, 2001) and Germany (Goldammer et al., 1997; Badeck et al., 2003; Thonicke and Cramer, 2006), but there were no research initiatives related to forest fires in Austria so far. The regional and local dominance of coniferous tree species such as Norway spruce (Picea abies), Scots pine (Pinus sylvestris) and black pine (Pinus nigra austriaca) makes many of the Austrian forests almost boreal-like (Schmidt-Vogt, 1985; 1987; Gossow, 1996) and insofar probably more susceptible to forest fires. Forest fires have not been considered as an important factor for the adaptive capacity and vulnerability of mountain ecosystems in Central Europe so far (Lindner et al., 2010). In that context it has to be considered that wildfire patterns are linked to human activities and land use (Conedera et al., 1996) including vegetation management (Prestemon et al., 2002). Especially the analysis of the additional impact of forest fires on natural disturbance regimes at highly vulnerable sites, like those with secondary coniferous forests, can help to understand these risks for future forest management in these areas (Birot, 2009). In the case of the occurrence of large wildfires in the Alpine Area sufficient prophylactic measures specifically against forest fires are in selected cases in place so far. Therefore it is necessary to identify and characterize forest fire „hot spots“ and understand the most important factors regarding fire occurrence and ignition in order to develop a proper early warning strategy for Austria.

This paper deals with the characterisation of forest fire records which have been sampled in Austria during the last years in terms of the causes, the seasonality, daytime of occurrence, their localisation, their size as well as forest types affected in the different altitudinal belts of the Ecozones including an assessment of the data reliability. The data and results presented in this study can serve as a basis for further development of a fire hazard model for mountain conditions taking into account the complex interactions between weather, vegetation, topography and socio-economic factors.

2. The wildfire database

In order to characterise recent forest fires in Austria a wildfire database has been established. On one hand information has been gathered through desk search activities by the use of public available information on the internet platforms „www.wax.at“ and „www.feuerwehr-news.at“ and by screening the compilation of reports on forest fires by fire brigades from various municipalities and provinces available online. This allowed to cover records of forest fires for the years 1993 to 2009 as the historical documentation by the different data providers was limited to that the period. Moreover the Austrian municipalities have been contacted directly via mail with the request to make available any existing information on forest fires within the boundaries of the municipalities. In addition the Federal Ministry of Agriculture and Forestry, Environment and Water Management (BMLFUW) has been contacted to provide information on forest fires, which have been reported by the municipalities for obtaining refund of damages for forest owners. In combining the fire records from different data sources it was tried to avoid a double recording of documented fires. In this context records from different sources having a similar location, date or time of occurrence have been checked for consistency in the database. Due to the additional means of collecting information on forest fires in Austria it has been possible to document 1502 fires in the database, out of which 1170 fires have been identified as forest fires for the period from 1993 to 2009. Figure 1 shows the number of forest fire records and the share of its data sources for the years 1993 to 2009. Although the recording of forest fires and fire frequency varies throughout the years and across provinces it seems reasonable that large fires (> 1ha) are mostly covered in our database as these events are quite rare in Austria and therefore very well documented. Small fires (<) 1 ha) and fire records with an unknown size of burnt area comprise a big share. However currently not all forest fires are covered by the database. According to the size of the burned area for each fire event the meta information available from the different data sources was documented ranging from 1m² up to 70 ha. For some fire events, no information on the size of the burnt area was documented in the historical sources. These events were classified as "unknown" and were not included in the analysis. Therefore the number of recorded forest fires in the database is likely linked to the different meteorological conditions throughout the years, variety of ignition causes, the varying interest for data recording by the most municipalities as well as the different amount of publicly available material in recent years (cf. Brown et al. 2002; Zumbrunnen et al., 2009). Due to the still ongoing process of scanning available data bases for historical forest fire records completeness of data cannot be assumed currently. Geographical patterns might therefore be the result of more or less complete reporting. Taking these general limitations into account the number of forest fires in the years 2003 and 2007 stand out notably with a higher number (Figure 1).

An old record of wildfire statistics covering the years 1953 to 1991 provided by the Federal Ministry of Agriculture and Forestry, Environment and Water Management (BMLFUW) was not included in the current fire database as the location of the forest fire events was not documented. Therefore it was not possible to use this old data record for further analysis, beside a comparison of seasonal trends in the current manuscript.

In order to be able to collect data related to forest and wildfires in the future an online reporting form has been established where municipalities and fire brigades can directly enter data on wildfires (http://www.wabo.boku.ac.at/affri.html).

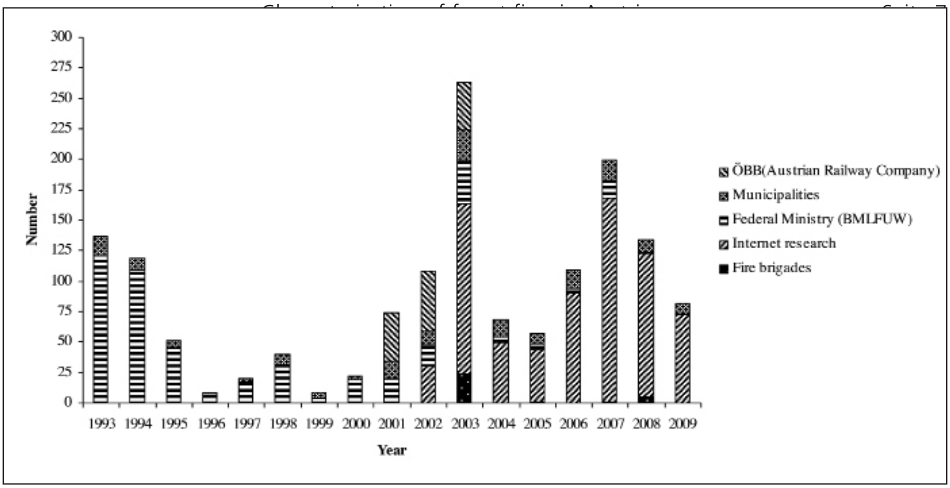

Figure 1: Data Sources of the Austrian forest fire database for the period 1993 to 2009 in Austria.

Abbildung 1: Datenquellen der österreichischen Waldbranddatenbank für den Zeitraum von 1993 bis 2009 in Österreich.

