RECONSTRUCTION OF SEVERE HAILSTORM OCCURRENCE WITH TREE RINGS: A CASE STUDY IN CENTRAL SWITZERLAND

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ABSTRACT

Dendrochronological methods were used to date hail injuries in tree rings of six mountain pines (Pinus mugo var. uncinata) at a site in central Switzerland. Annually dated injuries (1939–1996) were in 89% of the cases attributable to years with severe regional hailstorm occurrence (1957–1996). Days with severe hailstorms were successfully dated in either the earlywood and/or latewood portions of a tree ring in a given year. Tree rings provide an alternative proxy to existing data for reconstructing past severe hailstorm occurrence.

INTRODUCTION

Information on past hailstorm activity is of interest for climate research purposes, and considerable efforts have been undertaken to reconstruct spatial and temporal frequencies and intensities of such events. Generally, hailstorm frequencies and intensities are not directly measured at weather stations but are reconstructed from a wide range of indirectly recorded data. Historical hailstorm reports (e.g. Pfister 1998) give an account of individual severe hailstorms, but storms are reported locally and coincidentally and lack consistency. In the last ten years, hailstorm damage has been monitored increasingly by satellites (e.g. Klimowski et al. 1998) and weather radar (e.g. Schiesser 1990, 1997), which permit precise analyses of storm tracks and spatial variability of hailfall. Longer hailfall climatologies have been constructed from hail damage claim data provided by crop-insurers (e.g. Paul 1991; Dessens 1995; Smith et al. 1997; Changnon and Changnon 1997). These data permit analyses of trends in hailstorm occurrence over periods as long as 100 years (e.g. Schiesser et al. 1997). However, the use of hail damage claim data for reconstruction of past hailstorm activity has
limitations, including spatial and temporal variations in crop susceptibility, changing cropping patterns and insurance participation.

The objective of this study is to investigate the possibility that annual growth rings of hail-damaged trees record signals that could be used to reconstruct regional histories of severe hailstorms. Tree-ring samples from hail-damaged mountain pines (*Pinus mugo var. uncinata*) are analyzed to develop a chronology of severe hail for a site in central Switzerland. Dendrochronologically dated injuries in hail-damaged wood could be used (1) to lengthen existing hail climatologies, (2) to establish time series of most severe hailstorms (tree injuries only result from large hailstones), (3) to reconstruct hail histories for specific sites where alternative data on hailfalls are missing, and (4) to achieve a finer spatial resolution of hailfall patterns and variability.

Severe hailstorms are known to cause important damage to forest stands with both short-term and long-term effects (e.g. Cremer 1984), but hail damage to tree rings has received minor attention in forestry literature. Most studies focused on the immediate impact of a severe hailstorm on a tree stand (e.g. Dobbs and McMinn 1973; Gillis et al. 1990), recovery chances of various tree species (e.g. Riley 1953; Pechmann 1958; Linzon 1962; Evans 1978), harvest strategies in hail-damaged stands and resulting economical consequences (e.g. Badoux 1917; Cremer 1984). Impacts of large hailstones on trees cause primary injury (stem lesions, broken branches or defoliation) resulting in severe cases in secondary injury (crown dieback, reduced height increment, cankers, staining, bruises, fungal infection, or stemrot). Hail-damaged trees show several main characteristics. (1) Lesions occur only on the windward side of stems and branches (e.g. Gillis et al. 1990) whereas leeward sides are mostly without any sign of injury (Linzon 1962). Upper branches and those on the windward side of the crowns tend to shield those below and on the sheltered side. Dobbs and McMinn (1973) revealed that hailstones of 25–38 mm in diameter induced most severe wounding to the bark and sapwood and Gillis et al. (1990) reported that hailstones up to 20 mm in diameter caused lacerations to stems and branches. Doll (1988) found that the severity of hail injuries depends largely on the thickness of the bark layer protecting the underlying cambium. (2) Hail lesions and bruising effects occur on a large number of trees of various species within a stand, a distinction that is shared only with other physiological impacts such as fire and frost damage (Riley 1953). Several observers (e.g. Frei 1961; Schwerdtfeger 1991; Gillis et al. 1990) suggested that broad-leaved tree species are generally less vulnerable to hailfall than coniferous species. Dobbs and McMinn (1973) showed that stem lesions resulting from hail are more common in older trees, whose stems and branches are relatively inflexible, than in younger trees. The etiology of hail injuries is similar to wounds induced by other mechanical agents (e.g. rockfall) and injuries from insects (e.g. pith flecks from cambial miners), but the cause of damage becomes clear if viewed on the scale of the forest stand. (3) In hail-damaged forest stands, an increase in damage severity occurs with increasing exposure to the hailstorm (e.g. in dominant trees on the windward edge of a stand). (4) Beside hailfall, severe thunderstorms produce strong wind gusts (downbursts) that uproot trees, break crowns and bend stems. These large-scale effects remain visible even years after the passage of a severe hailstorm.

