PROBLEM OF FIRES ON EMBANKMENTS ALONG RAILWAY ROUTES IN AUSTRIA

Presented by

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Abstract

Flying sparks from braking trains and damaged brakeshoes falling off the trains are the main reasons for major forest fires along railway routes in Austria. Especially long, steep and curvy railway routes, as they frequently occur in Austria make frequent braking necessary and are therefore most susceptible for frequent fires. Together with topographic conditions climatic and fuel conditions characteristic for mountains play a significant role along railway routes as well as they facilitate the spread of fire beyond the embankments. The performance or lack of maintenance measures plays a significant role in enhancing or reducing the fire risk along railway routes.

Two railway routes characteristic for Austria were chosen for assessment. One route is part of the so-called "*Tauernstrecke*" and is located between Mallnitz and Pussarnitz in Carinthia and the other railway route is located between Bruck an der Mur and Frohnleiten in Styria and are part of two major international transit routes with a high train frequency. A third site has been chosen along the route between Villach and Arnoldstein, where a braking train has caused a major forest fire in July 2006. Along all three railway routes sparks from braking trains have caused major forest fires with significant economic and ecological damage.

Results indicate that all three railway routes are highly susceptible to fire. Fuel conditions on the embankments were found to differ significantly from each other depending on the state of maintenance. Whereas the embankments along the "*Tauernstrecke*" are in a rather good condition the embankments along the route between Bruck an der Mur and Frohnleiten were found to be in a relatively poor condition due to the lack of maintenance measures. Yet fire risk was found to be high along all railway routes making maintenance measures particularly necessary. Considering the role of climate change in this context it is necessary to develop management measures in order to significantly reduce the fire risk for the areas surrounding Austrian railway routes.

With the exception of the years 2003 and 2004 the ÖBB fire statistics placed at the disposal for this paper shows a significant decrease in fire occurrence on embankments along railway routes since 2001. The reason might be the increased maintenance measures taking place along the route. Due to the lack of respective documentation this could only be assumed.

Finally management considerations for the embankments along railway routes are provided in order to significantly reduce the fire risk for the adjacent area. Management considerations consist of bio-engineering measures as well as mechanical measures for the reduction of the fire risk along railway routes. Because forest stands are highly at risk of a fire outbreak – especially in places where they reach directly to the track – silvicultural measures to reduce the fire risk on embankments along railway routes are proposed as well.

Zusammenfassung

Funkenflug von bremsenden Zügen sowie herabfallende defekte und glühende Bremsklötze sind die Hauptgründe für große Feuer entlang von Bahnstrecken in Österreich. Insbesondere lange, steile und kurvige Strecken, wie sie häufig in Österreich zu finden sind, machen häufiges Bremsen notwendig und sind deswegen besonders anfällig für Brände. Zusammen mit vorherrschenden topographischen Bedingungen spielen die klimatischen Bedingungen sowie der Zustand des Brennmaterials auf den Böschungen und in angrenzenden Wäldern eine erhebliche Rolle. Der Aufbau des Brennmaterials sowie der Zustand des Brennmaterials auf Bahndämmen erleichtert order reduziert die Wahrscheinlichkeit des Ausbruchs eines Feuers über die Grenzen von Bahndämmen hinaus. Die Durchführung oder das Fehlen von Behandlungsmaßnahmen spielt ebenso eine wichtige Rolle.

Zwei Bahnstrecken, die typisch für die spezielle Situation in Österreich sind, wurden für die Studie ausgewählt. Eine Strecke ist Teil der so genannten "*Tauernstrecke*" und befindet sich zwischen Mallnitz/Obervellach und Pussarnitz in Kärnten. Die zweite Strecke befindet sich entlang der Bahnstrecke zwischen Wien und Graz zwischen Bruck an der Mur und Frohnleiten in der Steiermark. Beide Strecken sind Teil von zwei internationalen Transitstrecken und zeichnen sich durch eine hohe Zugfrequenz aus. Aus aktuellem Anlass wurde ein Waldbrand nahe Arnoldstein in die Untersuchung mit aufgenommen, der im Juli 2006 durch einen bremsenden Zug entstanden ist. Brände haben an allen drei Strecken bedeutende ökonomische und zeitweise auch ökologische Schäden verursacht.

Mit Ausnahme der Jahre 2003 und 2004 zeigen die zur Verfügung gestellten Brandstatistiken der ÖBB einen deutlichen Rückgang der Böschungsbrände entlang der Bahnstrecke zwischen Mallnitz und Pussarnitz seit 2001. Der Grund dafür könnte in den erweiterten Pflegemaßnahmen auf den Böschungen liegen. Aufgrund des Mangels an entsprechenden Informationen können in diesem Zusammenhang nur Vermutungen angestellt werden.

Ergebnisse deuten darauf hin, dass die Bahndämme entlang aller drei Strecken extrem anfällig für Brände sind. Der Zustand des Brennmaterials auf allen Bahndämmen unterscheidet sich abhängig vom Pflegezustand sichtlich voneinander. Während die Bahndämme entlang der "*Tauernstrecke*" in einem verhältnismäßig guten Zustand sind, sind die Bahndämme entlang der Bahnstrecke zwischen Bruck an der Mur und Frohnleiten aufgrund mangelnder Wartung in einem relativ schlechten Zustand. Besonderes Augenmerk muss in diesem Zusammenhang auf das Brennmaterial auf Bahndämmen sowie den Klimawandel gerichtet werden. Durch die damit verbundenen Veränderung der Feuerhäufigkeit und –heftigkeit werden die Flächen entlang von Bahnstrecken in Zukunft einem erhöhten Brandrisiko ausgesetzt sein, besonders dann, wenn keine Wartungsmaßnahmen zur Reduzierung des Feuerrisikos entlang von Bahnstrecken unternommen werden.

Aufgrund dessen werden Wartungsmaßnahmen für Bahndämme zur Reduzierung des Brandrisikos entlang von österreichischen Bahnstrecken vorgeschlagen, die sowohl ingenieurbiologische Maßnahmen als auch mechanische Maßnahmen zur Reduzierung des Brandrisikos beinhalten. Zusätzlich werden waldbauliche Maßnahen für die bewaldeten Bahnböschungen vorgeschlagen.

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Introduction

Previous to human influence on ecosystems and open land natural disturbances of all kinds have maintained or changed species distribution and abundance in all ecosystems. Fire has globally been a natural process, which has occurred in regular sequence influencing forest structure and composition. Vegetation composition of landscapes has changed through human activities associated with forestry, livestock grazing, cultivation, settlement and industrialisation. The result was especially a massive degradation of the forests. Over 90% of forest fires can be directly or indirectly traced back to human activities inside or outside the forest or inaccurate behaviour. Especially areas close to inhabited areas subject to high human pressure are susceptible to ignition. Socio-economic changes such as rural exodus, abandonment of agricultural land or urbanisation of rural areas are reasons for changes in the number of fires and area burned as well. Particularly the increasing use of the landscape for settlements and infrastructure raise the fire risk for the landscape[1]. At present fire risk is especially high in densely populated areas. Industry plays a major role in opening up areas through infrastructure. Together with industrialisation the opening up of the landscape by railway routes plays a significant role[2]. Austria being a predominantly mountainous and densely populated area is particularly susceptible to fire outbreaks, especially from railway routes.

In the past embankments along railway routes have been set on fire by sparks from braking trains and maintenance works along the track. Earlier investigations and the study of underlying reports have shown that braking trains are the major reason for fire ignition. Especially the condition of the brake shoes is an important aspect to consider when looking at fire risk along embankments[3].

Fire hazard arises especially along routes with long, steep and curvy sections, where trains frequently need to break and often in order to reduce their partially very high speed. Those grassfires pose a significant hazard for adjacent forests, agriculture and settlements in terms of economical damage as well as harm to human life and property.

[1] Mißbach, 1964; Hafner, 1979; Clarke, 1993; Ellenberg, 1996; Goldammer et al., 1997; Murray et al., 1998; Goldammer and Page, 2000; Taylor, 2000; Leone et al., 2000; Kipfmueller and Baker, 2000; Johann, 2000; Müller, 2001; Leone et al., 2002; Koutsias et al., 2002; Venevsky et al., 2002; Keeley, 2002; Wetzel et al., 2003
[2] Mißbach, 1965
[3] Mißbach, 1965; Cowles, 1972; ÖBB reports, Pernegg News, 1998; ÖBB correspondence, 1998; Lex, 2002

In the past fires caused by damaged brake shoes have spread into adjacent forests and caused considerable economic and often also temporary ecological damage. Those forest fires posed a major threat to human life especially during firefighting activities in the past as well. At the same time problems such as restricted visibility or respiratory problems occur due to smoke[4].

Important aspects to be considered when looking at fires along embankments along railway routes in Austria are climate, topography and vegetation. Those elements should be studied as one, since they are closely linked to each other and influence fire spread and behaviour to a great extent. Unfavourable weather conditions as well as hazardous fuel conditions together with topography contribute to a high fire hazard[5].

In this context the vegetation composition and the microclimatic conditions along the embankment are important aspects to be considered. The microclimate and the wind conditions characteristic for railroad routes influence fire behaviour and fire spread to adjacent areas to a great extent. The microclimate along the railway route differs significantly from the climatic conditions of the surrounding area. Wind conditions differ from the predominating wind conditions of the surroundings as well. Trains add turbulences to the natural wind field for a short period of time, therefore increasing wind speed and influencing fire behaviour and fire spread[6].

The vegetation composition and its condition on the embankments are of great importance regarding the fire hazard along railway routes. Depending on the density of the vegetation communities found on embankments the significance of vegetation as a fuel source changes significantly. Grasses and herbs dominate the vegetation composition of a significant part of railway routes as well as adjacent areas, even though trees may be found growing directly on embankments as well. Therefore fire risk, fire behaviour and fire hazard for areas adjacent to railway routes are increasing with growing fuel loads.

The condition of the vegetation on the embankments is important as well regarding the fire risk for the embankments themselves and their surroundings. Long dry periods cause fuels to dry out fast, which is leading to an increase in ignition probability.

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[4] Mißbach, 1965; Cowles, 1972; Cheney, 1997; Pernegg News, 1998; Feller, 1999; Lex, 2002
[5] Fuller, 1991; National Fire Coordinating Group, 1994; Felller, 1999
[6] Cowles, 1972; Lex, 2002

Woody debris found on embankments add to the fire risk by increasing the fuel loads and therefore being the reason for higher fire intensity and longer lasting fires. Grasslands and grass-dominated woodlands form environments with very specific microclimatic conditions, which influence fire spread and fire behaviour to a great extent. Also wind conditions are very different compared to closed forests. Together with the specific microclimatic conditions of railway tracks and embankments this influences fire risk along railway tracks significantly[7]. An embankment, which is not treated on a regular basis and where all sort of vegetation grow without any control is a great deal more susceptible to fire caused by trains than a well and regularly managed embankment[8].

Even though studies have shown that the extreme conditions along the embankments have formed ecosystems with species adapted to the conditions, treatment options to reduce fire risk along railway embankments are required. The exclusion of fire and other management measures from railway routes were found to cause an invasion of tree and shrub species on the embankments, which in turn increase fire risk[9].

Extremely long dry periods, such as in summer 2003 add to the extreme conditions influencing railway tracks and the embankments. Fuels present on the embankments dry out faster than usual. This leads to an increased amount of debris, which in turn leads to an increased fire risk on and around the embankments as well as to an increased fire severity. As discussed in a later chapter climate change is going to lead to more frequent droughts in the future. This in turn is going to lead to a higher fire frequency as well as a higher fire severity. In this context fires caused by braking trains are going to play a significant role. Figure 1 indicates the Austrian wildfire situation in 2003.

[7] Cowles, 1972; Freifelder et al., 1998; Lex; Rossiter et al., 2003
[8] Cowles, 1972; Lex, 2002
[9] Cowles, 1972; Lex, 2002; Middleton, 2002; Butler and Fairfax, 2003; Kruse et al., 2004; Grigulis et al., 2005; Bradley et al., 2006; Hunter and Omi, 2006; Hunter et al., 2006

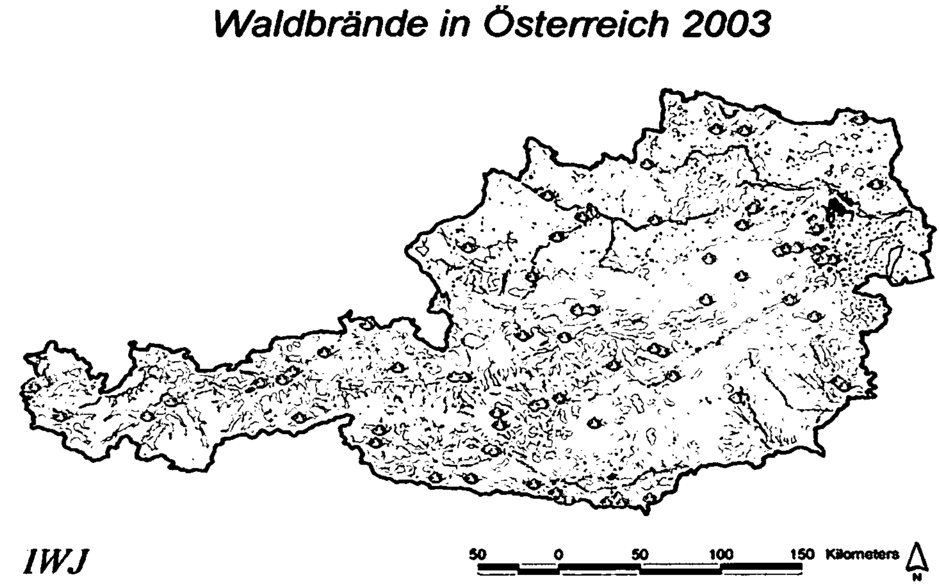

Figure 1: Wildfire occurrence 2003 in Austria (Gossow and Hafellner, 2005)

The forest fire situation in summer 2006, which was limited to two extremely hot and dry weeks in the second half of July, shows an obvious concentration of fires in southern Carinthia. This is illustrating the above average susceptibility of the landscape for wildland fires in this "hot spot" of Austria. The forest fire caused by a braking train close to Arnoldstein has been part of several forest fires occurring during this period. This was the reason, why the site has been chosen for this study. Figure 2 illustrates the distribution of forest fires in Austria as for summer 2006.

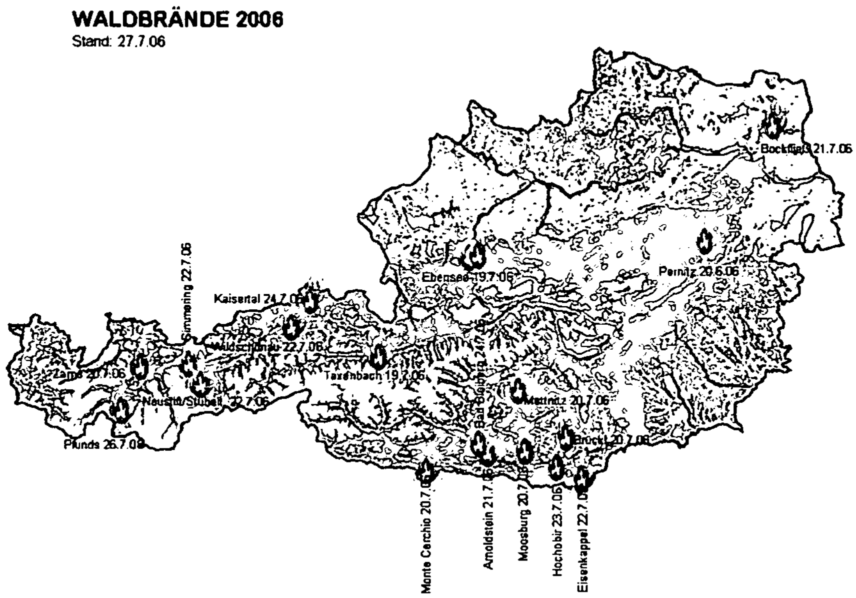

Figure 2: Wildfire occurrence in Austria 2006 (Gossow and Hafellner, 2006)

The aim of this study is to analyse the fire hazard along railway embankments, the risk of escape, especially during unfavourable weather and vegetation conditions and topography as well as the economical and ecological problems those fires pose to adjacent forest and agricultural property and settlements. It also points out the ecological significance of fire regarding the flora and fauna affected. Due to the limited possibility to collect appropriate data in the field, an extended literature analysis has been included to support the findings in the field and draw a proper picture of the situation present along railway routes.

Eventually treatment options and suggestions for a fire management plan for the embankments along railway tracks in Austria are proposed to avoid or at least reduce the fire hazard and the option of a Fire Danger Rating System is considered. In this context also the possibility of establishing a monitoring system will be discussed.

Background and problem

Austria is dominated by mountains and mostly alpine environments. This implies that the environment in terms of climate, vegetation and fauna is highly diverse. The topographic characteristics connected to the alpine environment influences climate as well as vegetation composition. This extremely distinct environment results in a wide variety of sites with different levels of susceptibility and predisposition to fire.

Railway routes are a key example for anthropogenic factors affecting the wildfire situation in Austria. Due to the mostly mountainous landscape of Austria railway tracks often run along mountain or hill slopes with diverse topography, aspects, habitats for flora and fauna and various climatic conditions. Therefore forests, agriculture and settlements along the Federal railway routes are particularly susceptible to wildfires caused by braking trains[10].

Analysis of the ÖBB fire statistics and other supporting documents provided by the ÖBB and forest owners has shown that especially on tracks where trains need to break often due to curves or ascents. Here a considerable fire risk is identified. Particular problems in this context are ruptured and glowing brakes igniting the vegetation on the adjacent embankment. During braking the brakeshoe is pressed against the wheel generating heat exceeding 1500 °C. Metallic fragments from brakes are causing a fire outbreak once they come in contact with dry fuels under dry climatic conditions.

According to a statement of an ÖBB employee also complete heated brakeshoes loosen and fall off from time to time and therefore also count as a reason for a fire outbreak. Sparks from ruptured brakes have caused major forest fires in the area adjacent to the railway route with significant economic and ecological damage. Especially cast iron brakeshoes, which fragment easily and retain heat during braking, are an important and frequent reason for starting fires. Composition brakeshoes are thought of being less at risk of starting fires, because they fragment less easy and heat retention is lower than that of iron brakes.