For most of the fire records no exact information was available on the localisation of each event. Comments referring to the place name, parts of addresses as well as hints on the owner allowed us to locate each fire within a certain buffer area. The more accurate the information was the smaller the buffer area for the location was, ranging from 50m up to a 5000 meter radius. Additionally the processed information for each fire event was qualitatively assessed according to its reliability of the start time, the reliability of the causes of ignition as well as the affected tree species. An overall assessment of the uncertainty related to each fire record allowed the classification of the individual events. Table 1 shows the data content included in the forest fire database.

Table 1: Parameters of the Austrian forest fire database.

Tabelle 1: Parameter der österreichischen Waldbranddatenbank.

Field	Content
Fire ID	Consecutive Numbering
Start date	Date of ignition
Year	Year of study period (1993 to 2009)
Month	Month of year of fire start
Day	Day of year of fire start
Time of outbreak	Time of day of ignition
Time of notification	Time of day of notification of fire
UTC_hour	Hour of outbreak UTC time
UTC_minutes	Minute of outbreak UTC time
Duration	Duration of fire in days
Data reliability	Quality assessment of reliability of start time in three categories
Postal code	Postal code of the municipality where fire was recorded
Province	Name of Province
Municipality	Name of Municipality
Latitude	Latitude as of WGS 84, dezimal and Lambert
Longitude	Longitude as of WGS 84, dezimal and Lambert
Date reliability location	Quality assessment of reliability of location in three categories
Size of area damaged	Size of area damaged (m^2)
Cause of fire	Artificial, natural or unknown
Detailed causes of fire	Lightning, Self-ignition, Arson, Railway, Campfire, Traditional fire, Controlled fire out of control, Other causes, Unknown
Elevation	Elevation of fire, if known
Tree species	Tree species
Vegetation/forest type	Vegetation/forest type affected
Data reliability tree species	Codes 1, 2 and 3 for three levels of reliability
Eco - Zone	Eco - Zone 1 to 9
Eco - Region	Eco - Region 1.1 - 9.2
Number of fire brigades	Number of fire brigades involved in fire extinction
Number of fire fighters	Number of fire fighters involved in fire extinction
Remarks	Additional information
Origin	Ministry of forests, Municipalities, fire brigades, internet portals of fire brigades
Contacts	Contact details of data suppliers
Data reliability total	Codes 1, 2 and 3 for three levels of reliability

As secondary data maps from the ecozones in Austria (Killian et al. 1993), a digital elevation model and an estimate of the most likely species composition based on the data from the Austrian Forest Inventory (AFI) have been used (cf. Gabler and Schadauer 2002; Bauerhansl et al., 2007). The forest fire database has been linked with the secondary spatial data in order to explore the potential characteristics of the forest fire records for the study period 1993 and 2009. Figure 2 shows the spatial distribution of all recorded fires over the Ecozones in Austria.

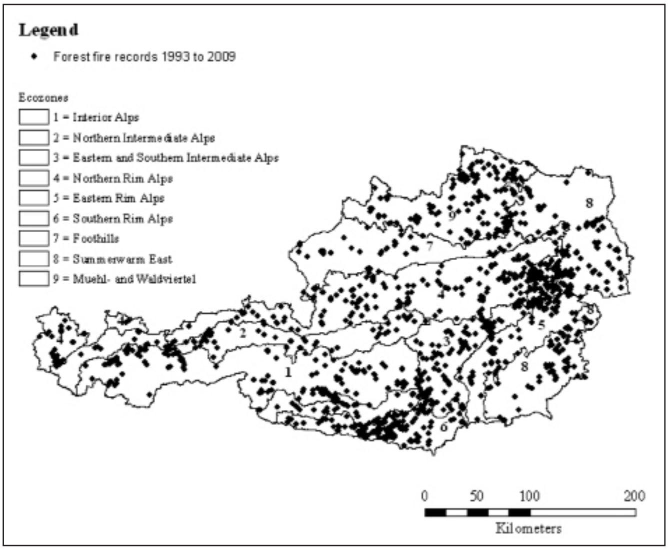

Figure 2: Spatial distribution of fire records over all ecoregions in Austria from 1993 to 2009.

Abbildung 2: Räumliche Verteilung der von 1993 bis 2009 aufgezeichneten Brände über die Wuchsgebiete in Österreich.

3. Characterisation of forest fires

During the period analysed human causes make up for the major part of forest fires in Austria (Figure 3). Out of the 1170 forest fires recorded 40.51 % have been identified as being human caused. The major causes of human caused forest fires range from controlled burning spread out of control, over sparks from braking trains or other railway related activities such as repair work along the tracks, to arson and cigarettes. For 41.11 % of the recorded forest fires the reason for ignition is unknown due to a shortage in documentation (Figure 3).

Besides human caused forest fires 18 % of forest fires were classified as „natural fires“, ignited primarily by lightning strikes. Austria as a predominantly alpine country experiences a high number of thunderstorms with locally very high densities of lightning strikes, which for instance have ignited nearly a quarter of all recorded forest fires in Carinthia within the study period. For Austrian conditions a maximum of lightning caused forest fires (30 %) in the course of the recent years have been observed in 2006 (Müller, 2010).

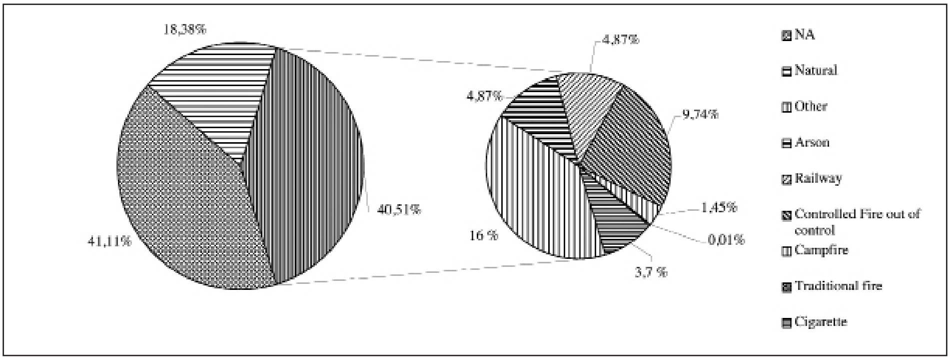

Figure 3: Fire Causes (%) for the period 1993 to 2009 in Austria.

Abbildung 3: Waldbrandursachen (%) für den Zeitraum von 1993 bis 2009 in Österreich.