The impact of large hailstones (diameters >20mm) produces injuries that show typical wood-anatomical morphologies of mechanical injuries described in Mullick (1977), Shigo (1984) and Larson (1994). Three types of hail injuries can be distinguished. First, hail may damage the outer bark only, causing no cambial damage and hence producing no tree-ring signal. Second, a hailstone may penetrate the outer bark and crush the cambium, resulting in a covered cavity oriented parallel to the tree ring, here called a corrasion. Third, the cambium as well as the underlying sapwood are penetrated by a hailstone and leave an open wound, here called a scar. Healing after injury varies with the tree species, the growth rate and stand factors, as well as the type and extent of the injury. Recovery from corrasion injury is rapid and normal wood cell growth resumes at the latest in the growth ring following the injury (Schweingruber 1988). On the other hand, scar healing and
Figure 1. Overview of Switzerland with main geographical regions outlined, the location of the ETH Radar (cross) with a detection range of 100 km (circle) and the location of the study area in central Switzerland (box). The enlargement shows individual communities of central Switzerland with the sampling site on the southwest exposed slope of Mt. Rossberg (Mt. Ro, altitude of 1580 m a.s.l.) and the communities of Arth (ART) and Steinerberg (STB). Well known mountains and major cities are labeled: Mt. Rigi (Mt. Ri, altitude 1798 m a.s.l.), Lucerne (LU), and Zug (ZU).

Wound closure can continue for years until the open wound is overgrown by wood and bark tissues from opposing flanks (Bangeter 1984). In the case of perennial cankers, caused by fungi, Linzon (1962) observed that hail wounds seldom heal over, but either extend their area of injury until the stem is girdled, or maintain a balance with annual callus growth. Pechmann (1949) and Riley (1953) analyzed hail-damaged wood and noticed a considerable reduction of tree ring growth in the year following severe hail injury. Following the healing process, hail injuries remain distinctive in the growth rings as corrasions or scars and can be dated with dendrochronological and wood-anatomical methods.

STUDY AREA AND METHODS

The sampling site lies at the northern border of the prealpine region of central Switzerland where severe hailstorms are frequently observed (e.g. Houze et al. 1993; Huntrieser et al. 1997; Schiesser et al. 1997), on the west flank of Mt. Rossberg in the community of Arth (Figure 1). On the upper part of Mt. Rossberg, vegetation can be described as Rhododendro hirsuti-Pinetum montanae (Keller et al. 1998) and is dominated by a scattered population of individual shrub-like mountain pines (Pinus mugo var. uncinata) that grow on a conglomeratic bedrock (Figure 2). The mountain pines on Mt. Rossberg appear to be ideal to establish a hail injury time series, because of (1) slow growing trees with thin bark layers, (2) comparable growth rates and age distribution of the trees over the slope, (3) isolated and unprotected stand conditions, and (4) trees are ideally exposed to the main track direction of hailstorms from southwest to northeast.

For the present study, six equally sized and exposed mountain pines were chosen over the slope...
at an altitude of 1,100 m a.s.l. From each tree, the stem and an equal number of similarly exposed branches were systematically cut into 20-mm thick cross-sections providing a mean number of 120 samples per tree. Mechanically polished, all samples containing at least one hail injury were visually inspected. The mean diameter, the bark thickness in the sector of the injury, the distance from the pith to the injury and the type of injury (scar or corrasion) were recorded. A few samples were prepared for microscopic studies, sectioning the wood samples with a microtome and staining with safranin (Schweingruber 1978). A hail-damaged growth ring was dendrochronologically dated to identify the year of injury, and the position of the injury within either the earlywood or the latewood formation of the tree ring was determined. Based on experience from comparable sites in Switzerland, the annual growth cycle of the present trees has been assumed to last from late-May to mid-September. The transition between the earlywood and latewood cell rows occurs around mid-July, since earlywood formation has already been completed and latewood growth was just about to start in the last tree ring of all trees when they were sampled on July 15, 1997.