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[10] ÖBB fire statistics 1998-2005; Kaponig 1982; News, Volunteer firefighters Pernegg; correspondence between Forstverwaltung Pernegg and ÖBB Immobilien & Recht

Minor reasons for a fire starting along the routes are exhaust carbon sparks, the burning of the track, journal boxes or repair works along the tracks. These reasons are not as important, since they are either extinguished right away or have been related to steam-engines, which are not used anymore except for private or nostalgic reasons. Steam engines are not as much the reason for forest fires along railway routes, since they are not in use anymore[11].

Railway tracks and the embankments form long narrow openings in the landscape with a characteristic microclimate. The body composed of steel rails, the rock ballast and black ties increase thermal radiation directly on the track and the area immediately adjacent to the track. The track heats up fast, especially when the area is sun exposed, which lead to higher air temperatures and lower air humidity. This in turn leads to a desiccation of the fuel and the living vegetation of the surroundings, which in turn leads to an increased fire risk. Furthermore the low heat conductivity of the rail body as well as the low capability of water storage adds to the increased fire risk.

Seasonally and daily changing meteorological conditions influence the microclimatic conditions to a great extent. Research has shown that most fires along the embankments as well as forest fires caused by escaped fires occur in early spring and in terms of time of day in the early afternoon. Own fieldwork has proven this experience. The wind behaviour along the tracks differs significantly from other areas as well. The figure of the track has a tunnel effect on the area. Passing trains cause gusts, which interact with the natural wind field of the area. This is an important aspect when looking at how fires start and spread along tracks and embankments[12].

Especially in areas where no gap is present between the track and the adjacent forest, fuel conditions on the site are significantly influenced by the conditions along the track, so that fire spreads easily into forested areas and causes significant damage. Firefighting activities usually do not show the desired effect and prophylactic measures are quite challenging.

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[11] Mißbach, 1964; Cowles, 1972; Lex, 2002

[12] Cowles, 1972; Lex, 2002

Examples for damages along the railway route are the devastating forest fires along the now abandoned track section between Mallnitz and Kaponig in Carinthia, where in total 10 hectares of forests belonging to the ÖBB burned in 1982 and the damaging forest fires along the track section between Übelstein and Laufnitzdorf on the route Bruck-Graz in Styria in February 1998. The main damage to forests occurred in the area between the reservoir Zlatten to the railway station Pernegg with some minor forest fires between Pernegg and Mixnitz[13].

The sites destroyed by the escaping fires have been used to reveal the fire risk for the whole area along the route proceeding from the embankment for both study sites. Furthermore the data obtained from the burned sites were transferred to the forests along the route in order to reveal the potential development of the forest stands in case of a fire. Additionally the burned sites were analysed towards their susceptibility to a repeated fire proceeding from the embankment.

For both study sites it was observed that left-hand-traffic was dominating along the routes causing the trains to run into the downslope direction on the uphill side of the track, whereas the trains run into the upslope direction on the downhill side of the track. Since frequent braking mainly takes place while driving downhill, most major fires have occurred on the upslope part of the embankment. Loose brakeshoes rather than sparks from braking trains were found to have caused local fires in the forests on the downslope side of the embankments.

[13] ÖBB fire statistics 1998-2005; Kaponig 1982; News, Volunteer firefighters Pernegg; Correspondence between Forstverwaltung Pernegg and ÖBB Immobilien & Recht

Material and methods

Material

Literature

Underlying literature has been chosen from different scientific backgrounds and disciplines. The authors are involved in a diverse array of scientific institutions ranging from different University Departments over institutes closely linked to University such as the Global Fire Monitoring Center to independent institutions such as the German Weather Service. Publications from government related institutes have been evaluated and taken into consideration for the paper as well.

ÖBB materials

The ÖBB has provided the fire statistics for embankments along railway routes in Austria from the years 1998 to 2005. This statistics includes all fires reported along the railway tracks in Austria. The statistics describes the situation along the route specifying the location of the fire, the number of fires on the site, date and time of occurrence and the indication of the kilometre along the route. Furthermore the fire statistics includes information about the reason for the fire, the method of extinguishment, the type and location of the damage along the route, the cost of damage and the damaged property. As for the type of damage the fire statistic states the damage fire has caused to the railway route, the embankments, to the forest, pasture, fences or threshold. As regards the damaged property the name of the owner of the land and the location of the damage along the route are recorded. On the basis of these statistics the research plots described later in the work have been assessed.

Furthermore three permits for conducting controlled burning along railway tracks are comprised in the underlying documents. Two permits are concerning four railway tracks in Carinthia. Three sections are lying along the so called "Tauernstrecke" and are located between Mallnitz and Pussarnitz, Bleiburg and Innichen as well as between Steinfeld and Oberdrauburg. The fourth section is located between Zeltweg and Lavamünd. The third permit is for the section between Neumarkt and Dürnstein in Styria. All permits define how to conduct controlled burning and other treatment measures along the specified railway tracks.

According to these permits the ÖBB has been obliged to conduct the above mentioned measures on the embankments along the railway tracks. Conservation laws and regulations needed to be considered. Controlled burning had to be conducted within two specified time frames in order to reduce the fire risk along railway route as well as any possible damage to forests or agriculture or harm to humans resulting from a potential fire. Additionally instructions on burning methods are identified.

As regards the forest fires only documents regarding the big forest fires of February 1998 along the railway route between Bruck/Mur and Graz in Styria were available in terms of fire reports, relevant correspondence between ÖBB and private forest owners as well as newspaper articles. The available information is listed in detail in the following.

The official fire report of the fire along the track between Bruck and Frohnleiten has been provided as well. The report provides information about the reason of the fires, time and location of occurrence, fire spread as well as the duration of the fire and firefighting activities as well as about parties involved in firefighting activities. The report gives evidence about the private property damaged as well. Also included is information about persons injured during firefighting activities. Information about costs occurred during firefighting activities in terms of food and other supplies are included as well. Additionally the fire report from the police department Kirchdorf/Pernegg submitted to the public prosecutor is included. This report has the same content as the official fire report.

The internal and external correspondence of the ÖBB provides information related to the fire, about firefighting activities as well as the damage caused by the fire to property adjacent to the railway route as well as future management needs. In this context expert opinions about the approximate succession costs are included. Additionally investigation reports about the damaged brakes of the accident train as well as a proposal for establishing management measures for the affected embankments are included in the underlying documents. Included in the correspondence is an inventory of the damages and the re-establishment costs. Newspaper articles published in two local newspapers in Pernegg give a brief overview about the fire events along the railway route.

Forest maps were provided for both the track between Mallnitz and Pussarnitz in Carinthia as well as the track between Bruck and Frohnleiten in Styria illustrating the property boundaries of ÖBB property along the railway tracks as well as the boundaries of the properties affected and damaged by the fire.

A further report has been provided about a forest fire caused by a train in a community forest close to Arnoldstein on July 22nd and 23rd 2006 along the railway track between St. Valentin and Thörl Maglern. This report provides information about the damage fire has caused in the forest, the persons performing the damage assessment as well as suggested treatment measures and the appropriate time frame for completion.

There was no report and other documentation provided for the forest fires of 1982 along the route between Mallnitz and Kaponig. Therefore only assumptions based on fieldwork can be made about the damage on the examined plots through recording relicts of the damage in terms of visible fire scars on living trees, snags and other damage visible at present. Only a forest map with the boundaries of the plots affected by the fire has been provided. Since those plots have mainly been left to natural succession they are of high ecological significance for the ecosystem, especially for wildlife.

As to the train passage along the chosen routes the infrastructure atlas of the ÖBB has been used. It provides information about the number and type of trains passing along the respective routes.

Documents provided by private landowners and the fire department

Documents provided by private landowners include correspondence with the ÖBB about the damage caused by the fire, the associated costs for re-establishment as well as compensation. Attached to the correspondence documents are provided comprising expert opinion about the damage to the forest stand, the soil, affected forest roads as well as information about subsequent costs in terms of clearing and restoration costs. In addition forest maps of the studied plots showing area boundaries, age classes of trees, contour-lines and neighbourhood were provided. The fire department of Kirchberg/Pernegg has provided a detailed report on the fire, its start, spread, behaviour and duration as well as on firefighting activities and resources involved.

Here the same constraints are valid as above. Complete documentation was only available for the section between Bruck/Mur and Frohnleiten in Styria. The report on the damage assessment of the burned site close to Arnoldstein is the only other documentation available for any forest fire in Carinthia.

Methods

The form developed for the data collection in the field is divided into four units covering all information necessary to assess the fire hazard proceeding from the embankment along the railway track.

The concept and several elements of the first part of the sampling form is derived from the SCA (Student Conservation Association, USA) fire hazard assessment form used by the Fire Education Corps to assess fire risk for structures, especially houses along the wildland/urban interface.

The sampling methods of the Fire Effects Monitoring and Inventory System (FIREMON) were used as a basis to develop own forms and manuals for data collection on the embankments along railway routes as well as on the burned sites. The Fire Effects Monitoring and Inventory System (FIREMON) have been developed by several US based research institutions. The FIREMON field forms have been modified for fieldwork, since they contain all relevant information needed for the assessment. Some elements were adapted to European conditions, especially regarding vegetation assessment. Some elements not fitting to European conditions were left out.

The Fire Risk and Values at Risk Point Rating conducted under the forest fire prevention and suppression regulations of the BC Forest Practices Code was used as a basis for the Fire Risk and Values at Risk rating for the area surrounding the railway route. The contents and elements of the tables were modified and adapted to European conditions as well as to this study.

The first part of the data entry form provides information about the location of the route and the kilometre section the analysed site is located along the route. The kilometre section specifies the position of the site according to the ÖBB infrastructure atlas. Other general information supplied is related to the aspect of the site and the elevation above sea level. The landform describes the general shape of the landscape surrounding the site. Included is information about the inclination of the area in percent as well as the vertical and horizontal slope, which describes the vertical and horizontal profile of the surveyed site. This information is important when assessing the susceptibility of a site to a fire and the components of fire spread and fire behaviour.

Furthermore information is provided about the size of area as well as road access and the distance to a major road. Additionally information is made available about the distance to a settlement, to forests, industry, agriculture and water. This is important in evaluating the fire risk of an area and the possibility to apply firefighting measures. The availability of road and water access is important for planning and performing firefighting activities as well. This aspect is especially important, when the terrain adjacent to the railway track is steep and the terrain is inaccessible. Containing a fire before it escapes from the embankment is crucial to avoid damage to the adjacent area.

General information about the type of vegetation, i.e. grass, herbs, ferns, shrubs or trees and vegetation density divided into "high", "medium" and "low density" is provided as well. Also considered is general information about the topography, i.e. "slope", "aspect" and the presence of "rocky features" as well as information about soil conditions measured in "dry", "fairly moist" and "wet". Those general site characteristics are measured in a distance of 0 to 5, 5 to 10, 10 to 50, 50 to 100 and >100 meters from the railway track. Not only the conditions on the embankment directly bordering the railway track are included into the assessment, but also the state of the area further away from the railway track.

Additionally a picture is provided to illustrate some general characteristics of the site to demonstrate the conditions in terms of fire hazard on the embankments assessed and the potential damages caused to sites affected by an escaped fire.

For the second part of the sampling form the field forms of the US Fire Effects Monitoring and Inventory System (FIREMON) have been modified. The basic codes for data entry have been derived from the FIREMON program. Merely the vegetation codes were adapted to European conditions.

The Plot Description describes general biophysical features of the site. It provides the ecological context for data analysis. The form contains information about the topographical setting, the general plant composition and cover, fuels, ground cover and information about the soil. The amount of dead and down woody debris, the depth of the duff and litter profile as well as the proportion of litter in the profile are sampled using the Fuel Load method. Here also the vegetative cover and height are estimated. Pieces of dead and down woody debris are tallied in the standard fire size classes: 1-hour reaching from 0 to 0.6 cm, 10-hour extending from 0.6 to 2.5 cm and 100-hour from 2.5 to 8 cm. Pieces greater than 8 cm in diameter are recorded by diameter and decay class and the litter depth is estimated as a proportion of total duff and litter depth. If possible the cover of live and dead vegetation is estimated at two points on the plot.

The Species Composition method gives a visual estimation of canopy cover and height measurements for the plant species present on the site. The data obtained are used to floristically describe a stand or plant community. This method is used for a broad range of vegetation types and is especially useful in plant communities with tall shrubs or trees. It proved to be useful for the assessment of the embankments as well. Rare and endangered species are included in the Species Composition form and marked specifically, since a connection between frequent fires on the embankments and rare and threatened species was found.

The fourth part of the data entry form consists of a Fire Risk and Values at Risk Rating. The values used for the fire risk and the values at risk rating are based on the BC Ministry of Forests fire hazard assessment for calculating a fire risk rating and an assessment for rating values at risk close to areas with a fire hazard in BC. Originally this fire risk rating and the rating of values at risk have been developed for the management of harvested areas. The ratings have been adapted to the own survey in order to calculate the fire risk and the values at risk for embankments along railway tracks and for the forested areas damaged by an escaped fire.

The objective of the Fire Risk Rating is to assess the fire hazard of the research sites for the surrounding area. In the rating on-site and off-site values are considered to quantify the fire risk of the area. Site information regarding size of the area, slope and aspect, information about the surrounding area regarding adjacent slash as well as the risk of ignition by lightning, person, railway, and traffic as well as the proximity to the road are relevant.

The Values at Risk Rating considers the risk of fire for life and property, timber values, habitat for plants and wildlife, visual and aesthetic elements as well as cultural values. For life and property values the distance of the site assessed to the next settlement as well as the size of the settlement itself have been considered. For timber values the contribution of the site to the Annual Allowable Cut, silvicultural investments and the silvicultural system, the aspect and slope position as well as the orientation of the valley have been included. As regards the habitat values valuation considered habitat values regarding vegetation, wildlife and fish. A valuation of visual and aesthetic values included visual aesthetic objectives. The cultural valuation takes into account the risk of fire for historical and archaeological sites.[14]

A point rating has been developed for the Fire Risk and the Values at Risk Rating, where numbers of different height are assigned to the site characteristics and characteristics of the surrounding area mentioned above. By adding the numbers obtained during the assessment the values for the Fire Risk and Values at Risk Rating are obtained. The tables developed and used for the point rating are listed in the Appendix.

In order to determine the fire risk of a site and the values at risk in the surrounding area threshold values were selected. The threshold value of 24 was chosen for the Fire Risk Rating and the threshold value of 29 was chosen for the Values at Risk Rating. In case the threshold values are exceeded, the site assessed is considered to have a fire hazard and management measures for a hazard reduction need to be carried out in order to eliminate or at least reduce the fire hazard for the area.

A completed example of the use of the forms is found in the Appendix together with the tables and the rating points for the Fire Risk and Values at Risk Rating.

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[14] Feller, 1999

Time frame and location of data collection

Data were collected along two railway routes in Austria. One route is located between Mallnitz and Pussarnitz in Carinthia and the other route is located between Bruck an der Mur and Frohnleiten in Styria.

Data collection along the rail route between Mallnitz and Pussarnitz was conducted in June 2006 and was divided into two parts. One part was conducted along the old route between Mallnitz and Kaponig. This section has been shut down in 2001 due to the opening of a tunnel between Mallnitz and Kaponig. Along this section four major forest fires have been caused by a braking train in 1982. Data were collected on the four sites in order to conduct a damage assessment, determine the succession state of the vegetation and to reveal damage done to the forest by game. The four burnt sites are a good example for fire being a trigger for forest succession and a local change in species composition. This aspect is especially important when considering the importance of the assessed sites for wildlife ecology. The data obtained along this part of the route show the susceptibility of the dominating vegetation type of the valley to fire and the conditions developing after fire, including selective browsing impacts by wildlife.

Along the active route the attendance of an ÖBB employee was necessary to carry out data collection. Based on the ÖBB fire statistics several sites were selected based on the kilometre information of the fires that have occurred along the route in the past. For this part mainly the embankments and the closer surroundings were considered. Due to the fact that it was mostly not possible to access the sites adjacent to the railway track because of inaccessibility of the terrain and the closeness of the railway as well as frequently passing trains, data of the sites next to the active railway track are mainly based on observations from the distance. In total 21 kilometres of railway track has been assessed, four kilometres along the closed railway route and 17 kilometres along the active rail route.

The railway route between Bruck an der Mur and Frohnleiten has been assessed in July 2006 as well as several times between August and October. Data collection was divided into two parts as well. The embankments along the track were assessed in attendance of an ÖBB employee due to safety reasons because of frequently passing trains. One forest site has been severely affected by the fires in February 1998 and has therefore been chosen as a sample site for all burned forest sites in the area. An unburned site with similar settings as the burned site located along the rail route in the neighbouring forest enterprise has been chosen to be assessed as a reference to demonstrate the seriousness of the fire hazard for adjacent forests, settlements and agriculture existing along the route. Along the route the peak "*Rothleiten*" is located, which is heavily frequented by hikers hiking up to the ravine as well as climbers. The same area is a habitat for alpine ibex as well.

Furthermore a site between Arnoldstein and Pöckau along the route between St. Valentin and Thörl Maglern has also been assessed out of current interest. The forest has been damaged by a fire that has escaped from the embankment along the railway track on July 22nd 2006 due to preceding dry and extremely hot weather[15], which has caused the vegetation to dry out to a point where fire could spread easily. As can be seen in figure 2 on page 4 the recording of forest fires of the hot and dry July 2006 shows a concentration of fires in the region close to the surveyed site.

Little to no information was available concerning the climatic conditions and the significant meteorological variables dominating the fire on the observed sites and their influence on the sites. Therefore this important aspect has not been possible to assess properly.

Due to the limited possibility of data acquisition during fieldwork an extended literature analysis has been carried out to give a detailed picture of fire hazard for the different settings along the routes.

[15] Gossow and Hafellner, 2006

Study sites

Two study sites have been selected that are characteristic for a considerable part of Austria in terms of geological and topographical conditions, vegetation composition, climate and human influence on the respective nature and cultural development respectively. Another reason for the choose of the study sites is that the railway routes are part of major international transit routes for passenger and cargo train traffic between Northern and Southern Europe. Trains are required to brake often along both routes due to the frequently occurring curvy or long, straight and steep sections.