The number of forest fires in the nine provinces is independent from the amount of forests present in the provinces (Figure 4). The highest number of forest fires per hectare of forest has been recorded for Lower Austria. Styria has the highest forest area compared to the other provinces, but a relatively low number of fires per forest hectare. Salzburg, Upper Austria and Tyrol have a relatively low number of forest fires weighed against the forest area. Vorarlberg and Burgenland - which hold the smallest amount of forest area of all Austrian provinces - are affected quite significantly with a quite large number of fires per forest hectare. The highest number of lightning-caused fires was found in Lower Austria followed by Carinthia and Tyrol, whereas Styria as the province with the highest forest area holds a relatively low number of lightning-caused forest fires (Figure 4).

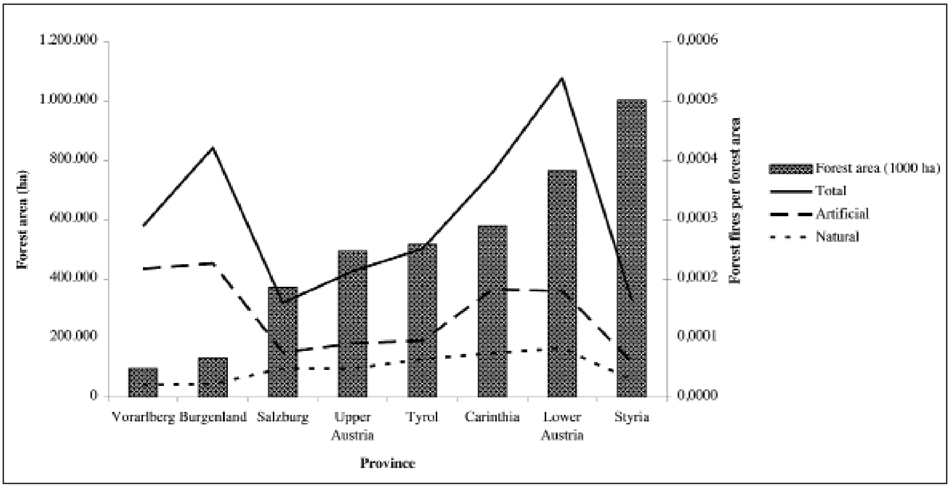

Figure 4: Number of forest fires (anthropogenic, lightning and total) related to forest area for selected provinces of Austria for the period 1993 to 2009.

Abildung 4: Anzahl der Waldbrände (anthropogene, natürliche Ursachen, gesamt) pro Bundesland bezogen auf die Waldfläche (ha) für den Zeitraum von 1993 bis 2009 in Österreich.

Forest fires have been recorded for 619 out of 2357 Austrian municipalities (lowest administration unit in Austria). The major part of municipalities has experienced two to five forest fires per year. A large amount of municipalities has experienced only one forest fire per year and six to ten forest fires respectively over the study period. The years 1993, 2003 and 2007 stand out notably. The share of municipalities experiencing up to five forest fires per year make up for the major part of the recorded forest fires. Even though only a rather low number of municipalities have experienced more than ten forest fires per year the mean share of municipalities experiencing a high number of forest fires (> six per year) lies around 19,6 % in the study period. Figure 5 shows the distribution of the classified number of forest fires per municipality in percent.

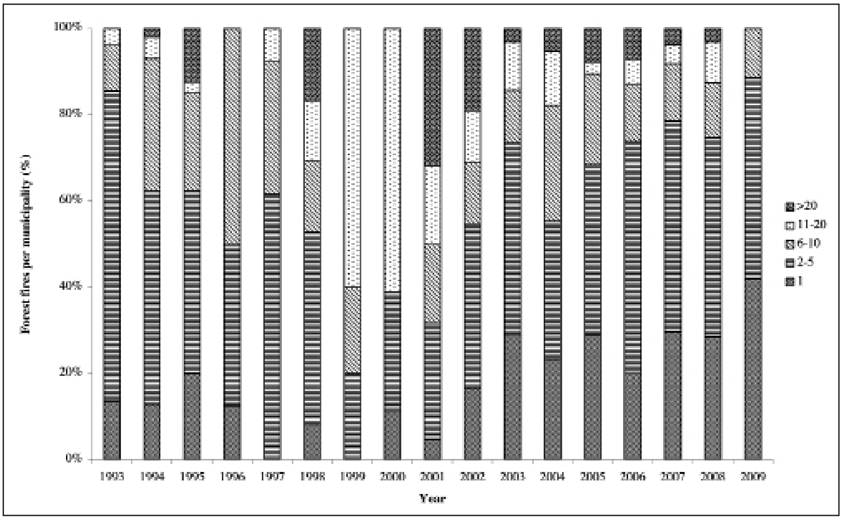

Figure 5: Number of forest fires per municipality (%) for the period 1993 to 2009 in Austria.

Abbildung 5: Anzahl der Waldbrände pro Gemeinde (%) für den Zeitraum von 1993 bis 2009 in Österreich.

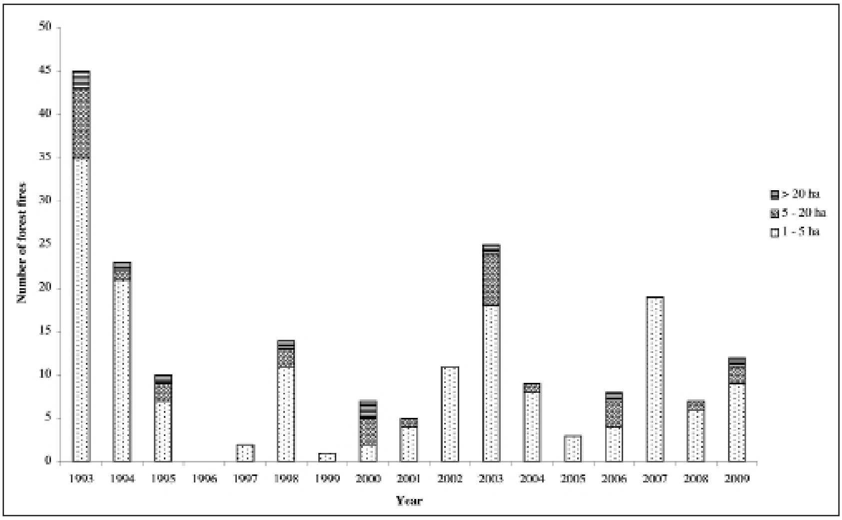

Figure 6: Number of forest fires (> 1 ha) according to the size classes of area burnt (ha) per year for the period 1993 to 2009 in Austria.