As branches have thinner bark layers than stems and are potentially more vulnerable to hailfall, the sample is over-represented by injuries within growth rings of the last decade. To guarantee a comparable vulnerability of stem and branch samples over all decades and to obtain a longer time series, only injuries within 0.5-3.0 mm of the pith were further analyzed. However, numbers of annually dated injuries can still be biased to a certain degree as (1) branches might still record more hail damage due to their angle of inclination towards hailfall, (2) branches can shelter the stem from hailfall and/or reduce the impact of hailstones, and (3) the exposure of the tree to the main storm direction can change over time. These biases can be neglected as the study aims to identify years with
severe hailstorms but does not seek to develop relationships for reconstructing annual hailstorm frequency from the number of dated hail injuries.

Information on hail damage to agriculture is available from the Swiss Hail Insurance Company since the 1950s on a daily (yes/no) basis for the majority of the Swiss communities north of the alpine crest. However, precise location of hail damage within a community as well as the damage extent is not directly available. The two communities that surround the sampling site are Arth and Steinerberg (Figure 1), where annual numbers of haildays have been recorded since 1957. Additional insurance data from further surrounding communities were available for validation purposes.

Willemse (1995) analyzed dimensions of hailstorm surfaces in relation to numbers and spatial distributions of daily claimed hail damages per community and found that the larger the hail-damaged agricultural surface, the more intense the storm and the larger the maximum hailstone diameters. Schiesser et al. (1997) grouped coherent daily hail damage claims into damage cluster surfaces that represent the area of communities where hail damage was reported. Severe hailstorms typically show a damage cluster of 25 km in length with concurrent damage claims from more than 30 neighboring communities. For the present study, hailstorms that occurred over central Switzerland and produced hail damage in Arth and/or Steinerberg are grouped according to associated damage cluster surfaces into: (1) strong storms with reported damage claims from >30 communities (large damage cluster surfaces), (2) medium-intensive storms with claims from 15–30 (medium damage cluster surfaces), and (3) weak storms with <15 hail damage claims (small damage cluster surfaces). Only storms displaying medium and large damage cluster surfaces, grouped as severe storms in the following, reveal the intensity and potential to damage tree rings and are retained for comparison with hail injuries. Weak storms (small damage cluster surfaces) are less likely to produce hailstones large enough to damage the living cell layer of a tree. Because insurance data alone provide no direct information on storm severity, the time series of annual haildays cannot be compared quantitatively to the hail injury time series; e.g. strong event years in both time series do not necessarily correspond, because all injuries of a given year could be initiated by one severe hailstorm. Classifying haildays according to storm severity (damage cluster surfaces) allows comparison of insurance data to the tree-injury data on a yes/no basis; i.e. years with severe (medium and large damage cluster surfaces) and non-severe (small damage cluster surfaces) hailstorms are related to years with dated hail injuries.

In order to monitor tracks of severe hailstorms in space and time, measurements from the ETH C-Band Doppler weather radar (Figure 1) were available since 1992. Radar data display reflectivity, which is a direct function of the sizes of precipitation particles in the illuminated thunderstorm. Large hail produces a strong characteristic radar echo. In the present study, radar measurements are used (1) to verify the passage of a severe hailstorm over the sampling area, (2) to locate the maximum hailfall intensity (function of the radar reflectivity) within the area determined the damage cluster surfaces, and (3) to estimate maximum hailstone diameters from upper-level Doppler velocities, based on the close relationship between updraft velocities and maximum sizes of hailstones (Witt and Nelson 1991).

RESULTS

Eliminating dendrochronologically non-datable injuries (within wedging and narrow growth rings or discolored sapwood), 273 injuries were retained for further analyses (Table 1). Hail injuries are typically located on the windward side of stems and upper part of branches, and several samples show numerous injuries in different growth rings (Figure 3). In cases where microcut samples of hail-damaged wood have been prepared (Figure 4), the morphological characteristics of the injuries become clearly visible and dendrochronological dating is facilitated. The sample displayed in Figure 4 contains three different injuries: one corrision in the 1987 and two scars in the 1983 and 1992 growth rings. In 1992, scar injury occurred after earlywood formation (late-May to mid-July) during the second half of the latewood cell rows (mid-July to mid-September) leaving an open wound
Table 1. Overview of samples within the defined pith-injury radii range (0.5-3.0 mm) from 6 mountain pines (Pinus mugo var. uncinata) sampled at Mt. Rossberg, central Switzerland; total of 273 injuries (1939-1996).