In the following the study sites are presented. Initially a general overview about the historical development of the use of fire by humans in Austria is presented. Then an overview about the development of the Austrian railway is provided followed by an overview about the geological formation of the Alps and an outline of the influences and consequences of the Ice Ages. Next the study sites are presented with an overview about the geology and vegetation of the area. Subsequently an outline of the settlement and forest history and agriculture, forestry and tourism present in the area will be given. Included is the use of fires by humans in both valleys for agricultural and industrial purposes. Additionally the increase of technical causes such as trains for major fire outbreaks is presented.

The first study site is located along the railway route between Mallnitz and Pussarnitz in Carinthia and the second study site is located along the railway route between Bruck an der Mur and Frohnleiten. As for the study site close to Arnoldstein similar characteristics in terms of natural attributes, geology and human history are assumed. Therefore these aspects have not been further described for this site.

Human use of fire and influence on the environment

Cultural development and increasing human influence on nature have significantly altered the natural fire regime in Europe. A cyclical forest-field-pasture utilization of the forest as it is still in use in many tropical countries has been widespread since the late Stone Age, where first settlements and agricultural activities took place. This treatment comprised regular burning of forest in order to remove trees damaged or killed by tannery. The fire released nutrients to the soil, which allowed agriculture on the site for one or two years. The burning of pasture land and forest clearing through fire have also affected adjacent forest intentionally or unintentionally, which has contributed to the degradation of forests, especially in the dry and windy foehn valleys of the Alps as well as in the coniferous forests of north-eastern Europe, which characteristically were low in precipitation[16].

Together with biotic effects such as grazing by wild animals the anthropogenic influences mentioned above are thought to be the reason for dominance as well as absence of tree species in the landscape and the occurrence of tree and other plant species on certain sites since the mid and early Stone Age. Especially in the high mountains, where climatic, topographic and soil conditions themselves cause a harsh environment for the vegetation, anthropogenic influences linked to mountain pastures, agriculture and intentional burning of the forest made the establishment of certain vegetation types more difficult. Besides the positive effects of fire for the cultivation of fields, fire is known to also remove certain nutrients from the soil, which hinders establishment of vegetation, especially trees. Post-fire conditions of a site have greatly influenced the comeback of forest to a burned site as well as species composition. On the other hand ELLENBERG cites GEISER, who states that intentional forest fires have never posed a significant danger to forest structure, in case they have not been set too often[17].

During all times in history professions and activities, which depended in one way or another on the forest and forest products have lead to a major degradation of the forest. Forest use can be divided into agricultural and industrial use of the forest. In some areas various uses have persisted until the middle of the 20th century. Examples are the agricultural use of the forest or the use of forests as pastures[18].

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[16] Ellenberg, 1996; Hasel and Schwartz, 2002
[17] Ellenberg, 1996
[18] Hafner, 1979; Hasel and Schwartz, 2002; Johann, 2004

The clearing of forests for agricultural purposes has been in use since the late Stone Age and has been an old usage right of farmers. In areas where the use of clear cuts was common fire has been used to clear the soil from litter and debris to make the land arable for agriculture. This procedure has been especially common in Styria. However, the agricultural use of a site has been only allowed for one growing season[19]. Fire has also been used to increase the agricultural productivity of fields. Woody debris and litter have been mixed under the soil and burned to increase fertility. Large trees have been used for domestic purposes, the branches and litter have been left on site to burn. In order to prevent fire to escape from the area cautious foresters have burned the area downslope to avoid an escape of the fire, but often the fire has been set uphill due to a lower work load. This has lead to an escape of the fire and as a result to devastating forest fires[20].

Due to an increased awareness of soil and forest degradation forest laws and regulations prohibited or at least limited the use of fire for agricultural purposes. Indirectly the regulations have reduced the fire risk for the forests as well. Since the 16th and 17th century burning of woody material in the forest has been forbidden by several laws and regulations under penalty or has been limited to burning only with a permit by the forester[21]. Figure 3 shows the forest law for Styria as of June 26th 1767.

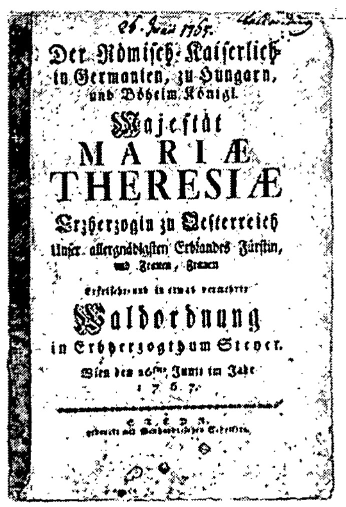
Der Römisch-Kaiserlich
in Germanien, zu Hungarn,
und Böheim Königl.
Majestät
MARIÆ
THERESIÆ
Erzherzogin zu Oesterreich
Waldordnung
in Erbherzogthum Steyer.
1767.

Figure 3: Forest law for Styria as of June 26th 1767 (Hafner, 1979)

[19] Johann, 2004
[20] Hafner, 1979; Hasel and Schwartz, 2002; Johann, 2004
[21] Hafner, 1979; Hasel and Schwartz, 2002; Johann, 2004

Industrial uses of forest resources and related activities have been a significant reason for fire outbreaks in the forest. All industrial uses utilizing timber have been performed inside the forest, some along rivers or other water ways due to the need of transport routes, but numerous have been carried out in remote areas of the forest. Those activities included resin, terpentine and tar production, firewood, charcoal and potash production as well as glass factories. Those goods have been produced in more or less open pits on wind-exposed sites mostly on slopes. This exposure to wind has had an influence on fire severity of escaping fires.[22] Even though most productions have used dead woody material first and therefore cleaned the forest from woody debris, they were still the main reason for forest fires and a significant degradation of the forests in the long run, which has made the forests susceptible to diseases and forest fires.[23] The industrial uses of the forests have always been followers of the forests. Every time a forest has been exploited, the whole industry has been moved to the next forest to repeat exploitation. Therefore whole landscapes have changed and have become susceptible to fire.[24] Figure 4 shows an illustration of the profession of the charcoal burner from 1689.

Figure 4: "The charcoal-burner", 1689 (Hafner, 1979)

[22] Hafner, 1979
[23]
[24] Hafner, 1979; Hasel and Schwartz, 2002; Johann, 2004

The same is true for forests around former salt-works and mines. They have been consumed for fuel and construction wood for mine galleries since the Celtic period. When forests directly adjacent to the mines have been depleted the required timber has been transported from areas further away. This has lead to an increasing degradation of the forests leaving them susceptible to wildfires.[25]

Only the introduction of mineral coal has lead to the separation of mining and forestry and therefore to a significant reduction of fire risk in the forests associated with charcoal production. By-products of mineral coal have been used for the artificial production of pot-ash and other goods formerly being dependent on timber as basic material. Therefore the professions related to their production have died out as well, as did the risk of forest fire related to them. In this context the construction of the Austrian railroad has lead to a shift in importance from the depletion of forests to sustainable timber production. To obtain valuable timber got more and more important, e.g. as construction material for mines or for railway sleepers.[26]

Wagons on rails as used in mines have been used in many parts in Styria since the second part of the 19th century to carry big loads in the forests, especially during timber harvest operations. Before the use of steam-engines the downhill travel of the wagons has taken place with the help of gravity and brakes, whereas the uphill transport has been accomplished by horse power. The use of steam-engines, which have been fired with debris, has made the wagons an efficient and cheap transport method. Due to declining profitability those forest railroads have been removed. However in some places across Styria this system has been in use until the 1960'ies.[27] Due to the fact that this "forest railroad" has been operating with steam-engines and with frequent braking during downhill travel, those wagons might have been a significant risk for a forest fire as well. Figure 5 shows a braking slope of a so-called "forest railroad".

[25] Hafner, 1979; Murray et al., 1998; Hasel and Schwartz, 2002; Johann, 2004
[26] Hafner, 1979
[27] Hafner, 1979

Figure 5: Braking slope close to Steinhaus, Styria (Hafner, 1979)

History of the Austrian railway

In the first half of the 19th century the Austrian empire stretched from the Bukovina and East Galicia over Poland, Austria and what is the Czech Republic today to the Lake of Constance in the West and in the North-South direction from the ore mountains north of Bohemia to the Lake of Garda in South Tyrol and to Triest at the Adria coast in the South. Towards the east the Austrian Empire included the Hungarian kingdom.

The construction of the railway through the empire encountered two problems. One was the overcoming of the high mountain ranges of the Alps and the other one was the provision of large mass transports over considerable distances. Especially for the routes leading through the Alps those problems needed to be solved through a new construction method of the routes, which could master the ascents and curves in mountain regions and through the construction of special engines, which were able to overcome the often narrow curves in mountain areas and had a maximum of tractive power.

Through the relatively low population density, the domination of agriculture and the considerable distances of the Empire caused a technically rather uncomplicated construction of the railway routes and relatively low travel speeds and train density.

In the early 19th century the construction of the railway has been conducted by the state as well as by private companies. Around 1854 924 of the total 1355 kilometres, this was 68 percent of the railway routes belonged to the state. In the middle of the 19th century the sale of the railways became necessary due to the governments debts as a result of the war against Prussia and other reasons. As a result only 18 kilometres of railway routes were owned by the state at the end of 1866. Not until 1874 the finances allowed the state to construct, to pursue and to re- acquire railways and railway routes. In the following 20 years the Austrian railway system grew to a considerable length. In the years 1884 and 1885 the state railway of the Austrian part of the Empire were integrated in the "*k. k. Staatsbahnen*". At the beginning of 1886 the total length of the railway net amounted to 21786 kilometres. At the end of the 19th century the single routes were connected with each other so that a continuous route system resulted. At the turn of the 20th century only a small part of the main railway routes were still privately owned.

Originally left-hand traffic existed along the double-tracked railway routes in Austria. After the "*Anschluss*" of Austria to the German Reich the federal railway started with the conversion to right-hand traffic. Since Austria obtained independence again after World War II this goal was not totally fulfilled so that today routes with right-hand traffic exist as well as routes with left-hand traffic.[28]

Formation of the Alps

The Alps are one of the most complicated structured areas of the world. The structure and exact age of the rocky features have not been understood or interpreted in a correct way. Only at the beginning of the 20th century it has been realised that a cover mountain range exists, where parts of the earth's crust originally located next to each other have been pushed on top of each other repeatedly so that today older layers are lying on top of younger layers.[29]

The present alpine relief has been formed by glacial and fluvial smoothing and additionally through the accumulation of rock masses. The development of the alpine relief has occurred in several phases. It is assumed that the present alpine relief has evolved from a hilly landscape over highlands to high mountains in the early tertiary period.[30]

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[28] www.oebb.at
[29] Tuppinger, 2001
[30] Dongus, 2003

During this period the European and the Eurasian plate respectively drifted to the south, whereas the African plate has drifted northwards. The Eurasian plate has been pressed underneath the African plate, whereas the rock formations of the northern geological zones were pressed under the southern geological zones. The southern geological zones on the other hand have been piled up northwards. Today the rock formations of the southern upper east alpine zone are lying on the top, whereas the helvetic and penninic zones originating in the north are lying underneath. The individual rock formations have been folded, scraped, broken and compressed several times during the whole process. Therefore many details of the formation of the Alps are still unclear. After completion of process in the early tertiary period the lifting phase has started causing the overlying layers cracking or gliding downwards. In connection with those movements the low-lying Penninic has reached the surface and formed the different "cracks" in the heart of the eastern alpine mountains. In some regions lifting processes are still going on.[31]

Influences and consequences of the Ice Ages

The Ice Age has been the second major forming process for the relief of the Alps, which obtained its present nature during this period. The earth's climate has cooled down several times during earth history leading to the glaciation of a significant amount of the alpine landscape. Especially the high mountains with its cirques and trough valleys have been formed during several glaciation periods. Only little parts of the southern West Alps and the easternmost East Alps have not been influenced by glaciation.[32]

The last Ice Age has occurred around 2 to 2.5 million years ago. Temperatures have dropped significantly for several times so that extensive glaciation has taken place leading to an extensive ice mass proceeding from the arctic region to the south as well as to glacier formation in the Alps. In total six or seven Ice Ages with periods of milder climate can be distinguished. A large amount of evidence is available from the so-called Würm Ice Age. Investigations have shown that for an extensive the climate has only been slightly cooler than today so that the vegetation over most of Austria corresponded to the vegetation found in the heath belt today. [33]

[31] Tuppinger, 2001
[32] Tuppinger, 2001; Dongus, 2003
[33] Tuppinger, 2001

During the Ice Ages the snow-line of the Alps was located around 1200 meters below the current snow-line. In the central Alps the snow-line was located between 1800 and 2000 meters, towards the northern end of the Alps between 1100 and 1200 meters and towards the southern end of the Alps around 1400 meters. Only towards the eastern edge of the Alps the depression of the snow-line has been lower due to a generally milder climate and due to the increasing influence of the continental conditions. During the Ice Ages the snow-line has been 800-900 meters lower than the present snow-line.[34]

During the Würm maximum almost all peri-glacial valleys have been filled up with ice, which formed glacial streams. A substantial part of the high mountains has become the source for the ice masses of Alpine glaciers emerging through the different valleys. Some of the glaciers have reached a size of more than 20 kilometres and covered a significant area. A significant part of the Austrian Alps were characterised by a net of glacial streams rather than a continuous ice field. The ice masses have scratched and planed the underground and transported several millions of tons of scree, which led to a significant landscape change. Today the different sediments left by the glaciers are important as construction material, industrial landscape and source of raw material as well as carrier for ground water. The sediments can be found in the main as well as the side valleys throughout the Alps. Through the increasing ice masses and the damming up of the glacial streams at the transition of the side valleys to the main valleys the glacial ice has been pushed above the snow-line. Only towards the edge of the Alps the surface of the glaciers sank below the snow-line due to the unlimited flow. During the main period of glaciation only the highest peaks of the Alps were ice free. The magnitude of the ice field was located between 1200 and 1300 meters. Due to the increase in magnitude of the ice fields and the higher flow velocity the intensity of ice erosion was greater in the main valleys than in the side valleys, which has lead to a lower abrasion of the side valleys.[35]

Due to a sudden increase in temperatures at the end of the Ice Age 18000 to 19000 years ago a rapid retreat of the glaciers has occurred in a period of 1000 to 1500 years. Spruce and larch have been able to colonise the slopes of the valleys among other vegetation communities. The retreating glaciers left massive deposits in the valleys and have changed the form of the rock basis. At the same time the formation of cirques in the high mountains took place, the rocks smoothed and round humps and glacial grindings were created.

[34] Dongus, 2003
[35] Tuppinger, 2001; Dongus, 2003

The slopes of the trough valleys, which are typical for formerly glaciated areas, are excessively steep due to abrasion. The retreat of the ice supporting the slopes has left the slopes instable. Depending on the basic material gravity the retreat of the ice has caused more or less massive landslides, which in turn has left holes in the mountain slope and has caused an accumulation of material in the valley. This has resulted in a substantial change in the landscape.[36]

Carinthia

The study area in Carinthia is located in the Möll valley between Spittal/Drau and Mallnitz. The south-western border of the National Park "Hohe Tauern" is running through the valley. The valley as well as all traffic routes runs in a north-western to south-eastern direction. The federal car route the Tauern rail route is the important transit route through the Möll valley. Both routes are, together with the Möll River the dominating geographical features of the valley. The communities Mallnitz, Obervellach, Reißeck and Mühldorf are the biggest townships in the valley. The villages in the surroundings are politically united under the different townships. The municipalities in the valley politically belong to the district of Spittal/Drau, which is located at the entrance of the valley. On the north-eastern side the valley is dominated by the Reißeck group, whereas the south-west side of the valley is dominated by the Kreuzeck valley. The Ankogel group confines the valley in the north; towards the south-east the valley is open.[37] A map of the valley is given in figure 5 on page 34.

Geology

The Möll valley belongs to the mountain range of the Hohe Tauern, which forms the main ridge of the Eastern Alps between Brenner and Katschberg corridor as glaciated high mountains together with the Zillertaler Alps. The region is characterised by the central gneiss and the *„Tauernfenster"*, which reaches its southern end in the region of the Möll valley. The central gneiss forms composed shapes with glacial formation and smoother slopes. The grassy and furrowed mountains consisting of schist layers form a contrasting picture to the one of the central gneiss. Lime phyllite characterise the mostly long valleys forming trough valleys with a estuary mouth which is divided by a ravine. The rocky flanks are mostly forested, whereas pastures are found in the valleys and the lower cirques. Little vegetated moraines show the position of the glaciers as of 1850.

[36] Tuppinger, 2001
[37] Tuppinger, 2001

In the "*Tauernfenster*" between the Brenner and the Katschberg furrow the deepest tectonic elements of the eastern Alps have emerged. The "*Tauernfenster*" is divided into the three main units of the central gneiss with the lower schist cover in the centre, the upper schist cover in the south and the lower eastern alpine frame around the penninic opening.

The uppermost structural unit of the mountain range is the eastern alpine ancient crystalline. Below the crystalline formations different patterns of slate mica predominate. Quartzite and marble emerge only secondarily. Deposits of the early Palaeozoic period such as loam, sand and different limes form the initial materials for those rocks and were formed through metamorphosis during mountain formation. Volcanic stone formations originated in the early Palaeozoic period, whereas lava rich in silica acid emerged during the variscan mountain formation and are present as granite gneiss, diorites and pegmatite. Lava rich in silica acid emerged during the alpidic mountain formation as well.[38]

The rock formations of the Kreuzeck group are geologically divided into a northern and a southern clod with light gneiss as well as light and dark eye gneiss tonalite and granodiorite in the central gneiss formation. Above the central gneiss late Palaeozoic layers and perm-triadic quartzite are located as well as limes and dolomites. During the Jurassic period layers containing lime, quartz and clay elements present as grey "Bündner schist", black phyllite or slate mica today were formed.