Abbildung 6: Anzahl der Waldbrände (> 1ha) in Abhängigkeit von Größenklassen der verbrannten Waldfläche (in Hektar) pro Jahr für den Zeitraum 1993 bis 2009 in Österreich.

As regards the size of area burnt the major part of the forest fires range up to a size of only one hectare. Fire records where the area burned is know and above one hectare cover only a small share of the total number of the recorded forest fires (N=198). The number of recorded large fires (> 20ha) appears to be very low over the whole study period. The share of records where the size of area burnt is not documented is consistently high over the study period. Figure 6 shows the number of forest fires (> 1 ha) according to the size classes of area burnt (ha) over the study period. The years 1993, 1994, 2003 and 2007 show the biggest number of fire records with a size of > 1 ha, which is comparable to the general pattern of the total number of forest fire records in our database (cf. Figure 1).

In terms of the duration of fires (reported in number of days) it was found that 81% of forest fires have been extinguished within one day. Forest fires lasting between two and twenty days only make up an extremely small amount (6 %). As to the season a large number of forest fires have occurred in spring and summer. On average almost 40 % of forest fires have occurred in spring time, 48 % during summer and only a small number of forest fires has taken place during fall and winter. Figure 7 shows the distribution of forest fire by season for the study period 1993 to 2009.

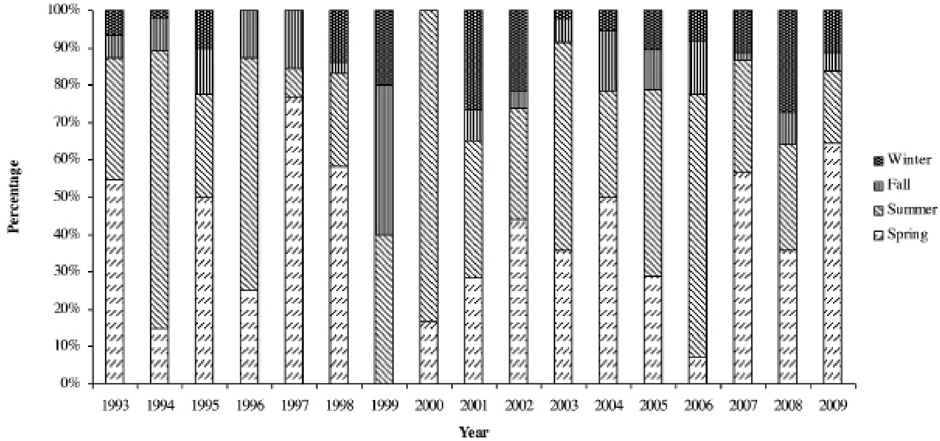

Figure 7: Distribution of forest fires (number of fires in %) by season in Austria for the period 1993 to 2009.

Abbildung 7: Waldbrandverteilung (Anzahl der Waldbrände in %) über die Jahreszeiten für den Zeitraum 1993 bis 2009 in Österreich.

Comparing the fire records of the current database with wildfire statistics covering the years 1957 to 1991 provided from the Federal Ministry of Agriculture and Forestry, Environment and Water Management (BMLFUW) it seems that the number of spring and summer fires is comparatively higher than the amount of winter and autumn fires (Figure 8). Besides that a general decreasing trend of recorded forest fires over the last century can be observed which should be not overestimated as it seems possible that here again the different intensities in forest fire recording are more responsible than any „real" forest fire trend.

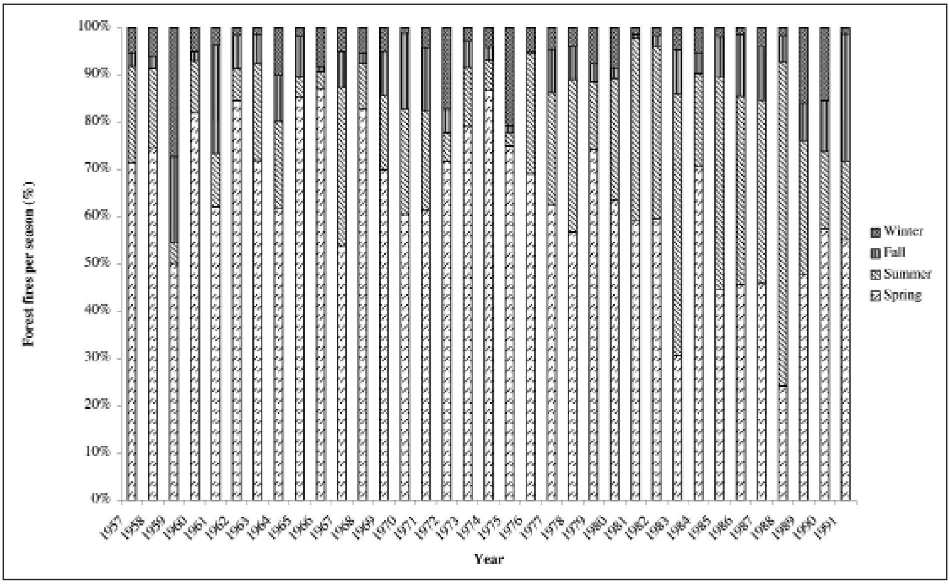

Figure 8: Distribution of forest fires (number of fires in %) by season in Austria for the period 1957 to 1991 (Source: Federal Ministry of Agriculture and Forestry, Environment and Water Management).

Abbildung 8: Waldbrandverteilung (Anzahl der Waldbrände in %) über die Jahreszeiten für den Zeitraum 1957 bis 1991 in Österreich (Quelle: Bundesministerium für Land- und Forstwirtschaft Umwelt und Wasserwirtschaft).

The majority of forest fires have been observed during the day with a main peak between 1 and 4 pm. In spring and summer the average reported starting times are more concentrated towards the early afternoon with an observed small increase in fire ignitions between 5 and 6 pm. Figure 9 shows the daily course of the start time of forest fires during the seasons. The daily course of the reported start time of forest fires is lower in fall and winter due to low temperatures, an increase in precipitation, higher humidity and snow cover. In spring and summer the daily course of reported starting time of forest fires is higher than in fall and winter. This supports findings that the number of forest fires is higher during spring and summer times.