<table>
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<tr>
<th>Tree</th>
<th>N</th>
<th>(D_{\text{min}}) [mm]</th>
<th>(D_{\text{max}}) [mm]</th>
<th>(D_{\text{BARKmin}}) [mm]</th>
<th>(D_{\text{BARKmax}}) [mm]</th>
<th>(R_{\text{INJURYmin}}) [mm]</th>
<th>(R_{\text{INJURYmax}}) [mm]</th>
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</table>

N: number of examined hail injuries.  
\(D_{\text{min}}/D_{\text{max}}\): minimum/maximum diameter of the sample containing the hail injury. 
\(D_{\text{BARKmin}}/D_{\text{BARKmax}}\): minimum/maximum bark diameter in the sector of the injury.  
\(R_{\text{INJURYmin}}/R_{\text{INJURYmax}}\): minimum/maximum pith-injury radius.

from which only one edge is visible on the microcut. According to the position of the traumatized cell rows that formed immediately after injury, hailfall must have occurred during the second half of August 1992 before latewood formation was completed by mid-September. From the available hail damage claim data and radar measurements it appears that a severe hailstorm passed over the study area on 21 August 1992 and caused the injuries dated in the latewood of the 1992 growth ring.

Severity of hail damage to trees depends largely on the size of individual hailstones and the thickness of the bark layer that protects the cambium from mechanical injuries (Doll 1988). In two of the present storms that initiated severe hail damage to trees, analyses of Doppler radar measurements revealed the presence of hailstones with diameters of 30 mm for the storm on August 21, 1992, and 20 mm for June 2, 1994. These findings are in agreement with the observation of Dobbs and McMinn (1973) and Gillis et al. (1990). Beside the size of hailstones, the extent of hail damage to trees can increase with the duration of hailfall and the horizontal wind component that can accelerate the stones before impact.

The time series of annually dated hail injuries (1939-1996) exhibits a general increase of annual hail injuries over time, with a minimum during the 1970s and large fluctuations thereafter (Figure 5a). Strong event years occurred in 1983 (25 injuries), 1984 (26), 1992 (29), and to a lesser extent in 1994 (21). Mean annual numbers of haildays (1957-1996) in the communities of Arth and Steinerberg (Figure 5b) show a general increase over the period of investigation with a maximum of 3.5 haildays per year in the mid-1980s and 4.5 hail-

![Figure 3. Cross-section of a hail-damaged mountain pine (Pinus mugo var. uncinata) stem, Mt. Rossberg, central Switzerland, enlargement 4X. Arrows indicate hail injuries from repeated hailfall events. Note that all injuries are within the same sector at the windward side of the stem.](image-url)
Figure 4. Microcut on the windward side of a mountain pine (*Pinus mugo* var. *uncinata*) branch, diameter 150 mm, Mt. Rossberg, central Switzerland, enlargement 40×. The microcut displays three injuries: one corrasion (1987 tree ring) and two scars of which only one wound edge is displayed (1983 and 1992); indicated is the earlywood (EW), latewood (LW), traumatized cell rows (TC) and locations of hail injuries (arrows).

days during the early 1990s. In comparison, annual haildays with severe storm occurrence (*i.e.* medium and large damage cluster surfaces) over central Switzerland and reported damage claims in Arth and Steinerberg (Figure 5b) show a similar trend with an increase until the mid-1980s, but show, however, a decrease during the 1990s. Both hailday time series indicate that (1) most of the days when hail damage was reported in the 1980s were days with severe hailstorm occurrence and (2) hail damage claims were initiated in most of the haildays by non-severe hailstorms (small damage cluster surfaces) in the following decade. Over the observation period, hail damage claims occurred on 72 different days of which eight days (11%) reveal storms with large damage cluster surfaces and initiated damage in both communities (Table 2). Days with storms revealing medium damage cluster surfaces constitute 25% of all recorded haildays with hail damage reports in either one or both communities (Table 2). Most hail damage on agriculture (64%) was initiated on days where weak storms (small damage cluster surfaces) occurred with hail damage claims in one of the communities.