Throughout the Alpidic Mountain formation the different layers have been mixed together and different covers and lamellas were formed. The cores of the central gneiss have remained in their original position and the ancient crystalline stones and Palaeozoic schist, the stone formations of the Permic Trias, the lamellas of the central gneiss and the young layers of the Bündner schist were mixed to different semi-autochthonous cover systems.[39]

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[38] Geologische Bundesanstalt 1980; Tuppinger, 2001
[39] Geologische Bundesanstalt, 1980; Tuppinger, 2001

Climate

To the north the Möll valley is closed by a mountain range and is open to the south east. Therefore the climate of the valley is influenced by a continental climate. The climate in the valley is a typical alpine internal climate with remarkably warm summers and cold winters with low precipitation in the valley. Precipitation increases towards the summits, where the climate has an Atlantic influence.

	Stall	Möll valley
Valley bottom	800 to 1000 mm	500 to 900 mm
Valley to 1400 m	1000 to 1200 mm	
1400 to 1600 m	1200 to 1400 mm	
1600 to 2200 m	1400 to 1600 mm	
Peak	1600 to 2000 mm	up to 2500 mm

Table 1: Mean yearly precipitation (Johann, 2004)

Sunshine duration is five to ten percent higher than in the rest of the Eastern Alps. The climate of the valley is very rough and the vegetation periods are very short due to low mean temperatures and a long lasting snow cover. The average vegetation period varied from 269 days in the valley bottom starting the first days of May to 169 days in 2000 meters starting in June (Johann, 2004). The average duration of snow cover lasts from three to four months in the valley bottom over four to six months on the slopes to more than six months over 1600 meters.

The mean temperature decreases with increasing altitude. Table 2 shows mean temperature values for different locations at different altitudes in the Möll valley between 1901 and 1950. [40]

Place	Altitude (m)	January	July	yearly mean	Yearly fluctuation
Sonnblick	3105	-13°C	1.2°C	-6.2°C	14.2°C
Heiligenblut	1378	-3.6°C	14.2°C	5.2°C	27.8°C
Mallnitz	1185	-3.6°C	14.4°C	5.2°C	28°C
Obervellach	675	-3.3°C	18.4°C	8.1°C	21.7°C

Table 2: Mean temperature 1901 to 1950 (Johann, 2004)

[40] Johann, 2004

Natural characteristics of the valley

Characteristic for the valley is the significant altitude difference reaching from 600 meters above sea level at the valley bottom to almost 3000 meters and the already mentioned dry continental climate. The railway route traverses an altitude of approximately 200 to 300 metres from Mallnitz to Pussarnitz. Therefore most natural characteristics described in the following can be found along the whole route.

The Möll valley is rich in different habitats with a high diversity in plants and animals. Human activities have formed the landscape during the past 6000 years as well. Especially the valley bottom has been influenced and formed by activities related to agriculture and forestry, often with negative consequences for nature. Habitats have been altered through anthropogenic alteration of the existing natural conditions including pastures in the valley and in high altitudes or with logging activities affecting forest structure and the timber line. Natural habitats have disappeared and have been replaced by habitats influenced and shaped by humans. Therefore they can only be found in inaccessible areas such as steep slopes and inaccessible screes and hold several rare plant and animal species.[41] The extreme mountainous conditions during the Ice Ages have shaped the whole valley, which is the reason for the occurrence of frequent natural disasters such as floods, avalanches and mudslides.

Soils consist of different materials depending on the altitude. Braunerde has accumulated mainly on the alluvial fans consisting of sand and coarse gravel, which consist of silicate. Brown soil is present along the slopes with different structures as well. The soils blend into the rock region and the scree without any special soil formation. Podsols are found in the valley as well. Fires have lead to a degradation of the soil until the middle of the 20th century.

The forest of the area belongs to two different forest types. The upper Möll valley is dominated by spruce, the lower Möll valley and the Malta and Katsch valley by fir-spruce forest. The coniferous belt of the west is dominated by spruce forests, whereas the forest in the east is dominated by the coniferous belt consisting of spruce and larch, which starts at the valley bottom and reaches up to an altitude of 1800 meters above sea level. Its quality is higher on the shadow side than on the sun side of the valley. [42]

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[41] Tuppinger, 2001
[42] Johan, 2004

Following the coniferous belt above 1800 meters the dwarf mountain pine region starts with stone pine, alder and dwarf mountain pine pursued by the heath belt with extensive alpine pastures up to an elevation of 2500 meters. Human influence and especially forestry has excluded the natural deciduous forests on the south slopes over centuries in favour of coniferous forests.[43]

On screes and rocky areas different grass communities come up. The composition depends on the soil basis, which influences the species richness of the community as well. The abandoned pasture land of the area is characterised by vast heath lands with *Vaccinium* and *Rhododendron sp.* and the areas around the creeks are characterised by different low shrubs and herbaceous plants. On several small and remote sites such as ravines plant communities consisting of *Acer sp.*, *Fraxinus sp.*, *Robinia pseudoacacia*, *Fagus sp.* and *Salix sp.* are found. Those ravines have become subject to nature conservation and are protected.[44]

The whole valley is rich in many different ecological niches, offering a habitat for many species. Besides the species typical for the alpine environment such as marmot, ptarmigan and capercaillie several endangered species as well as species at the boundary of their area of distribution and species adapted to a certain habitat such as bats occur. In the forests as well as in higher altitudes foxes, chamoix, martens, badger, red and roe deer are present. On dry sites the poisonous common viper as well as the Aesculapian snake (*Zamenis longissimus*) is present.[45]

History of human influence

Mining activities can be dated back to Celtic tribes and the Roman Empire, where gold has been mined. Gold mining has been centralised since the beginning of the 16th century under Emperor Maximilian I. The area around Obervellach and Reißeck did not have significant ore deposits, whereas the neighbouring Kreuzeck group had ore deposits of different composition, which were exploited in many little operations. Ores found reached from gold and silver in gravel to ores formed by galena, zinc blende, pyrite, copper pyrite and others. First records of ore mining can be found in the year 1480 followed by several other written documents in the following years.

[43] Johann, 2004
[44] Tuppinger, 2001; Johann, 2004
[45] Tuppinger, 2000; Johann, 2004

Colonization of the valleys is strongly connected with ore mining, especially in the Middle Ages, when the climate in the area has been favourable with temperatures 1 to 1.5° C higher than today. The highest settlement documented was located at an altitude of 2700 to 2900 meters.[46] The Little Ice Age however with its temperature decrease has brought a change for mining, which had to be stopped from September until Pentecost the next year. This means that mining had to be stopped in many mines during the 17th century. It terminated in the valley in the middle of the 17th century. Ore mining in the Reißeck group has been relatively insignificant and the exact locations of the mines are not known. In Napplach several smelting ovens and iron-rolling mills have been located, which have been altered into iron ovens after the deterioration of gold mining at the end of the 17th century. The timber for the ovens has been delivered from the forests in the Mallnitz valley. The decline and finally the termination of ore mining in the area all smelting ovens have been shut down during the beginning of 19th century.

Pasture farming and forestry are characteristic for the whole Möll valley. The best agricultural soils are found on the alluvial fans of the side creeks of the Möll as well as the major share of the settlement activity in the valley. Characteristic for the whole Möll Valley is also the contrast between the steep ascending shadow side and the sun side of the valley, which is divided into two terrace systems. The shadow side is mostly forested down to the valley bottom, whereas the sun side of the valley is occupied with single farms up to a height of 1500 meters. Above that the rock and ice region is located up to a height of 1800 meters and the firn region up to the height of 2200 meters.[47]

Settlements mostly consisted of farms with forest property and of so called "*Schwaigensiedlungen*" with forest usage rights in higher altitudes. Settlements of miners with no or little property were located in the valley, while the highest pasture settlements were located at an altitude over 2200 meters. The boundary of alpine pastures and the timberline is mostly ragged and a significant part of pasture hats were located above the natural timber line, which has been pressed down below the altitude the hats were located. [48]

[46] Tuppinger, 2000; Johann, 2000
[47] Johann 2000; Tuppinger, 2001; Johann, 2004
[48] Johann, 2000; Tuppinger, 2001; Johann, 2004

Forest pasture and litter removal as well as burning of debris have lead to a massive degradation of the soil and the forest in the whole valley and in the following to a significant change in forest structure and landscape. Due to the increased use of spruce branches for fodder and litter the spruce, which has been the dominating tree species, has been suppressed in favour of the larch.

Until the middle of the 20th century more than 60% of the valleys population has lived on the valley bottom in closed settlements with professions as temporary workers, small-scale industry workers, craftsman and other professions such as teachers or foresters, whereas the low-income small farmers were at the upper settlement boundary.[49]

Description of the railway route

For the underlying study the section of the "*Tauernbahn*" between Mallnitz and Pussarnitz has been chosen for several reasons. The "*Tauernbahn*" is a major transit route for both passenger and freight trains between Northern and Southern Europe. The curves and the gradient of the whole route lead to a frequent braking of trains in order to reduce their high speed. The construction of the Kaponig tunnel has lead to the shut-down of a section of the route, which has been subject to four major forest fires caused by a train, possibly by a braking train in 1982.

The rail route between Mallnitz and Pussarnitz runs along the north-east side of the valley. The dominating aspect is south to south-west facing, which explains the extreme climatic conditions along the embankments and in the adjacent forests or agricultural areas alongside the whole route.

The section of the route starts in Pussarnitz at the valley bottom and ascends constantly all the way to Mallnitz. For the most part of the route the railway runs along the lower and middle section of the slope. The terrain along the route has a slope of 70 to 80 percent and leads through rocky terrain. In total between 200 and 300 meters in altitude are overcome on the whole route. Several bridges pass the crossing side valleys. Figure 6 displays the Möll valley with the infrastructure leading through the valley.

[49] Johann, 2000; Johann, 2004

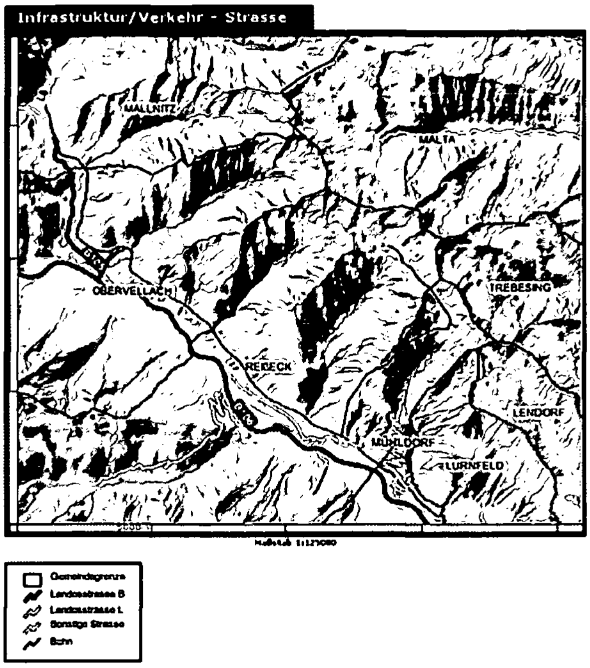

Figure 6: Route between Mallnitz and Pussarnitz (Source: ©KAGIS, BEV)

Several land use practices and property structures can be found along the railway route. The embankment directly adjacent to the route along the active route is the property of the ÖBB. The forests are partly ÖBB property and partly private property as are the agricultural sites. As for the forest property it was not possible to make out the property conditions in all cases except the ones where damage occurred due to an escaping fire, since no documentation regarding the property was provided.

The agricultural sites and settlements close or adjacent to the railway route are located between Pussarnitz and Mühldorf, whereas the rest of the route between Mühldorf and Mallnitz is surrounded by forest. Due to the proximity of the National Park "*Hohe Tauern*" and areas such as the Reißeck Mountain the Möll valley is highly frequented by hikers and the forests around the railway route are made accessible by hiking trails. Structures are present along the route between Mühldorf and Mallnitz in terms of the railway stations Penk and Kolbnitz and several farms and other housing. As regards the railway stations only the railway station of Kolbnitz is still in use, whereas the station in Penk is not in use anymore. Nevertheless the housing around the station is partly still in use. Figure 7 shows a farm house within pastures along the route.

Figure 7: Building along the route

Access to the railway track in terms of roads is not given along the whole route. Especially along the steep and rocky sections the route is inaccessible for vehicles except trains. This reduces the possibility of firefighting activities in case of a fire along the embankments. Paved routes are available at or close to the railway stations as well as close to settlements. In agricultural areas lanes are running along the railway route. Trails leading to Alpine pastures cross the railway route below the track on several locations. Figure 8 gives an example of the inaccessible part of the route.

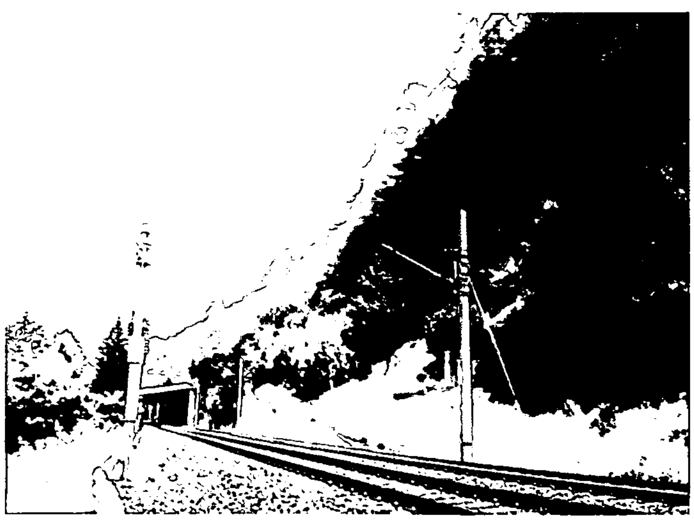

Figure 8: Inaccessible part of the route

The active route between Mallnitz and Pussarnitz is subject to major construction works in order to straighten out the curves to reduce the braking frequency of the trains. This gives the author the possibility to propose management measures for the newly established embankments to reduce the fire hazard along the route. During the ongoing construction works roads are built along the tracks to guarantee a better maintenance of the track and the embankments along the route. The roads may serve as a fire break and also provide a better possibility for firefighting activities. Figure 9 shows a newly constructed embankment with a maintenance road running along the track.

Figure 9: Newly established embankment

The four sites burned in 1982 are located along the inactive part of the railway route between Mallnitz and Kaponig. This section of the route is now used as a hiking trail and, together with the still existing tunnels of the old route as a rescue route for the Kaponig tunnel. There are two access routes to this section as well as a landing spot for helicopters. The old railway housing along the route has been sold to private persons. Therefore cars are regularly passing along this section as well. Figure 10 shows the forest fires of 1982 along the old route between Mallnitz and Kaponig.

Figure 10: 1982 forest fire sites

Site description Arnoldstein

A forest site along the railway route close to Arnoldstein in July 2006 has been included in the analysis, since a fire has destroyed ten hectares of community forest. The soil and the trees on the site have experienced major damages. The burned site is located close to a cargo station. Figure 11 shows the railway route and the site close to Arnoldstein.

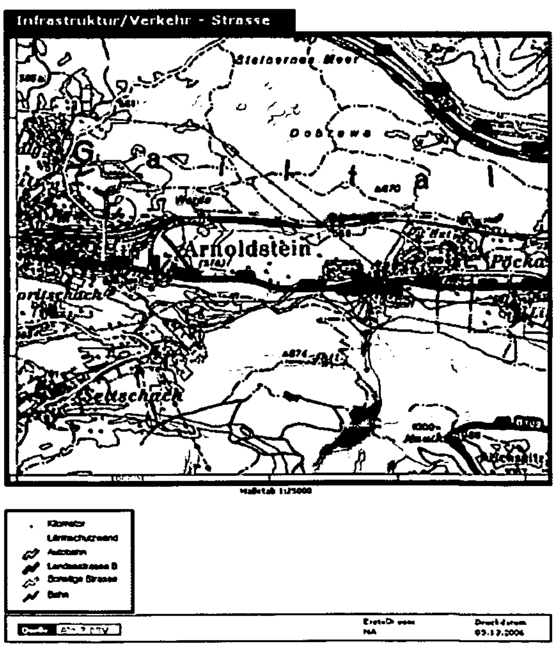

Figure 11: Railway route close to Arnoldstein (Source: ©KAGIS, BEV)

The slope of the site is located between 55 and 65 percent and the horizontal and vertical shape is undulating. This topographical feature has had a significant influence on fire behaviour and spread. The main aspect of the site is south. However due to the undulating terrain the aspects are changing so that site conditions are slightly different.

Along the top of the site a power line is located, which has been at risk during the fire. It has been switched off during firefighting activities. Along the bottom as well as along the top of the site forest roads are running along, which serve as access routes to the site.

The forest stand mainly consists of planted *Pinus sylvestris* and *Picea abies*. At some locations groups of deciduous trees have been standing. Due to the fire the understory was lacking, but it can be assumed that the understory along the embankment and the forest roads as well as underneath the deciduous trees has been dense.

The site has been severely damaged by the fire. The understory has been burned completely and the soil has been burned down to the mineral soil on a significant part of the site. The coniferous trees on the site have been affected quite severely by the fire, whereas deciduous trees did not show as much obvious damage. Apparently the fire has been only a surface fire, which has not developed into a crown fire. Nevertheless the fire has caused extensive damages on the trees. The bark has been scorched and ruptured severely on a major part of the trees up to a height of approximately 1.50 meters. Figure 12 shows the conditions ten days after the fire.

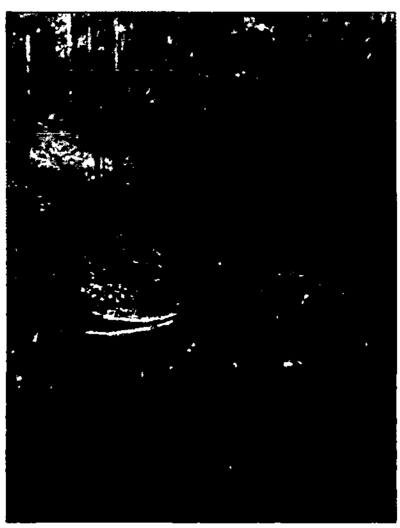

Figure 12: Conditions on burned site

In areas, where the understory has been burned completely and trees do not hold back the soil, erosion processes may occur in the long run, in case the vegetation does not reoccupy the site rapidly.