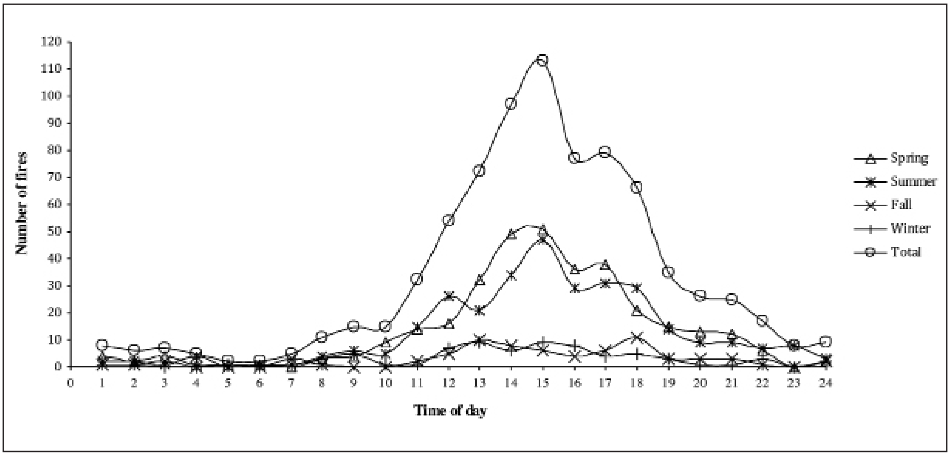

Figure 9: Start time of forest fires in Austria for the period 1993 to 2009 in relation to seasons.

Abbildung 9: Startzeitpunkt der Waldbrände in Österreich für den Zeitraum 1993 bis 2009 nach Jahreszeiten.

Regarding the ecological characterisation of forest communities affected by fires it was observed that the Ecozones and altitudinal zones in Austria have been affected quite differently over the whole study period. As it is important to relate the recorded total number of fires to the forest area table 2 indicates the number of fires per km² (100ha) forest area according to each altitudinal belt and Ecozone. In general an average density of 0.03 forest fire records per forest area is documented in our database so far. As the number of forest fire records is different for each altitudinal zone and Ecozone it becomes evident that the relatively highest number of forest fire records is changing with the amount of forest area in each zone. Within the Ecozones of the Eastern (0.049) and Southern Rim Alps (0.051), and the Summerwarm East (0.046) the highest number of forest fire records can be found in relation to the forest area. In the submontane zone (0.048) and low montane zone (0.044) the highest densities of occurrence have been observed so far. There were no records observed in the alpine zone.

Table 2: Number of forest fires per km² (100ha) forest area according to altitudinal zones and Ecozones for the period 1993 to 2009.

Tabelle 2: Anzahl der Waldbrände per km² (100ha) Waldfläche in den Höhenstufen und Wuchsgebieten für den Zeitraum 1993 bis 2010.

	colline		submontane		low montane		mid. montane	
	N°	N°/km²	N°	N°/km²	N°	N°/km²	N°	N°/km²
1. Interior Alps	0	0	8	0.088	15	0.037	39	0.031
2. Northern Intermediate Alps	0	0	9	0.021	19	0.020	19	0.020
3. Eastern / Southern Inter-mediate Alps	1	0	13	0.054	45	0.040	43	0.027
4. Northern Rim Alps	0	0	21	0.017	42	0.020	86	0.021
5. Eastern Rim Alps	2	0.016	83	0.052	68	0.070	20	0.023
6. Southern Rim Alps	0	0	52	0.066	20	0.035	11	0.029
7. Foothills	2	0.014	19	0.018	2	0.007	0	0
8. Summer warm East	58	0.039	36	0.022	0	0	0	0
9. Muehl- and Waldviertel	2	0.050	49	0.050	71	0.036	9	0.011
N° All records N°/km²	**65**	**0.039**	**290**	**0.048**	**282**	**0.044**	**227**	**0.023**

	high montane		low subalpine		high subalpine		NA		all records	
	N°	N°/km²	N°	N°/km²	N°	N°/km²	N°	N°/km²	N°	N°/km²
1. Interior Alps	32	0.020	14	0.011	2	0.004	11	0.002	121	0.023
2. Northern Intermediate Alps	14	0.020	4	0.016	0	0	6	0.002	71	0.019
3. Eastern / Southern Inter-mediate Alps	19	0.015	4	0.005	0	0	12	0.002	137	0.026
4. Northern Rim Alps	14	0.010	5	0.008	3	0.008	19	0.002	190	0.019
5. Eastern Rim Alps	4	0.008	0	0	0	0	27	0.006	204	0.049
6. Southern Rim Alps	16	0.041	0	0	0	0	21	0.009	120	0.051
7. Foothills	0	0	0	0	0	0	13	0.009	36	0.025
8. Summer warm East	0	0	0	0	0	0	48	0.015	142	0.046
9. Muehl- and Waldviertel	0	0	0	0	0	0	18	0.005	149	0.038
N° All records N°/km²	**99**	**0.016**	**27**	**0.007**	**5**	**0.004**	**175**		**1170**	**0.030**

Forest fires have been recorded in coniferous, deciduous and mixed forests from the colline zone up to the high subalpine zones. Figure 10 shows the share of larger forest fires (> 1ha) in coniferous forests across all altitudinal zones. The major part of forest fire records in mainly coniferous dominated forests were observed in the sub-, low and middle montane altitudinal zo-nes. The number of forest fires in the high montane and low subalpine zone is relatively low, only in some years (1993, 2002, 2003, 2006) larger fires (> 1 ha) have been observed in coniferous forests of the low subalpine zone. Additionally there were several years where no fires (> 1ha) were observed in the colline zone which is the natural range of deciduous forests. As regards deciduous forests it was found that fire records have been observed mainly in the submontane zone followed by the middle montane zone within the study period.