In the period 1957–1996, yearly comparisons between dendrochronologically reconstructed hail injuries (total 258) and haildays of severe hailstorm occurrence (total 28) show a good agreement over time (Figure 5c), as 230 injuries (89%) were identified in years with severe hailstorm occurrence and 15 injuries (6%) were dated in years revealing haildays with weak storms (small damage cluster surfaces). Thirteen hail injuries (5%) were dated in years without reported hail damage and in two years no injuries were identified despite existing hail damage claims from one of the communities. On an intra-annual basis, dates of reported hail damage claims in the two communities generally agree with dendrochronologically reconstructed periods of severe hailstorm occurrence (*i.e.* the position of a hail injury within the earlywood or latewood formation). Assuming a constant yearly transition between earlywood and latewood formation of mid-July, 93% of the attributed injuries correspond to dates of haildays with severe hailstorm occurrence (Table 2). In the remaining 7%, injuries were wrongly identified in the earlywood where hail damage to agriculture was reported during the time of latewood growth and *vice versa*. Intra-annual correspondence is most obvious in years with storms revealing large damage cluster surfaces (Table 2); *e.g.* in the 1992 (1994) growth ring, all injuries were exclusively dated in the latewood (earlywood) and must have been initiated by the severe hailstorm of August 21, 1992 (June 2, 1994). In years where one severe storm occurred either during the earlywood and/or the latewood cell growth, injuries were successfully assigned (Table 2); *e.g.* in 1983 (1984), hail
injuries were dated both in the earlywood and late-wood and were most likely initiated by the severe storms on June 10 and August 1 (June 24 or July 12 and July 25). However, when several severe storms occurred during the earlywood or latewood growth period, precise assignment of hailstorms is not possible (Table 2); e.g. in 1987, three storms with medium damage cluster surfaces occurred between May and July and initiated the hail injuries that were dated in the earlywood formation of the 1987 tree ring.

DISCUSSION

The severity of hail damage to tree rings depends on the hailstone diameter, the wind speed that accelerates the stones before the impact and the bark diameter that protects the cambium. If reports of hailstone diameters (e.g. by the public, meteorological observers, newspaper reports) are not available as in the present study, Doppler radar measurements can be used to determine the maximum size of hailstones. As shown in other studies
Table 2. Overview of 28 days with severe hailstorm occurrence (medium and large DCS) in Arth (ART) and Steinerberg (STB) and 230 dendrochronologically dated hail injuries in tree rings of mountain pines (Pinus mugo var. uncinata); Mt. Rossberg, central Switzerland (1957–1996); 44 days with weak hailstorm occurrence and 28 dated hail injuries are not shown in the table. Note that in years when several severe storms occurred, numbers and types of hail injuries are given in the table at first storm date.

<table>
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<th>Date</th>
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<th>STB</th>
<th>DCSₘ</th>
<th>DCSₘ</th>
<th>N₉₀₉</th>
<th>Nₛₕₐ₅</th>
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<td>1996</td>
<td>0607</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

ART/STB: hail damage recorded within the community of Arth (ART)/Steinerberg (STB).
DCSₘ/DCSₘ: large/medium damage cluster surface (DCS) deduced from insurance data in central Switzerland.
N₉₀₉/Nₛₕₐ₅: number of dated corrasions/scars.
Nₑ₅/Nₑₕ: number of dated hail injuries within the earlywood/latewood.
TOTAL: total number of identified hail injuries per year.
ERROR: number of attribution-errors between positions of hail injuries and the date of haildays with severe storm occurrence; a constant transition between earlywood and latewood formation has been assumed for all cases in mid-July.
(Dobbs and McMinn 1973; Gillis et al. 1990), only hailstones of diameters >20 mm have the potential to damage a tree in the way that wounds remain visible in the growth rings. Fine-scale measurements of wind velocities (e.g., from weather stations or Doppler radar velocities) and wind directions were not available for the present study but would provide information on the impact velocities and angles of hailstones on the sampled trees.

The present hailstorm climatology is based on dendrochronologically dated hail injuries from branch and stem samples of a given pith injury radius. A time series based on branch samples alone would identify years with severe hailstorms of the last decade, whereas stem samples would show severe events of past decades only. The longest and most coherent time series of hail injuries is obtained if branch and stem samples are combined, assuming that stems and branches within a certain pith injury radius range are equally sensitive to hailfall. The proportionally high number of annual hail injuries during the last two decades (Figure 5a) could be the result of a large number of branch samples. It would be necessary to account for such bias if hail injury were used to reconstruct annual hailstorm frequency. The objective of this study, however, was to determine whether hail injuries could be used to identify years in which at least one severe hailstorm had occurred.