Styria

The second railway route analysed for this paper is located in the Mur valley between Bruck an der Mur and Frohnleiten. The section is part of the rail route between Bruck an der Mur and Graz and runs in a north-south direction along the valley bottom. The forest fires caused by damaged brakes of a freight train occurred in February 1998 between Übelstein and Laufnitzdorf, a curvy section of the route. Together with the federal car route the rail route is one of the main connections for traffic between northern and southern Europe.

Trains travel as far as Greece. Similar to the railway route in Carinthia the rail route, the federal car route and the Mur River are the dominating geographical features in the valley. The valley is an important settlement and market area. Settlements are dominating the valleys and are increasing in number so that nothing is left from the natural landscape with the shaping role of the river.[50]

Geology

The study site in Styria is characterised by two different geological formations. The area between Bruck an der Mur and Mixnitz belongs to the geological system of the *Stub-* and *Gleinalpe*, the south western *Fischbacher Alps* and the crystalline area of *Anger*, whereas the area between Mixnitz and Frohnleiten belongs to the *Grazer Bergland.*

The mountains of the region are characterised by curved forms and peaks poor in rocks reaching into the region of Alpine pastures and are rich in forests. Only the highest mountains have cirques dating back to the Ice Ages. The highest peaks are the *Stubalpe*, *Ameringkogel* (2186 m); *Gleinalpe*, *Speikkogel* (1988 m); *Fischbacher Alps*, *Rennfeld* (1629 m). The northern slopes are facing towards the Mur valley and in the east towards the Mürz valley.

[50] Fossel and Kühnert, 1994

The area around Pernegg belongs to the *Mugel-* and *Rennfeld crystalline*. Granite gneiss of different texture and composition occur in low quantities together with the dominating schist, plagioclase, biotite granite gneiss and amphibolites and which form the Paragneis cover. The rock formations show post-crystalline deformations and traphoresis, which can be associated with the alpidic orogenesis.

The study site close to Mixnitz is located on the boundary of the "*Grazer Bergland*" and the geological formation of the *Gleinalpe*. The "*Grazer Bergland*" is a low mountain range with a structure high in diversity implied by a large range of rock formations. The Mur breaks through the crystalline mountain range of the Syrian mountain rim in a steep and rocky valley. The highest mountains consist of limestone. The *Hochlantsch* is a characteristic mountain range and rises above the other ranges. Several well-known caves such as the "*Bärenschützklamm*" are located in this karst region. In between the high mountain ranges gentle hills are formed by softer strata or basins. Altitude differences up to 700 meters, locally up to 1300 meters were formed by the relief energy. The highland and the plains interlock with each other.

In the area between Frohnleiten and Breitenau the *series of Laufnitzdorf*, composed of dark shale schist and limes of Ludow, the *Dornerkogel* layers, built of sand stones, grauwacken and schist of several 100 meters in depth and the magnesites of the Breitenau were united to the *Dornerkogel group* together with the pebble schist of the region.[51]

Climate

The study site is located in the Styrian mountain rim and has a rather continental character. The moderately winter cold and summer warm characterises the valley through a better ventilation, a lower fog and high fog frequency with a rare occurrence of stifling heat through favourable circulations of local wind. The precipitation in this region is lower than in the adjacent mountain ranges and shows a decreasing trend from the Southwest to the Northeast. The most important climatic elements of the region are summarised in table 3.

[51] Geologische Bundesanstalt, 1980; Fossel and Kühnert, 1994

January °C	- 3° to - 4°C
July °C	15° to 18°C
yearly mean °C	6° to 8°C
yearly fluctuation	19° to 21°C
daily fluctuation	9° to 10.5°C
mean absolute minima	-18° to -20°C
absolute minima	-26° to -29°C
mean absolute maxima	29° to 31°C
absolute maxima	33° to 36°C
duration of vegetation period	1./10.4. to 1./5.11. (204-220 days)
length of vegetation period	204-220 days
days with fog	40 to 70 days
days with thunderstorms	30 to 40 days
days with precipitation	100 to 115 days
magnitude of precipitation	1200 (SW) to 900 (NE)
days with snow cover	70 to 90 days
mean wind speed	1 to 2 m/s

Table 3: Climatic conditions of the region (Wakonigg, 1978)

The favourable conditions of this climatic range generally are positive for summer tourism. An exception is the region between Frohnleiten and Gratkorn, which belongs more to the terrace climate of the foothills with its winter temperatures over -3°C and summer temperatures over 18°C, a precipitation below 850 mm and only 50 to 60 days with snow cover. This climate is suitable for grain, maize and fruit cultivation. At the same time the area is not well suited for tourism because of the predominant significance for industry. [52]

The climatic zone of the valley bottom passes over to the climate of the lower mountain step of the mountain rim. This region is a narrow altitude zone between a lower boundary of 900 meters and an upper boundary of 1400 meters. This area is regarded as a climate area of its own due to the favourable atmospheric conditions in winter. This climate can be considered as moderately cold in winter and cool in summer. The high fog stratum is dominant in this region. Therefore winters are less severe and the conditions of sunshine are better. The climatic conditions in this altitude range are listed in table 4.

[52] Wakonigg, 1978

January °C	- 3° to - 4.5°C
July °C	13° to 16°C
Yearly mean °C	4° to 6.5°C
Yearly fluctuation	17.5° to 19 °C
daily fluctuation	6° to 7°C
Mean absolute minima	- 17°C
Mean absolute maxima	24 to 28 °C
days with frost	130 to 150
summer days	10
duration of vegetation period	10./30.4. to 18./31.10.
length of vegetation period	170 to 205 days
days with fog	60 to 120
days with more than 10°C	100 to 140
days with precipitation	122 (SW) to 115 (NE)
Magnitude of precipitation	1400 mm(SW) to 1000 mm (NE)
Days with snow cover	110 to 140 (SW); 100 to 130 (NE)

Table 4: Climatic conditions of the lower mountain region (Wakonnig, 1978)

This climate region is located in the lower coniferous belt and represents the highest zone of agricultural use and settlement. The area suffers from a rural exodus, which leads to a drop of the settlement boundary towards the initial settlement boundary. Because of its relative aridity and favourable sunshine conditions this region is more suited for cures than for a skiing industry, since snow conditions are too unsafe and the duration of winter is too short.[53]

Above this zone the upper mountain zone south of the main ridge of the Alps follows. This zone is located between the upper settlement boundary at 1100 to 1400 meters and the timberline at 1700 to 1900 meters. This fact determines the thermal conditions of this climatic belt. In this zone also high valleys and narrow dusky valleys are found, which are unsuitable for settlement. The winters in this climatic zone are cold to severe, whereas the summers are cool to harsh. In total the climate of this region can be regarded as extreme. The mean and marginal values are summarized in table 5.

[53] Wakonigg, 1978

January °C	- 4° to – 7°C
July °C	10° to 13.5°C
Yearly mean °C	2° to 4.5°C
Yearly fluctuation	16° to 18 °C
daily fluctuation	5° to 7.5°C
days with frost	130 to 150
summer days	10
duration of vegetation Period	1./19.5. to 8./20.10.
Length of vegetation Period	143 to 173 days
days with fog	80 to 150
days > 10°C	50 to 100
days with precipitation	115 to 140
magnitude of precipitation	1050 to 1500
days with snow cover	120 to 180
wind speed	2 to 4 m/s

Table 5: Climatic conditions of the upper mountain region (Wakonnig, 1978)

In the high valleys the mean temperature in July exceeds 14°C, whereas the yearly fluctuations exceed 19°C and the daily fluctuations exceeded 8° to 9°C. Frost is also common during summer in this region and real summer days can only be expected every now and then. The number of days with fog is increasing due to cloudiness. The relative amount of sunshine lies in winter around 40% and is very favourable, whereas it does not reach 50% during summer. Precipitation increases towards the south and the *Koralpe* as well as to the North towards the main alpine ridge. Here also a vertical increase can be found. The distribution of number of days with snow cover is similar. This notable range is based on the big difference in altitude found in this zone.

This zone is located in the coniferous belt above the upper settlement zone. Besides forestry also Alpine pastures are found in this region. The use of Alpine pastures experiences a recession and the area is reoccupied by forest. Locally conditions for skiing tourism in winter are favourable in the main season, but for an extended season not possible below the altitude of 1700 meters. Conditions for tourism activities in summer are too unfavourable. Then this zone is located below the area interesting for alpine tourism. [54]

[54] Wakonigg, 1978

Natural characteristics of the valley

The landscape of the Mur valley has a diverse structure. It reaches from the relics of the flood plains along the Mur and the forests mainly consisting of *Picea abies* and *Larix europaea* to the alpine meadows and karst peaks. The deciduous forests of the "*Grazer Bergland*" are dominated by *Carpinus betulus*, *Quercus sp.*, *Castanea sativa* and *Sorbus torminalis*. *Picea abies* is the most important tree species used for timber production. On steep and drier soils *Pinus sylvestris* is growing. *Daphne sp.* and *Pulsatilla styriaca* are found in the understory. A special structure to be mentioned is the extensive marsh area in the valley of Tragöß. In all zones various conservation areas are to be found. The rests of former flood plain forests are found along the whole Mur. Those rests still give an impression of the meandering river bed of former times.

Along the whole Mur several remarkable landscape elements are found including lakes, tree groups, relic floodplains or landscape fragments influenced by human activity, which have a high value. Several locations in the valley hold various representatives of endangered species being listed in the Red Lists. Around those landscape elements conservation areas have been established.

The conservation area "*Kirchkogel*" close to Pernegg holds a remarkable collection of rhododendron. This site has developed through human influence over a long time. In order to preserve this unique site management measures will be necessary in order to thin out the *Pinus sylvestris* stand. Other particularities of the region include Mediterranean species such as *Linum flavum* and *Iris graminea*, which grow on dry sites together with a number of *Orchidaceae sp.*

A special characteristic of the region are the different caves located in the limestone. Distinctive for those caves are the Dolines as well as the remarkable stalactites and stalagmites.[55]

History of human influence

The first significant human interference into the natural forest structure has most likely started in the Hallstatt period around 1000 B.P. Archaeological findings in several caves of the Mur valley have revealed settlement activities dating back as early as the Middle Stone Age. The well-known "*Drachenhöhle*" close to Mixnitz for instance has been inhabited in the Neolithic and the Bronze Age for an extended period.[56]

55 Fossel and Kühnert, 1994

56 Hafner, 1979; Fossel and Kühnert, 1994

Agricultural area was obtained by a slash-and-burn practice. The soils fertilized with ash carried good quality yields for the first years. After a decrease in yield the fields were left to the forest and new forested areas were burned.

400 years before present Celtics advanced from Gallia. Findings provide evidence that they settled in Styria since 200 B.P. Especially iron and salt mining took place during this period. 16 years before present the Romans occupied the region. 45 A.D. Styria became Roman province. The migration of people destroyed the culture and lead to a reforestation of the area. During the late 6th century the Slavs advanced into the area and Styria became a part of *Karantanien*. Several tribes have tried to gain control over the area again in the 8th century A.D. It became German reign and Christianised. The territory was considered as Kings Asset and has been distributed to Aristocrats and the church.[57]

The major part of the country belonged to foreign dioceses. Monasteries have played a major role in making the dense forests arable. The donations to aristocracy and the foundation of monasteries have been the basis for today's land property. During the centuries especially the monasteries have been responsible to making the land arable, for road construction and the establishment of settlements and agriculture.

The duchy Styria has been established in 1180 by king Friedrich I. Barbarossa and given to Otakar IV. After several wars in the middle of the 12th century Styria and Austria were given to Albrecht and Rudolf von Habsburg on the *Reichstag* of Augsburg in 1282. Since this time those two domains were the basis for the Habsburg Empire. Until the reign of Emperor Maximilian I. the domains experienced several separations. Only from this time all Austrian domains have been centralised and united.[58]

[57] Hafner, 1979
[58] Hafner, 1979

Site description

The railway route between Bruck an der Mur and Frohnleiten runs on the valley bottom along the east side of the valley in North-South direction. The length of the route that has been assessed amounts to 25 kilometres. Along to the track forests, agriculture and settlements are present likewise, the agriculture and settlements mostly located along the river and in the plain, the forests on the steep mountain slopes. The river Mur runs in meanders along the route directly adjacent to the track. Some parts of the river still have floodplain characteristics. These parts are located directly adjacent to the embankment. The so called "*Murradweg*", a paved biking trail runs along the whole route on the east side of the track. Directly adjacent to the "*Murradweg*" the mountain slopes start out. The forests of the valley are mainly located on those steep mountain slopes. Figure 13 shows a map of the railway route.

Figure 13: Railway route between Bruck and Frohnleiten
(Source: ©GIS Steiermark, BEV, Mag. Graz)

The embankment has a width of roughly 10 to 15 meters along both sides of the track. The west side of the track is situated along the river plain and along the floodplain for a great part of the route and has a slope of zero percent. Also a great part of the settlements extend along this part of the eastern embankment. The embankment located on the east side of the track has a slope of 80 percent and is separated by the adjacent forested mountains by the "*Murradweg*". In some places settlements and agricultural areas border the embankment. The agricultural area directly bordering the embankment mostly consists of apple orchards and pastures, rarely of fields. In some locations the forested area reaches close to the track without a proper embankment.

The vegetation along the embankment is composed of trees, shrubs and grasses. Along a large part of the route deciduous trees are a dominating feature on the embankment together with *Rubus sp.*, which play a major role along the whole embankment. Due to the closeness of the floodplain on a considerable portion of the route tree species such as *Salix sp.* and *Populus sp.*, which are typical for a floodplain environment are, together with other species, the most prominent species. *Robinia pseudoacacia* seems to establish easily along embankments and appears to have invaded the area during the past decades (oral statement of a local). Grasses and herbs cover 100 percent along the embankment, whereas shrubs and trees both cover around 60 percent of the total area. The most notable herbaceous species is *Impatiens glandulifera*, which is an invasive species and has increased in the area during the past decades.

The forests reaching down to the track are primarily coniferous forests composed of planted *Picea abies* and *Pinus sylvestris* with mostly insignificant presence of understory. At the same time the forested areas directly bordering the railway track are located on the steepest slopes of the area and contain rocky features. Here the total tree cover along the embankment is 100 percent. Along these sections of the route the border to private forest property is flowing and without a break, which puts the forested area at high fire risk. Figure 14 shows the image of the embankment characteristic for a major part of the route. As it can be seen the *Murradweg* acts as a boundary between the embankment and the adjacent forests.

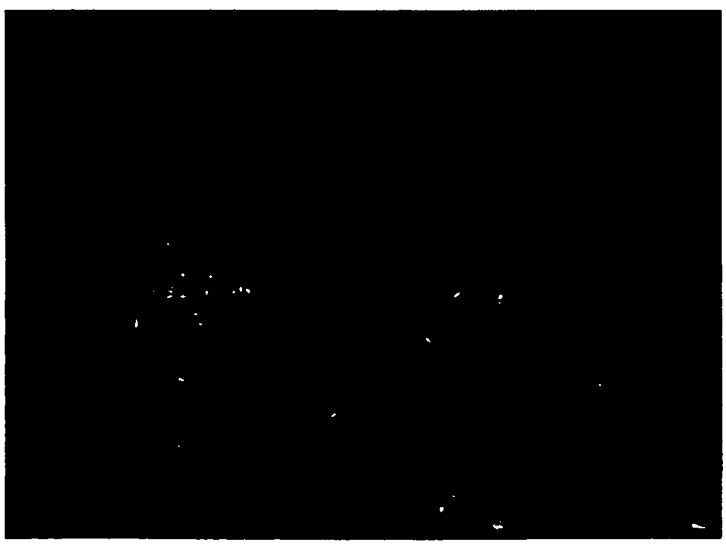

Figure 14: Embankment along the route with the *Murradweg*

The embankment along the railway route is property of the ÖBB. The forests and the agriculture adjacent to the embankment belong to several big and small private forest owners and farmers as well as to the ÖBB.

The site assessment along the railway route between Bruck an der Mur was partly conducted along the railway track as well as along the "*Murradweg*" in order to evaluate the situation on the embankment and the respective conditions. Site assessment has been carried out on chosen sites in the forests adjacent to the railway route as well in order to reveal the fire risk proceeding from railway routes. The presence of the "*Murradweg*" along the greatest part of the route made it possible to assess most of the embankment from the road.

The second site assessed was part of a set of forest fires caused by loose train brakes in February 1998 and is located in the property of the "*Guts- und Forstverwaltung Schloß Pernegg*" in the *Gabraungraben* north of Pernegg.

Three hectares of forest of several age classes up to an age of 90 years have been destroyed and forest roads have been damaged. The fire has jumped over the "*Murradweg*" and spread into the forest. The south-facing slope has a gradient of 80 percent and a convex shape. The convexity of the site has had a significant influence on the fire spread and fire behaviour. The convex terrain has caused a chimney effect, which has caused the fire to produce its own winds – nearly like a "*fire storm*" - causing the fire to escape and burn an area with an irregular boundary. The tree species occurring on the site are *Picea abies*, *Quercus sp.*, *Fagus sylvatica*, *Betula pendula* and *Acer sp.* A part of the trees, *Picea abies* and in some locations the *Quercus sp.* have been replanted, whereas other species have grown on the site by self-seeding. *Rubus idaeus* and *Rubus fructicosus* are the dominating shrub species on the site and form a dense understory. Several grass and herbaceous species form a dense layer. After the fire the ash layer locally had a depth of one meter. The nutrients in the ash have promoted the growth of tree species, especially on the exposed parts of the site. It was found that the trees that grow on sites with the ash layer have shown an advanced growth when compared to other trees the same age. There is still a significant number of dry snags and dead woody debris left on the plot that cannot be removed due to the difficult terrain. They are posing a danger to the newly established vegetation in case of a further fire outbreak on this site.

The site is made accessible by three forest roads on the upper part of the area. A lane leading to the near "*Murradweg*" is running along the lower part of the site. The next water source is the Mur, which is approximately 800 meters away from the lower part of the site. Industrial sites are not close to the site as are agricultural sites. The next settlement is around one kilometre away from the burned site. Figure 15 shows the Gabraungraben in a satellite picture.