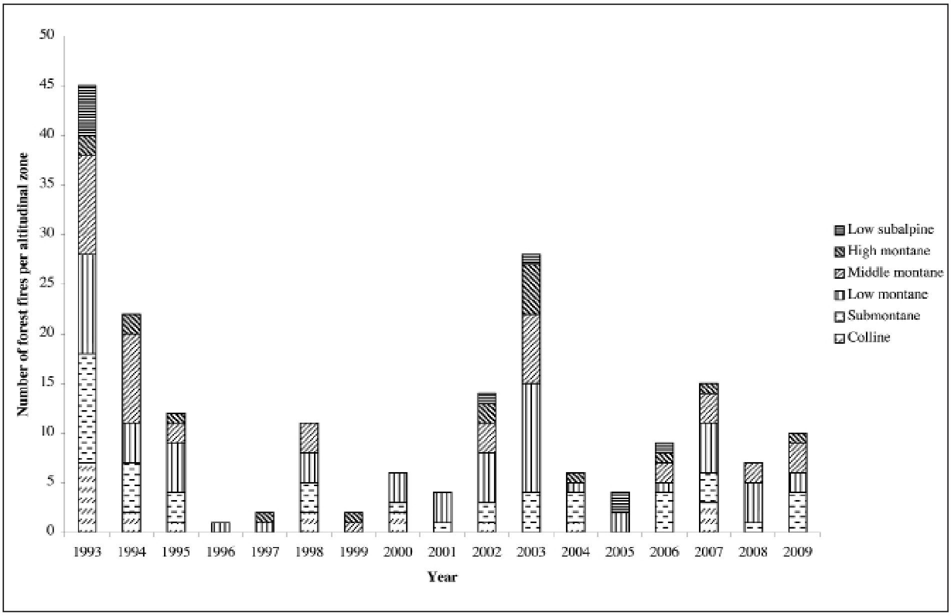

Figure 10: Number of forest fires (> 1 ha) in coniferous forests per altitudinal zone (in %) for the period 1993 to 2009 in Austria.

Abbildung 10: Anzahl der Waldbrände (>1 ha) in Nadelwäldern verteilt über die Höhenstufen (in %) für den Zeitraum von 1993 bis 2009 in Österreich.

With reference to the aspect of the forest fires reported the major part of forest fire ignitions (44%) were taking place at south-facing exposures. The second largest group of forest fire ignition was found at north-facing aspects (35%). However the major part of forest fire ignitions with a north-facing exposure was found to have a North-East aspect (14%). Forest fire ignitions on eastern (12%) and western (9%) slopes only made up for a relatively small amount. Figure 11 shows the distribution of the reported forest fires according to the aspect.

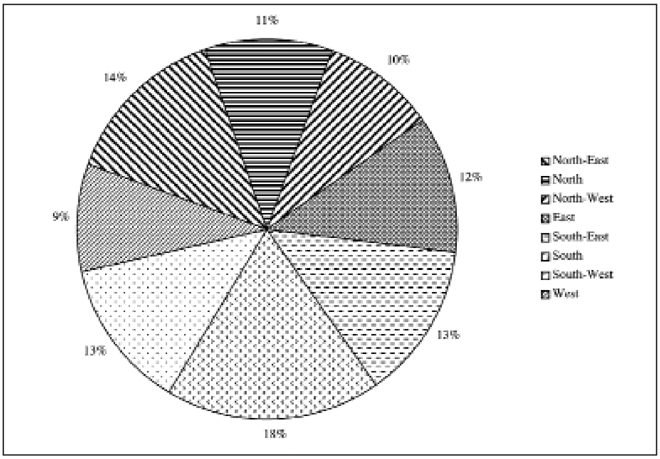

Figure 11: Distribution of forest fire ignitions according to aspect for the period 1993 to 2009.

Abbildung 11: Verteilung der Waldbrände nach der Exposition für den Zeitraum 1993 bis 2009.

Each fire event was qualitatively assessed according to its reliability. As a result it was possible to derive an overall assessment of the uncertainty related to each fire record. Data reliability was divided into three classes with 1 indicating the highest data reliability and 3 indicating the lowest data reliability and measured for the categories time, location, and size of area burned, source of ignition, tree species affected and total data security. The reliability of the underlying data proves to be quite heterogeneous. Information regarding the time and location of the fire, size of area burned and causes of ignition proved to be relatively reliable. The highest insecurity is to be found in the information regarding tree species damaged by forest fire. The overall assessment indicates that most of the cases have a high reliability (category 1) and only a small number of fire records have a low level (category 3) of data security. Figure 12 shows the reliability of forest fire data for the different categories. Due to the fact that data reliability is not available for the forest fire records with unknown causes reliability can be evaluated for the known cases only.

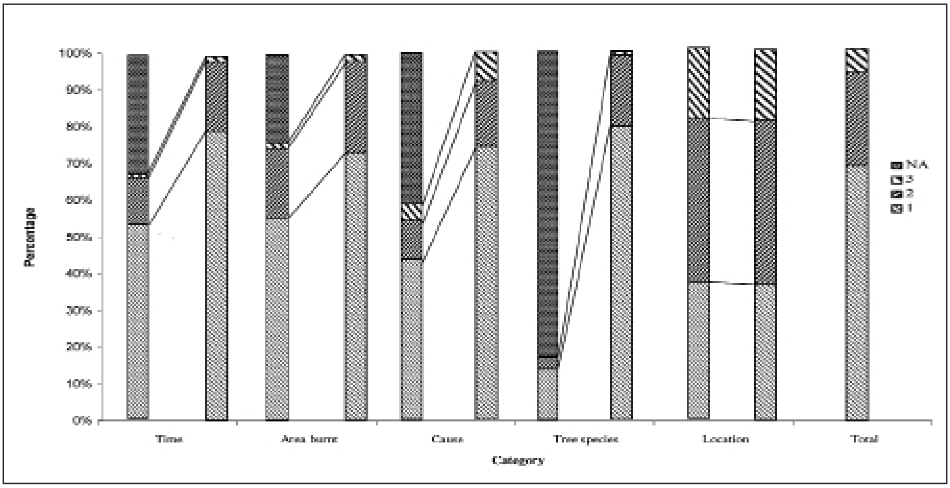

Figure 12: Data reliability (%) of forest fires for the period 1993 to 2009 in Austria.

Abbildung 12: Datensicherheit (%) der Waldbranddaten für den Zeitraum von 1993 bis 2009 in Österreich.

Regarding the localisation of the fire events it was observed that the ignition point for the majority of the forest fires was located in forested areas (89 %). However, there is a small share of fires where the ignition point has been located in other vegetation types and the forests in close distance have been affected as a consequence of the assumed fire spreading behaviour. These fires have been classified according to the related neighbouring vegetation type as forest/railway embankment (4 %), forest/farmland (5 %) and forest/meadow (2 %).