The hail injury time series reveals an overall increase in hail injury from 1957–1996, which is consistent with a general trend for the Swiss Mittelland identified in (1) Schiesser et al. (1997), where a general trend towards an increase of days with hail damage claims in more than one of the Swiss communities north of the alpine crest (1920–1993) was found and (2) Willemse (1995) who revealed that annual numbers of large coherent damage clusters (>25 km) north of the alpine crest (1949–1994) increased generally over the years. The studies of Willemse (1995) and Schiesser et al. (1997) show a relatively high hailstorm activity in the entire Swiss Mittelland during the 1970s, while both the hail injury and the damage claim time series from Arth and Steinerberg, reveal a decrease during that time (Figure 5c). This discrepancy in hailstorm activity shows not only that reduced hailstorm activity in the 1970s is a local phenomenon but also that hail injury time series can be used to identify local trends in hailstorm occurrence.

Overall, the study shows that 89% of the annually dated hail injuries (Figure 5a) occurred in years when severe hailstorms were identified from damage claim data (Figure 5b) and that actual dates of severe storms fall in 93% of the cases into the appropriate dendrochronologically reconstructed periods. Possible errors in annual correspondence between the data can be from various sources. First, as hail days are based on claims from crop-insurers, it is likely that hail damage to non-insured land such as forests are not recorded and are therefore missing in the statistics. Second, a hailstorm that produced hail damage to crops in the community of Arth and/or Steinerberg, did not necessarily move over the sampling area on Mt. Rossberg and damage the sampled trees. As crops are far more sensitive to hailfall than trees and hail damage claim data do not directly reveal hailfall intensity, damage cluster surfaces (i.e., coherent surfaces of daily hail damage reports over several communities) can be used to distinguish storms according to their severity. Third, some of the errors in dendrochronological dating are due to the occurrence of severe hailstorms around the transition between earlywood and latewood growth in mid-July (e.g., 8 July, 1970, or 9 July, 1969). Dating errors can be reduced if such samples are not considered due to the temporal uncertainty of the transition between earlywood and latewood. A detailed study of the growth cycle of mountain pines in the study area itself or on a comparable site would further improve the results. Fourth, the presence of hail injuries in parts of stems and/or branches that are within the 20-mm thick samples (and were not assessed), could provide additional information on severe hailstorm occurrence. Intraannual dating could be improved by counting individual cell rows of the earlywood and/or latewood according to the growth cycle depending on the species and area.

Although the use of dendrochronological methods is restricted to wooded areas, and only impacts of severe hailstorms that produce hailstones large
enough (> 20-mm) to damage tree rings are recorded, tree rings reveal an alternative proxy to insurance data and historical chronicles for past hailstorm occurrence. The study has shown that tree rings can be used to identify years during which severe hailstorms occurred. A further step would be to link the number of hail injuries to the number of haildays available from crop-hail insurance data and to reconstruct frequencies of haildays for years where relevant insurance data are not available.

CONCLUSIONS

The present case study has concentrated on the reconstruction of past severe hailstorm activity from hail-damaged shrub-like mountain pines (Pinus mugo var. uncinata) sampled at Mt. Rossberg, central Switzerland. Based on 273 dendrochronologically dated hail injuries in tree rings, a regional time series (1939–1996) was established and compared with annual days of severe hailstorm occurrence (1957–1996) on an annual and intra-annual basis over central Switzerland, using damage claim data from two relevant communities. The study showed the following key results:

1. Tree rings are most vulnerable to impacts of large hailstones, estimated in two severe storm cases to be around 20 mm and 30 mm in diameter.
2. Time series of annual hail injuries, haildays of two relevant communities, and haildays with severe hailstorm occurrence over central Switzerland all show a general increase of local hailstorm activity (1957–1996) which is consistent with a general trend for the Swiss Mittelland (1920–1993).
3. Years in which hail injuries were dendrochronologically dated corresponded to 89% of years with severe hailstorm occurrence. (4) Intra-annual correspondence between dendrochronologically reconstructed periods of severe hailfall (position of the hail injury either in the earlywood or latewood formation of the growth ring) and dates of hail damage claims associated with severe storms was 93%.

The results show that dendrochronological methods open up new possibilities to reconstruct past local severe hailstorm activity. Hail injury time series are ideally established from hail-sensitive, isolated and slow-growing trees that typically grow on bedrocks or xeric slopes that are exposed to the main direction of hailstorm tracks. If hail-damaged trees from several comparable sites are analyzed, local hail injury time series can be combined into a regional series, and could provide new data on past hailstorm occurrence in areas where hailstorms have not been monitored or alternative data are not available. Additional data on frequencies of past severe hailstorms will certainly contribute to a better understanding of present fluctuations in hailstorm activity. The present study is only a first step in what could be continued on a larger scale by further investigations involving other tree species from a variety of sampling sites.

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