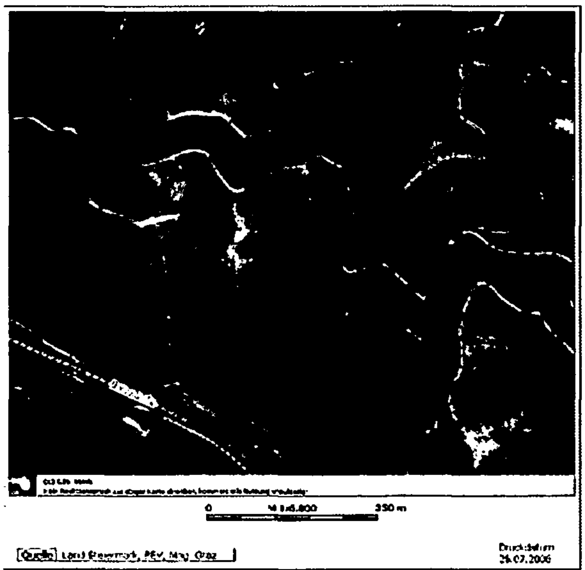

Figure 15: Gabraungraben (Source: ©GIS Steiermark, BEV, Mag. Graz)

The third site is located south of Mixnitz in the forest property of the "*Forstverwaltung Mayr Melnhof-Sarau*". The site was chosen, because it shows similarities in topography and vegetation with the site in Pernegg and because it has not been affected by fire for at least the past 100 years. The site has a convex topography and a slope of 80 percent. A small creek runs through the centre of the gully. The area is very wet along the gully bottom. Vegetation along the creek is mainly composed of deciduous trees and a dense understory. The main tree species along the creek are *Fagus sylvatica, Carpinus betulus, Acer sp., Quercus sp., Aesculus sp., Sorbus aucuparia, Fraxinus excelsior* and *Robinia pseudoacacia.* A dense shrub, grass and herb layer forms the understory. Ferns are present abundantly.

Deciduous trees (mixed with some conifers) also grow along the gully almost down to the railway track. On the slopes of the gully old growth with coniferous trees, namely *Picea abies* and *Pinus sylvestris* is present. There is also a low understory of herbaceous species present. Those trees are used commercially and are at risk in case of a fire due to the steep terrain and the general susceptibility of coniferous trees to fire as well as the topography of the terrain. The total tree cover on the site amounts to 90 percent and the understory to 80 to 100 percent. Piles of dead fine and coarse woody debris from logging operations are present in the coniferous stands. Together with the convex topography of the site the increased load of dead fuel adds up to the increased fire risk on the site.

Bare soil is not found on the whole site, whereas rocky feature, gravel and mosses and lichens are abundantly present. Gravel, mosses and lichens are mostly present along the creek, whereas rock formations are present in the whole stand and especially along the boundary to the railway track. The stand height lies around 15 meters for the deciduous stand and approximately 18 meters for the coniferous stand. The canopy cover is 100 percent and the canopy fuel base height, which represents the distance between the understory and the first branch of a tree amounts to 0.4 meters.

A road access is present on the site in the form of a forest road leading through the upper part of the site. The "*Murradweg*" is leading along the lower boundary of the site close to the railway route. A paved road leading to the site is present in the form of the "*Murradweg*". The distance to the next settlement amounts to 1.2 kilometres, whereas the next agricultural area is one kilometre away. The distance to the Mur as the next available water source amounts to less than one kilometre. Figure 16 shows an aerial view of the undamaged site close to Mixnitz.

Figure 16: Site at risk close to Mixnitz
(Source: ©GIS Steiermark, BEV, Mag. Graz)

Other locations close and within the property of the "*Forstverwaltung Mayr-Melnhof-Sarau*" along the railway route, where a specific fire hazard is present for adjacent settlements, tourism and wildlife, were included in the site assessment. As a sample area the area around the *Rothleiten* mountain was observed, since it is home to a considerable ibex population and the mountain is frequented by climbers and hikers. The well-known "*Bärenschützklamm*" and the "*Drachenhöhle*" are located nearby. Therefore major parts of the area are highly frequented by tourists and more or less susceptible to fire risk. Those sites won't be described in detail here in terms of vegetation composition and topographic conditions. They represent special points of interest when considering fire risk proceeding from embankments along railway tracks for different areas of interest.

Results

With regard to a better understanding of the consequences of fire for the surroundings of railway tracks a literature analysis has been carried out in addition to fieldwork. It clarifies the significance of fire for various natural processes as well as the importance of establishing maintenance measures to protect forests, habitats for wildlife, agriculture, tourism and settlements.

Literature analysis

Fires and soils

Fires have a significant effect on soils throughout all ecosystems and vegetation types. Studies have shown that surface fires reach temperatures up to 400°C. In a soil depth of 2 centimetres temperatures reach 160°C. Different fire intensities cause organic matter and humus layer to decrease. Surface temperatures increase after fire due to the loss of vegetation, a thinner or lacking humus layer and the blackening of the soil. Soil temperatures rise approximately 10°C causing natural processes as snow melt, melting of permafrost or the flowering of plants to take place ahead of time. The increased heat transferred to the soil changes the hydrological cycle and soil chemistry, thereby changing microclimate and soil conditions, namely a higher pH and cation concentration and lower moisture content.[59]

Soil nutrients contained in the vegetation are lost via volatilisation, particulate movement or leaching. Mineral nutrients are mainly released as oxides and carbonates causing the pH value of the soil to rise. Due to the irregular distribution of fuel before fire nutrient loss is spread unevenly on the site as well. Areas with a higher fuel load before fire show a higher nutrient loss than areas with a lower fuel load, since fire severity is higher in areas with higher fuel load than in areas with a low fuel load. The drainage system of the soil has a significant influence on the loss of carbon in the soil. Greater losses of carbon usually occur on better drained soils, whereas wet soils usually show a low loss of carbon. This means that the availability of carbon for plant growth depends on the soil conditions on the site.[60]

[59] Gorbachev and Popova, 1996; Fuller, 1991; Mälkönen and Levula, 1996; Pietikänen, 1996; Thonicke et al., 2001; Schmidt et al., 2003; Russel-Smith, 2003; Hart et al., 2005

[60] Feller, 1988; Goldammer et al., 1998; Fuller, 1991; Mälkönen and Levula, 1996; Pietikänen and Fritze, 1996; Harden et al., 2000; Müller, 2001; Russel-Smith et al., 2003

Intense fires kill the soil microorganisms up to a certain depth. Some microorganisms, such as nitrogen fixing bacteria are more sensitive to the increased temperatures caused by fire than others. This means that these bacteria get killed faster than others. However, those bacteria multiply rapidly so that they recover fast. The lack of microorganisms in burned soil may cause an increased plant growth after fires due to the lack of competition. Some plants establishing on burned sites already have nitrogen-fixing bacteria on their roots so that they do not suffer nutrient deficiencies.[61]

On the other hand ashes are deposited on and in the soil and are therefore available as fertilizer. Its content is highest in the upper soil layers and decreases with increasing depth. The lower the soil layers the less carbon is available for net primary production. Other nutrients are added to the soil as well, aiding vegetation to become re-established. Especially nitrate and ammonium act as fertilizer and vegetation has a growth advantage on sites with significant ash deposits.[62].

High-intensity and high-frequency fires remove the vegetation cover as well as the humus layer for a certain period of time. This lack of vegetation cover encourages soil erosion processes, which can become devastating, especially in mountainous regions. Intense fires influence water-holding capacity and erosivity of the soil through oxidation and erosion of organic matter. Depending on fire intensity the upper soil layers become hydrophobic as well so that water is not able to drain into the soil. This causes a more or less extensive overland flow and erosion until vegetation is able to recolonize the damaged site.[63]

Fires and vegetation

Fire leads to a destruction of habitat for plant and animal species for a period of time. However it does not impair habitats for a long time. Vegetation re-invades the burned area quickly as do animals. After fire it takes several years for vegetation to become re-established. Although grasses, herbaceous species and shrubs cover the area, the extent of destruction is still visible for a long time and from a considerable distance. Elevation has a significant influence on regrowth on a site. Burned sites at lower elevations usually recover faster than sites located at higher elevations.[64]

61 Fuller, 1991; Mälkönen and Levula, 1996; Pietikänen and Fritze, 1996

62 Fuller, 1991; Henig-Sever et al., 2000; Coelho et al., 2000; Thonicke et al., 2001; Wang et al., 2001; Goto, 2004; Bond-Lamberty et al., 2004

63 Coelho et al., 2000; Thonicke, 2001; Müller, 2001; Camia et al., 2002

64 Fuller, 1991; Gossow, 1996; Goldammer et al., 1997; Goldammer et al., 1997; Goldammer and Page, 2000; Fulé et al., 2004

The influence of the above mentioned factors on fire vary over the area burned and the intensity of the damage may be quite different on different locations on the site. Inversions – especially at night, varying fuel moisture, the aspect of the slope, old burns, strong winds and differences in species composition especially influence fire intensity. Inversions cause fires to remain on the floor and the higher the fuel moisture, the lower the chance of ignition. The aspect of slope influences fuel moisture to a great extent. Strong winds cause a fire to spread rapidly so that the extent of the damage to the single tree or other vegetation remains relatively low. Conifer stands tend to be subject to higher fire intensities. Fire intensities in deciduous stands are usually lower due to the different fuel qualities of conifers and deciduous trees. Deciduous trees have a lower fuel quality than conifers.[65] Concerning the ignition probability of foliage differences among species exist as well.[66] Plant mortality was found to be size-dependent and higher in juvenile plants than in mature plants.[67] This indicates that areas already burned are susceptible to repeated fires.

Damages on surviving trees make them susceptible for follow-up damages by insects, bacteria, viruses and fungi causing them to fall out a long time after the fire. Adjacent forests become susceptible to diseases – especially beetle outbreaks. [68]

Nutrients released by fires stimulate the growth of vegetation. Plants benefit from the additional nutrients deposited in the soil by an increase in nutritional status. Especially the carbon released by a fire and made available through ash deposition aid the vegetation through a growth advantage. Nitrate, nitrogen and ammonium aid seedlings to become established.[69] The improved nutrient status of the soil eases the establishment of non-native plants as well, which alter the native plant community and pose a threat to recovery of the native plant community.[70]

[65] Carcaillet et al., 2001
[66] Fuller, 1991; Feller, 2001; Fonda, 2001; National Wildfire Coordinating Group, 2004
[67] Vignolio et al., 2003
[68] Fuller, 1991; Babintseva and Titova, 1996; Kalinin, 1996; Matveev and Usoltzev, 1996; Andersen and Müller, 2000; Müller, 2001; Goto, 2004
[69] Elliot and White, 1987; Fuller, 1991; Henig-Sever et al., 2000; Radho-Toly et al., 2001; Goto, 2004
[70] Hunter and Omi, 2006; Hunter et al., 2006

The distribution range of species plays a significant role in the response of germination to fire. Rare species show a lower germination rate and a higher sensitivity to the higher temperatures caused by fire. In areas with the occurrence of fire and the presence of game at the same time browsing might reduce species abundance on burned sites. Only clustered feeding of game allows vegetation to become established in higher amounts.[71]

Sites burned by fire are subject to succession. Pioneer species become established first and dominate the burned site for a certain period of time due to their high adaptation to the extreme climatic conditions of open areas. Herbaceous plants and grasses establish first, followed by shrubs and trees forming a sequence. Plant species richness and density are highest in the first years after fire decreasing with increasing time after fire and with ongoing succession. Sites, which are important for timber harvest, are subject to artificial regeneration as well. Light and other resource become limiting with time so that the stand structure is changing so that species composition of the understory is changing. Light demanding tree and shrub species as well as grasses and herbaceous plants are replaced by more shade tolerant species. The species dominating the site before fire occurrence become re-established after a specific period of time. Grasses and herbaceous species tend to become established rapidly, whereas woody species take a longer time to become established again.[72]

Succession, time elapsed since fire, forest type and stand age are closely linked to a change in net primary production of a forest stand. Fires consume the annual net primary production of ecosystems to a great extent. Net primary production is lowest directly after fire. It increases rapidly at a certain age and decreases again with increasing stand age. The net primary production of a burned stand is dominated by especially seedlings in young stands and other trees in older stands. Stand age, soil drainage and understory production influence interannual variability of net primary production to a great extent. Whereas young stands are moderate Carbon sources, middle aged stands are relatively strong carbon sinks and old stands are neutral in terms of net ecosystem production.[73]

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[71] Ellenberg, 1996; Goldammer et al., 1997; Coops and Catling, 1998; USDA Forest Service, 2000; Goldammer and Page, 2000; Calvo et al., 2000; Camia et al., 2000; Luna et al., 2000; Radho-Toly et al., 2001; Hessl and Graumlich, 2002

[72] Fuller, 1991; Ellenberg, 1996; Gossow, 1996; Hong and Mladenoff, 1999; Müller, 2001; Camia et al., 2002; Santalla et al., 2002; Williams et al., 2003; Laughlin et al., 2005; Coops et al., 2000; USDA Forest Service, 2000

[73] Harden et al., 2000; Wang et al., 2001; Thonicke et al., 2001; Bond-Lamberty et al., 2004; Govender et al., 2006

Root density is affected by fire and time elapsed after fire as well. Studies have found that root growth is stimulated by increased levels of CO_2 after fire. By reaching a high density some years after the fire event, root growth was found to decrease again.[74]

Fire frequency, fire intensity and season of fire influence plant abundance and density, vegetation composition as well as species richness to a great extent. While some species increase in abundance and density through high fire frequency, other species are adapted to a low fire frequency for recovery. Increasing fire frequency and intensity favours annuals and fire-tolerant species, especially grasses and herbaceous species, whereas lower intensities or the absence of fires benefits fire-sensitive and fire-intolerant species as well as woody plants. Species able to tolerate frequent fires are able to persist and therefore play an important role in species composition in vegetation communities.[75] At the same time a low fire intensity and severity causes the rate of extinction of species to be lower on sites with deciduous stands than on sites subject to a higher fire intensity.[76] The fuel load of a stand grows with increasing post-fire age increase the fire risk of the area.[77]

The plant community dominating the site before the fire influences diversity and species richness. Deciduous stands generally show a higher diversity and species richness after fire than conifer stands, even though species richness and species diversity varies within conifer stands as well. Studies have shown that the recovery process is slower in conifer stands compared to deciduous stands. The same is true for different shrub ecosystems. Some ecosystems require less time for recovery after fire than others. The link of the species community on the burned site to the species pool of the surroundings has a significant influence of changes in species richness on the site through seed dispersal and related processes. Topography has a significant influence on species richness of a site as well. Mountain slopes with a south exposure show a higher species richness and diversity than slopes with other aspects. Soil conditions found on burned sites influence total species richness on a site as well. Sites with higher clay and nitrogen content and a higher pH value and therefore a higher nutrient content showed a higher species richness than sites with a higher sand content in the soil.[78]

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[74] Day et al., 2006

[75] Calvo, 2000; Luna et al., 2000; Middleton, 2002; Jacobs and Schloeder, 2002; Clarke, 2002; Williams et al., 2003; Parisien and Sirois, 2003; Russel-Smith et al., 2003; Kruse et al., 2004; Enright et al., 2005; Spencer and Baxter, 2006; Govender et al., 2006

[76] Williams, 1999; Santalla, 2002; Camill et al., 2003; Goto, 2004; Ojeda et al., 2005

[77] Govender et al., 2006

[78] Santalla et al., 2002; Calvo et al., 2000; Laughlin et al., 2005; Carrington and Keeley, 1999

The re-establishment of a site after fire occurs by resprouting, by immigration of seeds or by doing both. Fire frequency influences the type of re-establishment to a great extent. Frequent fires with a high intensity eliminate resprouters giving way to re-establishment by seeders, while resprouters are found on sites subject to less frequent fires with a low severity respectively, because high-intensity fires destroy the rhizomes of certain plants so that competition for seeders is eliminated. Given certain climatic conditions in terms of regular rainfall, seeders occupy areas, which usually are inhabited by resprouters. Conifer stands re-establish solely by seeds, whereas deciduous stands are also capable of resprouting after fire. Coniferous trees therefore are the most aggressive invaders on a site after frequent fires.[79] However studies have shown that sprouting is an important mechanism of woody species for a high post-fire survival and therefore for persistence in the disturbed area. Sprouting vigour was found to depend on the size of the individual before the disturbance. The taller the individual before the fire the lower the sprouting vigour was after fire. Therefore the growth rate was found to be low.[80] Depending on fire intensity, germination is to be expected from a seedbank as well. Especially grassland communities depend on re-establishment through a seedbank in many places and therefore are vulnerable to fire intensity.[81] In this context a weak inter- and intraspecific competition was found to aid seedlings to become re-establish and increase their chance growing into large trees.[82] Weather, climate and season have a significant influence on the re-establishment of vegetation. Given substantial rain, seedling establishment may be successful, whereas a fire before germination might cause extinction of species.[83] Landscape features are an important element influencing the response of species to fire frequency. Elements such as rocky islands in forests, which are frequently found in mountain regions, create different habitat types across the area. Together with fire frequency the different habitat types cause speciation and selection in species. Studies have found that certain species are killed by fire in one habitat type, whereas the same species has adapted to an environment with a higher fire frequency by re-establishing by resprouting.[84]

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79 Goldammer et al., 1998; Pfab et al., 1999; Clarke, 2002; Goto, 2004; Kupfer and Miller, 2005; Ojeda et al., 2005
80 Gurvich et al., 2005
81 Goldammer et al., 1998; Rice and Westoby, 1999; Higgins, et al., 2000; Jacobs and Schloeder, 2002
82 Henig-Sever et al., 2000
83 Carrington and Keeley, 1999
84 Clarke, 2002; Kupfer and Miller, 2005

Symbiotic fungi such as *mycorrhizae* are killed by fire as well, since they are especially susceptible to heat. Together with their symbiotic plant roots they are critical components of plant ecosystems. Symbionts are responsible for nutrient uptake of the host plant and the maintenance of soil structure and they influence soil nutrient cycling as well. Infrequent high intensity fires destroy the fine root system of the vegetation and the associated *mycorrhizae* completely so that it takes a long time until the symbiotic fungi recover and recolonize the burned site again. Studies have shown that repeated burning reduces fine root length and fine root biomass as well as the associated mycorrhizal root biomass to a great extent. Other studies have found that obviously certain *mycorrhizae* species survive a fire, while others don't. The nitrogen and phosphorus storage associated with fine roots and *mycorrhizae* is destroyed as well.[85]