4. Discussion

The data reliability of the forest fire data reported throughout the study period is relatively satisfactory although some factors proved to have a quite low data security. It needs to be stated that the distribution of forest fires throughout the years needs to be looked at carefully since the number of forest fires recorded varies throughout the years. Years, as for instance 1996 and 1999, where only a very low number of forest fires have been recorded, should be seen critical and the results should not be overestimated. As the data sources for the development of the forest fire database are quite heterogeneous with a wide range in data quality and quantity it can be hypothesized that the total number of forest fires might change in relation to the invested time for studying the archives. Especially the increased number of online platforms and the archive material provided could influence the number of forest fire records. In this context it can be observed that many fire brigades are starting to document their fire management activities in a more systematic way and update their records, which are also made available online. This will allow a more complete and systematic data recording in the future.

Nevertheless we are quite confident that within our research all fires which reached a minimum size of one hectare are included in our database as these forest fires are quite seldom in Austria. However, there are plenty of cases where either no information on the size of the burned area or a very small size (<10m²) is documented. These cases should be used carefully when characterizing the general Austrian forest fire situation (cf. Brown et al 2002). Therefore we had a closer look at the larger fires (> 1ha) in particular (cf. Fig. 6 and Fig. 10) in order to correspond to this limitation. On the other side, 175 forest fires could not be placed within the current forest boundaries due to their inaccurate location. Therefore it was not possible to assign them to specific altitudinal zones and include them in further analysis. This weakness should be improved by a standardized protocol for the documentation of forest fires. The comparison of fire characteristics coming from different fire size classes or different reporting sources is an ongoing process which will allow improved analysis in the future.

The reason for the lack of information and the data insecurity is caused by the fact that a major part of the reporting institutions either do not have a detailed knowledge in forestry to be able to report details on tree species affected or assess the size of area burned adequately. Insecurity is related to the cause of fire as well. In a high number of cases the detailed cause of fire is unknown and not specified, respectively.

According to a detailed analysis of temporal trends, it needs to be considered that the documentation of forest fire records provided by the Federal Ministry of Agriculture and Forestry, Environment and Water Management (BMLFUW) for the time between 1957 and 1993 is showing some shortcomings and has therefore not been included in this analysis. As a matter of fact it is not possible to compare the data of the wildland fire statistics of the BMLFUW with the forest fire records presented in this paper directly due to the low level of data quality and weak spatial localisation of the old records. These old records from former forest fire statistics are only available on the level of the provinces and for the months concerned, but additional details were scarce. Especially as the records were related to reimbursements of forest fire damages, it can be expected that further research and investigations are needed to improve our fire database in that respect and include a longer time series for future analysis. Nevertheless one may look to the preliminary analysis of this data sample in previous years by Gossow et al. (2008, 2009).

In the so far documented fire records human causes account for a major part of forest fire ignition across Austria. Together with the high population density, the highly developed infrastructure and the eminent significance of tourism human activities play a significant role for forest fire ignition throughout the country. Even though Austria has not been very susceptible to forest fires so far, international studies show that the significance of human activities for forest fire risk is most likely to increase in the future (Barbero et al., 1990; Vega-Garcia et al., 1995; Goldammer 2002). Other studies propose socioeconomic factors such as infrastructure, population density (Brosofske et al., 2007), agricultural activities (Chuvieco et al., 2009) and tourism (Mercer and Prestemon, 2005) in addition to the ecological and climate variables that are typically used in wildfire risk analysis (Veblen et al., 2000; Cardille et al., 2001; Donnegan et al., 2001). Caldararo (2002) and Goldammer (2002) suggest that the human influence on the landscape, forests and ecology - especially activities linked to the transfer of the rural population to the cities and the herewith connected land abandonment - is linked to an altered fire regime. Gimmi et al. (2010) propose to disentangle effects related to climate change and human activities on forest ecosystems and superimpose the human impact over the effects of climate change. As for a large proportion of our fire records the cause of ignition is unknown it is difficult to estimate the total share of natural and human caused forest fires. However, based on the findings of Müller (2010) it can be assumed that the majority of the unknown ignition causes may possibly related to human activities. At this stage of the Austrian Forest Fire Research Initiative it is not possible to relate these findings from international studies to the Austrian forest fire database. However, further analysis of the most likely human factors influencing fire ignition will allow developing a fire hazard model for Austria (cf. Arndt et al., 2009).

Spring and summer fires make up for a major part of forest fires in Austria. The main reason for spring fires is generally associated with the accumulation of dry fuels during winter and the increase in temperature during springtime as well as the local occurrence of weather phenomena like warm and stormy „Foehn“ winds typical for alpine regions (Reinhard et al., 2005). Findings from around the world imply an increase in the number of spring fires in the future (Westerling et al., 2006; Telesca and Pereira, 2010). A high number of summer fires is mainly caused by high temperatures, periods low in precipitation and a decrease in air humidity causing fuels to dry out (Trigo et al., 2006; Telesca and Pereira, 2010). In the years 2003 and 2007 a high number of forest fires can be observed, which is comparable to the years 1962, 1976 and 1981 in previous decades (cf. Fig. 8). In 2003 there was - besides two quite typical peaks of fire events in spring (second half of March) and primarily in summer (August) - a third one detectable in the second half of June. This could possibly correspond with the period of summer solstice and ritual fires related to church holidays, which are usually ignited high up in the mountains (Gossow et al., 2008; 2009). In 2007, with the second highest number of recorded forest fires during our study period, again spring fires were dominating. In 2006, forest fire ignitions were mainly found during the summer period. Most of them ignited in a comparatively short fire weather window in July, with a high amount of lightning-caused fires (Müller, 2010).

In spring and summer the number of forest fires reported around the early afternoon is higher than for fall and winter fires, which might be linked with an increase in global radiation and temperatures together with a general decrease of air humidity in spring and summer (Mitscherlich 1981; Talkner et al., 1990; Haeckl, 1993). The daily course of the start time of forest fires resembles the daily course of global radiation, daily temperature and air humidity to a great extent. The increase of global radiation and temperature up to a first maximum in the early afternoon (Kasten, 1977; Talkner et al., 1990) and a smaller peak in the early evening goes together with a decrease in air humidity during the day, which reaches its minimum during the early afternoon (Kessler, 1973; Ross, 1975; Westerling et al., 2006). Preliminary results of a study for the period from 2002 to 2008 indicate that this second small increase probably corresponds to lightning-caused forest fires which show a prominent peak around the late afternoon (Müller, 2010). As a result the early to late afternoon appears to be the most susceptible for fire ignitions.