Species such as *Pteridium aquilinum* or *Calamagrostis epigeios* are frequently found in forest stands after fires forming a dense cover and dominating the understory with other acidophilus species to a great extent. Those species establish soon after fire and become dominating species in the understory. *Pteridium sp.* was especially found in areas subject to frequent fires.[86]

Significance of fire for grasslands

Grassy vegetation is destroyed by fire to a great extent and bare ground is left for succession. Light demanding species, especially grasses and herbaceous species become established first.[87]

Fire frequency and soil moisture contents influence the vegetation composition to a great extent. Low moisture conditions and frequent fires hamper trees to become establish in grasslands in the first place. In this context fire is an important tool to inhibit tree recruitment in grasslands by killing young trees, delaying or suppressing tree growth and photosynthetic activity and therefore keeping grasslands open.[88] Especially in boundary regions between grasslands and forests the probability of fires is increased due to the fuel characteristics specific for this area.[89]

[85] Fuller, 1991; Hartnett et al., 2004; Bruns et al., 2002
[86] Müller, 2001; Camia et al., 2002; Spencer and Baxter, 2006
[87] Ellenberg, 1996; Rice and Westoby, 1999; Laterra et al., 2006; Wahren and Papst, 2001
[88] Higgins et al., 2000; Bond et al., 2003; Butler and Fairfax, 2003; Mistry and Berardi, 2005; O'Reilly et al., 2006
[89] Mistry and Berardi, 2005

The lower decomposition rate of grass litter compared to shrubs leads to an increased litter production of grasses and a decreased shrub productivity.[90] At the same time a change in fire regime leads to a decline of trees and shrubs in the area in particular, which in turn facilitates grass invasion and increases the chance of future fires in the area. This so-called grass-fire-cycle is known to exist in many regions of the world.[91] Studies have shown that a low CO_2 content is a significant factor of tree reduction of an area.[92] Frequent fires however reduce the population growth rate of grasses and the life-history traits. The success of grasses to become established depends on survival rate and germination time of seedlings. The earlier the germination of seeds takes place in relation to fire occurrence the higher the survival rate due to the increased size.[93] The invasion of non-native grass species was found to be involved in the conversion of woody shrublands into grasslands as well. Grasses and trees compete for soil moisture and nitrogen.[94]

Mycorrhizal symbiosis is of great importance for grasslands. In many parts of the world mycorrhizal symbiosis plays a key role for the grass population and the ecosystem function. It influences growth, reproduction, demography, competition patterns, community structure, species diversity and successional dynamics. Frequent fires kill the mycorrhizal fungus reduce grass and herbaceous species depending on mycorrhizal symbiosis to re-colonise the burned area. [95]

Light surface fires do not heat the soil to a high extent so that seeds survive the fire to establish successional vegetation. Hot surface fires on the other hand heat up the soil to an extent that regeneration establishes only slowly due to the destruction of a high percentage of seeds. On sites subject to repeated fires the vegetation is subject to selective processes. Grass species adapted to a high fire frequency become established first and resprout vigorously after fire. Herbaceous vegetation as well as shrubs establishes on sites with a high fire frequency as well.[96]

[90] Grigulis et al., 2005
[91] Rossiter et al., 2003; Bond et al., 2003; Enright et al., 2005; Gardner, 2006
[92] Bond et al., 2003
[93] Garnier et al., 2001
[94] Elliott and White, 1987; Middleton, 2002; Cione et al., 2002; Butler and Fairfax, 2003; Kruse et al., 2004; Mistry and Berardi, 2005; Grigulis et al., 2005; Kupfer and Miller, 2005; Setterfield et al., 2005; Bradley et al., 2006; Hunter and Mladenoff, 2006; Hunter et al., 2006
[95] Hartnett et al., 2004
[96] Ellenberg, 1996; Rice and Westoby, 1999; Laterra et al., 2006; Wahren and Papst, 2001

Frequent fires and other disturbances related to human activities aid exotic grasses to occupy an area and change ecological conditions of the ecosystem to a great extent.[97] Invasive grasses were found to cause ecological changes in ecosystems, such as the change of species composition, nutrient cycling, resource availability and a change in disturbance regimes, the alteration of fire regimes being one of the most important ones. The increased fuel loads caused by invasive grasses influence fire frequency, intensity and extent. Higher fuel loads support fires with intensity around eight times higher than that of native grasslands.[98]

Invasive grasses and herbs have a significant impact on native species through competition. The reproductive output of native species is significantly reduced when growing in combination with exotic species. Fires were found to change the competitive situation in grasslands and to have contrasting effects on native grasses and herbs through the alteration of the microclimate by reducing dead and living biomass. Invasive plants as well as native plants are reduced on burned plots and fruit production per plant of native species increases, whereas seed establishment after fire is decreased. As a consequence the positive effects of controlled burning on native plants might only be seen several years after fire. However, in areas where the cover of dominant native grass species was found to be high, the establishment of non-native species is deterred. This is important in considering future management measures along the embankments. Besides the effects on native vegetation the expansion of invasive grasses was found to change the importance of an ecosystem as a carbon sink to a carbon source.[99]

Areas such as embankments along railway routes are of great importance as a habitat for rare and endangered species. Especially grasslands contain several rare and endangered species. Current land use practices have lead to a decrease in those high-value habitats. Certain rare species, which are not adapted to fire, are negatively affected by the conditions caused by fires. This leads to the retreat of plant and animal communities to areas, which are not subject to disturbance by land use practices such as controlled fires.

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97 Cione et al., 2002; Setterfield et al., 2005; Kupfer and Miller, 2005

98 Cione et al., 2002; Rossiter et al., 2003; Butler and Fairfax, 2003; Kupfer and Miller, 2005; Mistry and Berardi, 2005; Grigulis et al., 2005

99 Hunter et al., 2006; Bradley et al., 2006

On the other hand fire was found to be an important tool to maintain habitat structures for certain other rare and endangered species, which are adapted to frequent disturbances.[100] The removal of dry grasses through controlled burning at the beginning of the vegetation period contributes to the distribution of certain vegetation structures. Controlled burning of pastures and heath has always been a measure of eliminating unwanted weeds and woody plants.[101]

Fire and wildlife

Disturbance through fire determines the composition and structure of animal communities to a great extent. Especially wildlife is influenced through the modification of its habitat. Fires contribute to changes in plant species composition and therefore in the associated species composition of animal species as well. Species intolerant of fire as a disturbance never become established again on sites subject to a relatively frequent fire regime. On the other hand fire is important for many invertebrate species by creating a mosaic of different successional stages and therefore a good quality habitat, especially regarding habitat features related to the availability of food sources. Several species are adapted in different ways to the changed structures, but generally animals with flexible habitats adapt better to the new situation as animals adapted to conditions in mature ecosystems. The different reaction of species to fire may be an indicator for the fire history of a site. The higher the fire frequency on a site, the lower the presence of fire sensitive species and the higher the number of species adapted to frequent disturbances. Studies have shown that species richness around logs and other structures are increased, probably through the protecting effect of those structures for some species. The effects of fire as a disturbance on species composition, richness and abundance depends on the habitat type to a great extent. The higher the habitat complexities before a fire the more species experience a change in habitat complexity.[102]

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[100] Goldammer et al., 1997; Goldammer et al., 1997; Goldammer and Page, 2000; Gillespie and Allen, 2004; Beyers, 2004; Kruse et al., 2004; Hunter and Omi, 2006; Hunter et al., 2006; Maccherini, 2006

[101] Higgins et al., 2000; Butler and Fairfax, 2003; Mistry and Berardi, 2005; O'Reilly et al., 2006

[102] Fuller, 1991; Andrew et al., 2000; Radho-Toly et al., 2001; Santalla et al., 2002; Moretti et al., 2004; Ratchford et al., 2005; Spencer and Baxter, 2006; O'Reilly, 2006

In forest ecosystems fires – like clear cuts - create so called "*edge effects*", which provide habitat for a wider range of species than an unburned old growth forest characterised by a low understory and therefore has a low quality in terms of available food sources. Studies have revealed that the creation of "*edge effects*" through fire leads to an increase in species richness, especially regarding interior forest species and forest edge specialists. Insect and beetle species experience an increase in species richness as well.[103]

Natural succession after a fire increases the number of edible plants for animals through the removal of competing conifers and the accumulation of minerals in the soil. The increased nutrient status of available plants, especially the improvement in protein content attracts various animal species. Ungulates and other vertebrate species were found to feed on ashes and charcoal, which act the same way as a salt block. Burning stimulates the resprouting of plants and improves the quality of plants as food source attracting animals living in the surrounding area. Studies have shown that ungulates prefer to forage on burned sites due to the higher forage quality and availability. The higher nutrient content of plants and the increase in the amounts of foliage leads to an increase of herbivores on the burned site. Studies have shown that the increased availability of food on burned sites attract animals of all species. Some species were found to forage on burned sites because of an increase of a favourite food source soon after fire. Studies have revealed that the microclimate and physical structure of a habitat is of higher importance for some species than the species richness of an area. Due to the increased abundance of prey species on burned sites predators are attracted as well. Coincidences were found between fires and predator-prey cycles. Fire and plant succession following a fire event are the influential mechanisms for predator-prey cycles.[104]

Studies have revealed a higher vulnerability of small mammals and other small animals compared to large animals, since the chance to escape an advancing fire, especially in high fuel loads is low to nonexistent. The numbers of small mammals present on a burned site before fire occurrence are significantly reduced directly after fire and often experience a further decline in winter, when winter foraging is not possible in the amount necessary to sustain the population. As a result the animals depending on the smallest animals as food source experience a dramatic decline as well.[105]

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[103] Fuller, 1991; Moretti et al., 2004; McEntire and Fortin, 2006

[104] Fuller, 1991; Gossow, 1996; Johnson, 1997; Radho-Toly et al., 2001; Vernesi and Hayden, 2001; Moretti et al., 2002; Zavala and Holdo, 2005

[105] Fuller, 1991; Johnson, 1997; Vieira, 1999; Monamy and Fox, 2000; Moretti et al., 2000; Moretti et al., 2002; Moretti et al., 2004; Green and Sanecki, 2006

Species such as squirrels, which depend on cones, may disappear from the burned site for a long time. Studies have found that some species may be favoured by fire occurrence and replace other species that have been more common on the site before fire. Population sizes of most small mammal species show a decline compared to unburned sites. The scarcity of food sources for some time after fire plays a significant role in the duration of recolonization of a site. Some species are so-called fire followers occupying early successional stages. [106]

In this context it needs to be mentioned that wildlife browsing impacts on reforestation is an important issue on burned sites, especially in forests used for timber production. Since artificial regeneration often is the first plant material present on recently burned sites, it stands for a fast and readily available food source for game species as well as small mammals. Therefore browsing damage on burned sites is inevitable.

In terms of the effects of fire on bird species studies have shown that birds are positively as well as negatively affected by fires. Positive effects of fires include the release of tree seeds, which are a welcome food source for birds living in adjacent areas.[107] However short-term effects on bird communities are mostly negative. Studies reveal a sharp decline in bird species after fire due to the habitat destruction resulting from fire. Fire removes the protecting function of tree foliage as well as nesting habitat and the food source on the burned site.[108] Bird diversity and abundance increase on the burned plots with increasing time from fire. However studies have found differences in the presence or absence of some species on the sites. Due to the fact that fire reduces shrub and tree canopy cover and grass height is significantly lower on burned plots than on unburned sites, bird species depending on trees or shrubs for mating or nesting purposes are less frequent or completely absent on burned plots. The forage type of birds plays a role as well. Herbivores are rather found on unburned sites with abundant forage.[109] Many tetranoid species were found to respond positively on controlled burning. Controlled burning maintains an open landscape, which are the main habitat requirements for species such as the grouse. In some areas controlled burning is done in order to maintain the habitat for tetranoid species as game bird. Other animal species depending on open habitats benefit from this practice. However negative effects of burning on other bird species are known as well.[110]

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[106] Fuller, 1991; Johnson, 1997; Vieira, 1999; Monamy and Fox, 2000; Moretti et al., 2000; Moretti et al., 2002; Moretti et al., 2004; Green and Sanecki, 2006

[107] Fuller, 1991

[108] Green and Sanecki, 2006

[109] Gossow, 1996; O'Reilly, 2006

[110] Gossow, 1996; Moretti et al., 2004; Yallop et al., 2006

Invertebrates react differently to fire. The dominant vegetation type has a significant influence on the rate of recovery of invertebrates. A high resilience of forests after fire causes invertebrates to recover faster as well, whereas invertebrates recover at a slower rate on sites with a slow recovery rate of vegetation. The environmental characteristics of a region have an influence on fire resilience of invertebrate communities as well. Especially in dry habitats differences in resilience between burned and unburned sites are lower than in moister areas. Certain communities, especially insect and arthropod communities respond differently to fire and are strongly modified by different fire regimes. Immediate effects of fire such as mortality or emigration influence communities to a great extent. The density and species richness of various communities is affected as well. While the species richness of some populations increases, other populations have been reported to experience a decrease in species richness. Studies have found that general species richness tends to be higher on burned than on unburned sites. Other studies have found that arthropods and insects increase in number after fire due to the increased nutrient status of foliage. Pyrophilous species are attracted by the smoke of a fire causing them to immigrate and feed on trees injured or killed by fire.[111]

Especially rare species are adapted to specific ecosystems. Frequent fires often maintain suitable habitat conditions on a site. Since natural fires are eliminated from nature in Central Europe, controlled burning may help in restoring or maintain certain habitat types. On the other hand fire can eliminate rare animal species by habitat destruction.[112]

Fire and climate change

Climate change has been the main trigger in change of fire frequency and fire regimes in the past. Over the past 50 years human activities were found to have changed ecosystems fast and to a great extent. Anthropogenic climate change has triggered an increase in temperatures and CO_2 concentrations as well as a change in precipitation patterns over the past century. This in turn leads to a change in vegetation composition and distribution. Ecosystem effects were found to be enhanced by the direct influence of human activities on natural disturbance regimes such as fire ignition or through indirect effects such as on vegetation composition. Those effects are predicted to even occur more rapidly and extensively in the future.[113]

[111] Andersen and Müller, 2000; Radho-Toly et al., 2001; Orgeas, 2001; Müller, 2001; Parr et al., 2004; Kiss et al., 2004; Ratchford et al., 2005; Arnan et al., 2006

[112] Goldammer et al., 1997; Goldammer et al., 1997; Goldammer and Page, 2000; Martin, 2001; Moretti et al., 2004; Means et al., 2004

[113] Grigulis et al., 2005; Czimczik et al., 2006; Carrer and Urbinati, 2006; Chapin et al., 2006; Scholze et al., 2006

Global climate change is going to lead to an increase in frequency of severe weather events. Days of extreme fire severity related to the increased occurrence of droughts are going to increase as does the length of the fire season as well as fire frequency. The higher fire frequency is going to lead to a significant change in species diversity, vegetation structure, composition and productivity as well as in ecosystem functioning.[114]

The sensitivity of endemic and non-endemic species to climate change depends on their geographical distribution and ecological properties.[115] Endemic species as well as other species adapted to certain ecosystem conditions and sensitive to others are most likely to become extinct in the long run.[116]

Soil respiration and decomposition rates of soil organic matter as well as the deposition of atmospheric N were found to be influenced by climate change to a great extent. Soil respiration rates and decomposition rates of soil organic matter as well as the deposition of atmospheric N were found to be increasing. Together with the resulting increase in the availability of nutrients this influences and changes the growth dynamics of certain plant communities to a great extent. The growth dynamics of certain species, especially of specific conifer species is reduced, whereas other species such as many broadleaved species experience a growth advantage.[117]

Frequent heat waves and droughts are going to be most severe in areas already sensitive, such as Southern Europe. In areas presently not yet subject to extreme heat waves, e.g. Central Europe or North America future heat waves will cause significant damages to ecosystems[118]. Climatic regions experience a shift towards the poles and upslope in mountain regions replacing existing ecosystems and causing a shift in plant species composition at the same time. In mountain regions climate change induces the loss of the coldest regions and therefore the loss of ecosystems as well.[119]

[114] Condit, 1998; Goldammer et al., 1998; Carcaillet et al., 2001; Williams et al., 2001; Mouillot et al., 2002; Wotton et al., 2003; Camill et al., 2003; McKenzie et al., 2004; Brown et al., 2004; Brunetti et al., 2004; Calef et al., 2005; Grigulis et al., 2005; Carrer and Urbinati, 2006; Czimczik et al., 2006; Sibold and Veblen, 2006; Fuhrer et al., 2006; Scholze et al., 2006

[115] Broennimann et al., 2006; Carrer and Urbinati, 2006

[116] Condit, 1998; Easterling et al., 2000; Parmesan et al., 2000; Carcaillet et al., 2001; Mouillot et al., 2002; Walther et al., 2002; Beniston, 2003; Camill et al., 2003; Wotton et al., 2003; Brunetti et al., 2004; McKenzie et al., 2004; Calef et al., 2005; Taylor and Beaty, 2005; Calanca, 2006; Gobbi et al., 2006; Thuiller et al., 2006; Jump et al., 2006

[117] Calef et al., 2005; Carrer and Urbinati, 2006; Boisvenue et al., 2006; Scholze et al., 2006; Czimczik et al., 2006

[118] Easterling et al., 2000; Wotton et al., 2003; Taylor and Beaty, 2005; Meehl and Tebaldi, 2006

[119] Beniston, 2003; Calef et al., 2005; Carrer and Urbinati, 2006

Mountain regions and the respective vegetation composition are especially sensitive to climate warming, since the climatic and biogeographical zones contain various different ecosystems within a relatively small area. The complex topography of mountain areas is causing rapid changes in climatic parameters and therefore more or less rapid changes in ecosystems as well.[120] Studies have found that climate warming is triggering a shift in the temperature-sensitive period in certain plant species as well as a lengthening of the growing season. This would mean that the growing season would be prolonged especially in temperature-limited environments of mountains.[121]