A major part of forest fires in Austria does not last more than one day neither does it exceed more than five hectares. With reference to the small size of forest area burnt and duration of forest fires in Austria it is assumed that the quick initial attack of fire brigades can explain that finding. The quick extinction is probably made possible due to a higher settlement density and an assumed quick notification of fire brigades in the case of fire. As the legal competence for fire fighting is linked to the individual municipalities, the high number of voluntary fire fighters (> 340.000) and fire brigades (> 4500) in Austria supports the quick response rate additionally. Also the high density of forest roads in Austria with an average of 35 m/ha (Gabler and Schadauer, 2002), which are suited for heavy fire fighting equipment makes the quick arrival of fire fighters at the fire sites understandable. Even tough the number of municipalities with more than ten reported forest fires per year is still rather small, this development needs to be watched closely in the future, since other international studies have identified several possible drivers influencing fire frequency, size, duration and spatial pattern. Caldararo (2002) and Goldammer (2002) even suggest that the change of landscape, forests and ecology related to human activities may be linked to an altered fire regime.

It is evident that the major part of forest fires recorded in our database is concentrated in a zone comprising the Eastern and Southern Rim Alps and the Summerwarm East. That corresponds quite well to meteorological modelling results from Austria as well as other countries located in the European Alpine region (Lindner et al 2010; Kocmankova et al. 2010). The northern and interior Ecozones are by far less affected by a high number of forest fires. The climatic conditions of the eastern and southern part of Austria are characterised by a more continental and pannonic climate with cold winters and hot and dry summers, whereas the western parts are mainly influenced by an oceanic climate with mild winters, warm summers and high precipitation (Ellenberg, 2010). At regional level the altitudinal zones are superimposing the occurrence of forest fires in the Ecozones. Findings from other studies indicate that altitude plays a significant role for forest fire hazard and fire severity (González and Pukkala, 2007; Bekker and Taylor, 2010). Findings from other parts of the world have shown that a connection between steep and inaccessible terrain and a high forest cover exists for forest fires as well (Southworth and Tucker. 2001). This is partly illustrated quite well by larger forest fires on storm blow-downs on steep terrain in connection with salvage logging operations (Gossow and Frank 2003). The extremely small number of forest fires recorded for the low and high subalpine regions observed in our study could be linked to a relatively low human activity in these altitudinal zones (Grabherr, 1964; Weibel et al., 2009). This may account for the high subalpine zone as well insofar as this ecozone has been remarkably reduced in the past due to anthropo-zoogenic impacts such as the use of open areas for pasturing purposes (Nikolussi and Patzelt, 2008; Pecher et al., 2011). Consequently an effective fire hazard model needs to be established in order to predict the forest fire hazard and related damages in the Austrian mountain forests (cf. Valese et al. 2010).

Forest fires proved to affect conifer forests in Austria to a great extent during the study period. Although fire behaviour and fire intensity is different between Norway Spruce (Picea abies) and Scots Pine (Pinus sylvestris) forests it can be assumed that forest fires may well pose a considerable threat to Austrian conifer forests as they do in other parts of the world (Bergeron et al., 2004; Aleksic et al., 2009; Moser et al., 2010). Since the Austrian forest cover consists of 67% of coniferous forests (Hauk, 2005) forest fires in general pose a risk to the Austrian forests as well as for the economy and to human well-being.

Natural causes - especially those related to lightning - were found to be of relatively low relevance (18%) as a cause for forest fire ignition for the period 1993 to 2009. Müller (2010) however analyzed a selected data set of forest fires in Austria from 2002 to 2008 and identified an amount of 17% of forest fires with natural causes. Since the 1980´ies a remarkable increase in weather extremes has occurred, including not only floods and winters with extreme snowfall and crown breakages, but also storm blow-down events, bark beetle outbreaks and thunderstorms (Lindner et al. 2010; Lorz et al., 2010). These events represent natural causes for increased fuel amounts, which are relevant in fire ignition and especially spread. In extreme fire weather summers, as in 2003 and 2006, summer fires are dominating, and also the amount of lightning-ignited forest fires became remarkably high, especially in Carinthia (Gossow et al. 2008). However contrary to Müller (2010), who identified Carinthia as holding the highest number of lightning-caused fires followed by Tyrol and Lower Austria our findings reveal that Lower Austria holds the highest number of lightning-caused forest fires followed by Carinthia and Tyrol. According to a different number of forest fire records analysed in both studies these findings need to be further investigated. Conedera et al. (2006) addressed lightning-induced fires as an increasing problem in the Alpine Region as well. In the Central Alps and especially on the southern slope of the Alps lightning fires are common in summer time, have increased in frequency and resulted in increasing costs for their control. For their Swiss and Italian study areas Conedera et al. (2006) found that lightning fires occur at higher elevations on steeper slopes and are usually harder to extinguish because of the limited accessibility in the difficult mountainous terrain.

The predominantly south facing aspect of forest fire ignitions in Austria agree with findings from other international studies, where a significantly higher number of forest fires was recorded on south-facing than on north-facing slopes (cf. Gavin et al., 2003, Huyen and Tuan, 2008). Beaty and Taylor (2001) even suggest shorter fire return intervals and rotations for south facing slopes than for north-facing slopes. The number of forest fires on western slopes was found to be only of medium size. Findings from Taylor and Skinner (1998, 2003) support this finding. In this context we assume that the aspect supports the existence of certain forest types, which are adapted to the prevailing conditions on the site. Gavin et al. (2003) and Beaty and Taylor (2001) indicate that the occurrence of forest types were closely linked to the aspect of a site. It needs to be investigated further which role a combined significance of aspect and forest type could play for forest fire risk in Austria.

With the current forest fire database of the Austrian Forest Fire Research Initiative it is not possible to reveal a clear picture of the forest fire situation in Austria during the last two decades, since the data quality, which is influenced by a varying reporting intensity and quality does not allow a thorough analysis of trends. However, beside these limitations it can be concluded that prophylactic measures are worth to be set in place in order to reduce potential economic and ecological damages forest fires may cause in Austria.

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