Besides the changes in plant and animal communities and respective distribution ranges droughts and other extreme events cause a shift in seasons. Medium term climatic cycles influence the population dynamics of a high number of plant species. The distribution range of a high number of species is transformed especially along their southern limit as well as along the alpine tree line through the increasing number of drought periods extreme events.[122] The higher fire frequency and severity is leading to a selective reaction in species to the changed conditions favouring individuals adapted to the extreme conditions.[123] Fire severity was found to increase during dry years after wet years that have caused an increased plant production across all vegetation types and have therefore lead to an increase of available fuel of a certain area. Aridity alone on the other hand was found to have a low influence compared to the increase in fuel load during humid periods.[124]

Besides the impact on plant species composition and soil dynamics human-induced climate change influences the hydrological cycle and the biodiversity of mountain regions.[125] The consequences of climate warming on the hydrological cycle of mountain regions are important regarding fire risk in Austria. Especially in mountain regions a warmer climate is going to lead to an increased evapotranspiration rate. This is linked to a drop in evaporation efficiency at the same time. Critical soil moisture levels closely linked to increased evapotranspiration rates as well. The soil water content in mountain regions is going to drop significantly due to the increased evapotranspiration rates. The change in the soil water budget caused by an increased frequency of droughts is leading to a decrease in fuel moisture. This in turn is going to lead to an increased flammability of fuels.[126]

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120 Becker et al., 1999; Beniston, 2003; McKenzie et al., 2004; Stephenson et al., 2006
121 Carrer and Urbinati, 2006; Chapin et al., 2006
122 Fensham et al., 2003; Jump et al., 2006; Carrer and Urbinati, 2006
123 Clarke, 2002
124 Camill et al., 2003; Felderhof and Gillieson, 2006
125 Beniston, 2003; Chapin et al., 2006
126 Mouillot et al., 2002; Taylor and Beaty, 2005; Ohlemüller et al., 2006

Mountain regions are especially sensitive to an increase in drought occurrence regarding the shift in plant species composition and the increase of fire extent and fire severity. A special problem for mountain regions connected with the change of climatic conditions is the invasion of ecosystems by non-native plants. They are causing a change in vegetation composition and fuel loads of an area. Native species are suppressed and fuel loads are increasing. These changes in fuel loads are going to lead to an increase in fire frequency, intensity and severity and therefore also to an increased fire risk for Austria. Therefore it is necessary to adapt fire management strategies to the new conditions to meet the increased fire risk.[127]

Railway routes

The main reason for fire outbreaks alongside the chosen railway routes are sparks from braking trains as well as glowing brakeshoes. Metal sparks were found to ignite fires along a long stretch of the route, especially in steep and curvy terrain, whereas glowing brakeshoes have ignited fires only locally and therefore damage has been confined to a limited area as well. Maintenance works are irrelevant as a cause for fire beyond the embankments along the railway routes, since the fires are extinguished right away and do not get a chance to escape beyond the direct vicinity of the track. The ÖBB fire statistics and other documentation as well as statements from ÖBB employees confirm the findings.

The microclimate characteristic for railway routes influences the embankments and the directly adjacent area to a great extent. The railway track heats up fast through solar radiation. This leads to a hot environment around the track, which in turn leads to the development of an ecosystem adapted to the extreme conditions. The frequent fires along the route as well as controlled fire have helped in promoting the establishment of rare and endangered habitats. Fuels present along the track and the embankments dry out quickly, which increases the fire risk along the embankments and for the surrounding area.

[127] Condit, 1998; Carcaillet et al., 2001; Wotton et al., 2003; Beniston, 2003; Brown et al., 2004; Taylor and Beaty, 2005; Grigulis et al., 2005; Thuiller et al., 2005; Thuiller et al., 2006; Bradley et al., 2006; Chapin et al., 2006; Sibold and Veblen, 2006; Calanca et al., 2006; Chapin et al., 2006; Stoy et al., 2006

The wind field around the route differs from the natural wind field of the surroundings as well. Passing trains add turbulences to the wind fields for a short period of time, increasing the wind speed and therefore influencing fire spread and fire behaviour. The different types of embankments and the state of maintenance found along the two study sites have a significant impact on the microclimate of the track and the wind field as well. They increase the effects of both the extreme microclimate found along tracks as well as the influence of passing trains on the natural wind field. Both will be discussed in the following.

Types of embankments and fire risk

Different types of embankments are found along railway routes. Their diverse profiles influence the conditions dominating the track and its direct surroundings as regards fire risk, fire spread and fire behaviour. In mountainous areas such as in most parts of Austria railway routes frequently run along mountain slopes. This implies that the topography of an area has a significant influence on the shape and the slope of the embankment. Due to the rugged terrain often no embankment is present along a big part of the railway route so that the adjacent area, which often consists of forests, directly borders the track. This is especially true for the routes, which run along the middle of the slope. Railway routes running along a mountain slope on the valley bottom have quite a different figure. On one side the figure of the embankments is influenced by the adjacent slope and often ascents with a steep inclination. The figure of the embankment on the other side of the track is influenced by the valley bottom, so that it is largely flatter than the opposite embankment. Other parts of the rotes run through the plain valley bottom, where the figure of the embankment looks quite different from the embankments along the mountainous slopes. In this situation the figure and the conditions of the embankments are influenced by the surrounding flat terrain. In general the steep slopes are mainly forested, whereas agricultural areas and settlements are mainly found on the valley bottom, so that fire risk needs to be reflected differently along the railway routes, especially close to settlements. The different types of embankments occurring along the study sites are described in the following.

In mountainous areas the route frequently runs along the mountain slope with one side of the embankment ascending uphill and descending downslope on the opposite site. Figure 17 shows an illustration of an embankment in mountainous areas. Both embankments are completely forested. Usually there is barely a break between the track and the adjacent forest. At some spots a meadow is located along the upslope or the downslope embankment. Significant fire risk is given on the uphill as well as on the downhill part of the embankment. Fire caused by sparks spreads mostly uphill, whereas a loose hot brakeshoe easily rolls downhill causing fire on the meadow as well as in the adjacent forest.

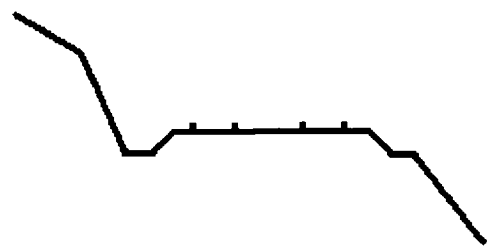

Figure 17: Embankment along a mountain slope

In places, where gullies cut the terrain, the railway route runs over bridges and an embankment is only present on the uphill side of the track. Figure 18 shows a respective profile. The fire risk is high for the uphill embankment, although fires get started below the bridge as well, in case glowing brakeshoes smash through the railing of the bridge and drop into the forest beneath.

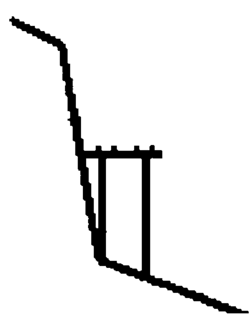

Figure 18: Profile of embankment next to a bridge

Reinforcements along uphill slopes are typical for mountainous areas as well. Especially between the cracks of walls vegetation becomes established and acts as a ladder for sparks travelling upwards into the adjacent forest areas. Figure 19 shows a reinforced embankment as it is found along railway routes. Even though the forests above the reinforced embankments might not seem to have a high fire risk from braking trains, the fire risk for the adjacent forest is high due to the ladder effect of the vegetation growing in the cracks. The area adjacent to the downhill embankment may have a different appearance. In this situation the adjacent area is pictured as even. The fire risk depends on the distance of the route to the adjacent vegetation as well as on the type of vegetation adjacent to the railway track as well. As discussed later in this chapter the fire risk is quite different for various vegetation types.

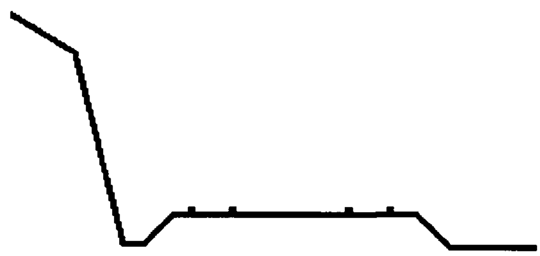

Figure 19: Embankment with reinforcement

Other parts of the route are forested on both sides. The uphill part of the embankment rises, whereas the areas adjacent to the downhill embankment are mostly horizontal. Often the vegetation on both embankments grows so close to the track that a high fire risk is present. Especially some trees lean into the track. Figure 20 demonstrates such a situation. A special situation occurs when a high amount of dead woody debris is accumulated on the embankment besides the living vegetation and reaches close to the track. This situation along the route indicates an increased fire risk. The extreme microclimate along railway routes and embankments influences the vegetation types next to the embankments to a great extent increasing the fire risk.

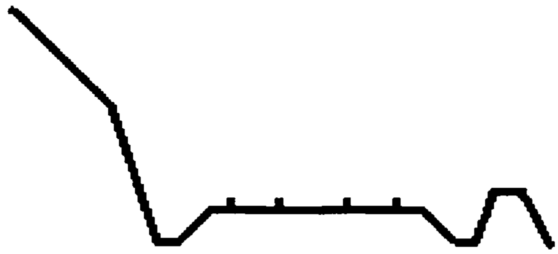

Figure 20: Forested embankment

Another type of embankments ascends on both sides of the track causing a tunnel effect along the route. Due to this fact the microclimate characteristic for railway routes is intensified causing a hotter environment and increasing the fire risk to a great extent. The local wind field is influenced by the tunnel effect along the railway route as well. The tunnel has a significant channelling effect. The winds are forced to advance along the railway route into one direction. Additional to the channelling effect the wind turbulences caused by passing trains are intensified as well. Fire risk along the railway route is significantly increased along sections with this type of embankment especially in case the embankment is densely vegetated. Figure 21 illustrates the tunnel effect of an embankment.

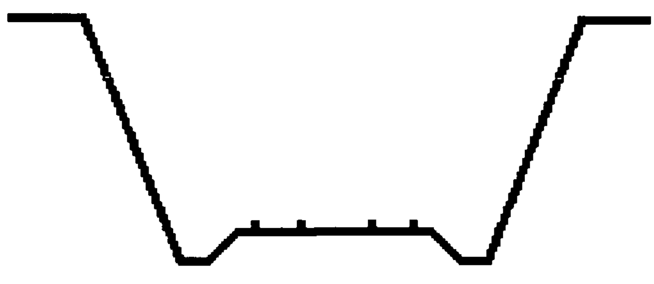

Figure 21: Tunnel effect of embankment

Another type of embankment found is similar to the one shown in figure 8. The embankment ascends on both sides of the track as in the situation described before. The difference is that the embankment on one side might for instance act as a dam against high tide along a river, whereas the embankment on the other side further ascends towards the mountain side. The road between the embankment and the forest acts as a break between both areas. Figure 22 shows the respective embankment type.

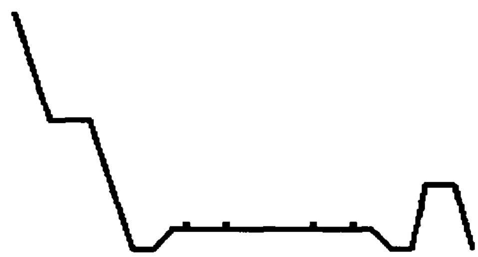

Figure 22: Embankment along river plain and mountain slope

In places the route runs along the valley bottom the embankment has a diverse image. Here the track is elevated compared to the surrounding area and the embankment has a downslope character. The embankments are mostly vegetated with grasses, although trees can be found along the embankment as well. This type of embankments is surrounded by fields, pastures and settlements. Fire risk along this type of embankments is relatively low. Lanes running along both sides of the railway route act as fire brakes and can be used during firefighting activities. The low grasses of the pastures do not carry fire very well so that fire spread is not significant. Fire risk on fields is only high in late summer, when the crops are dry enough for carrying a fire. Throughout the rest of the year fire risk is low due to the absence of crops. Figure 23 reveals a situation, where the track is surrounded by fields and pastures.

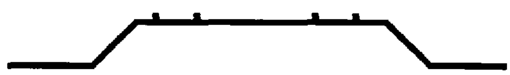

Figure 23: Embankment type in flat areas

Figure 24 illustrates a similar situation. This type of embankment is found at the transition between mountain and valley bottom. Pastures are found on the rising part of the embankment, whereas agriculture is found along the even surrounding of the route. The vegetation along the embankments consists of grasses and herbs. As along the type of embankment described above fire risk is low along this kind of embankment, since the fuel load is not as significant

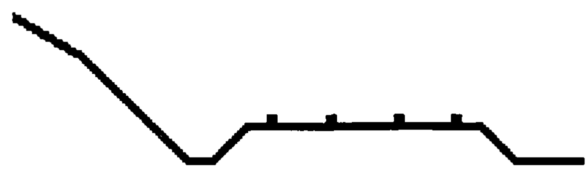

Figure 24: Embankment within fields and pastures

All embankments described above are present along all routes assessed and pose different fire risks to the adjacent areas. As regards the fire risk several characteristics of a railway route, the embankments and the surroundings are used for a comparison of the three railway routes assessed. The characteristics were found to be quite diverse for all three routes. The following tables show the different concentrations of the characteristics along the three routes.

The fire risk on all types on embankments is influenced by a number of characteristics typical for embankments along railway routes as well as by maintenance measures and their intensity of application on the embankments. Some characteristics showed similarities along all three routes assessed, whereas some showed differences. Maintenance measures were either present or absent along the three routes.

Table 6 shows a comparison of features found on and close to the embankments of all three sites assessed, where fires on the embankments and in the adjacent forests took place or did not take place.

Characteristics	Mallnitz-Pussarnitz	Bruck-Frohnleiten	Arnoldstein
Track and embankment			
Left-hand traffic on mountain side	X	X	X
curvy sections	X	X	
main position	mountain slope	valley bottom	valley bottom
main aspect	S-SW	W-S-N	S
steep descends	X	X	
steep embankment	X	X	
tunnel effects	X	X	
grasses/herbs	X	X	X
trees/shrubs	X	X	X
high fuel load	X	X	X
medium fuel load	X		X
low fuel load	X		
Management measures			
mowing	X		
controlled burning	X		

Table 6: Comparison of embankments at sites assessed

The conditions of the area surrounding the tracks and the embankments influence the risk for the spread of a fire beyond the boundary of the embankment to a great extent as well. Conditional of the type of landscape use adjacent to the embankment the importance of protection measures is different. Especially the type of forest and the respective understory adds up to the increased fire risk. Depending on the topographical conditions along the route, the accessibility and water availability firefighting activities can be carried out in a more or less appropriate way.

Table 7 shows a comparison of the situation in the area surrounding the three railway routes assessed.

Characteristic	Mallnitz-Pussarnitz	Bruck-Frohnleiten	Arnoldstein
steep slopes	X	X	X
rough topography	X	X	
good accessibility		X	X
poor accessibility	X		
water availability		X	X
forests close to track	X	X	X
timber production	X	X	X
agriculture	X	X	X
settlements	X	X	X
high fuel load	X	X	X
medium fuel load	X		
low fuel load	X		
grasses/herbs	X	X	
shrubs	X	X	
conifer forests	X	X	X
deciduous forests	X	X	

Table 7: Comparison of area along the tracks

Carinthia

Situation and fire risk between Mallnitz and Kaponig

The fires along the section of the route between Mallnitz and Kaponig took place in 1982. The route has been inactivated in 2001 due to the finish of the Kaponig tunnel and has been transformed into a paved hiking trail. The trail is used as an emergency road for the railway tunnel as well with a heliport at the northern end of the road. The trail runs along the slope in a curve. This has made frequent braking necessary. The braking of a train has lead to four forest fires destroying in total 10 hectares of old growth forest mainly consisting of *Larix europaea* and *Picea abies* on a length of six kilometres. Table 8 illustrates the species, cover and age of the old growth forest surrounding the burned areas.

Species	Cover (%)	Height (m)	Age
Larix europaea	100	15-20	100 +
Picea abies	100	15-20	100 +

Table 8: Dominant tree species of the region

Three formerly burned sites have a size of approximately three hectares each, whereas one site has only a size of one hectare. The four sites differ significantly from the surrounding unburned area in terms of vegetation composition and stand characteristics. A moisture gradient was found along the route being the reason for the differing vegetation composition. Together with the different aspect of the sites this has played a role for fire behaviour and fire spread during the 1982 fires. The inclination of the slope lies between 80 and 90 percent for all sites. The vertical slope is linear for all sites, whereas the horizontal slope is patterned. Together with the high fuel load that is assumed to have been present on the sites and the assumed weather conditions topography has had a significant influence on fire behaviour. Fire has spread uphill and has destroyed the forest on the sites completely. Drawing a conclusion from the high fuel loads present in the old growth surrounding the burned sites fire intensity must have been extreme and the trees on the sites have been killed completely.

The northernmost site, which at the same time is also the smallest burned site is located next to the heliport and is characterised by moist to wet conditions. A creek is running through it and the "*Rabischschlucht*" is located close to the site. The aspect of the site is west so that climatic conditions during fire have not been as extreme as on the other sites. Those conditions might have been the reason that the fire has not extended further into the old growth forest on this location.

The second and third site are influenced by a western to southern aspect. The southern aspect has a significant influence on all three sites. Here climatic conditions are drier and hotter than on the first site. The fourth site is influenced by a south-western aspect and is the hottest and driest of all. The dry conditions significantly influence vegetation composition and soil. This is the reason that damages on those sites are greater than on the first site along the route.

The hiking trail and the surrounding forest are property of the ÖBB. Besides some planting of *Picea abies* on the first site hardly any silvicultural measures have been carried out after the fires. Therefore only natural succession has taken place within the past 24 years. Today the vegetation consists of mostly deciduous forest with a dense understory between the age of 1 and 30 years. The forest on the burned plots has a strong pioneer character and contains primarily pioneer species, both trees and bushes. Table 9 shows the dominating pioneer species on the sites. The plant species composition dominating the region was found to re-establish on the sites.

Species	Cover (%)	Height (m)
Betula pendula	60-70	7-12
Corylus avellana	30-70	7-10
Alnus incana	30	12
Acer pseudoplatanus	10	7-12
Fraxinus ornus	10	7-12
Salix caprea	5-10	4-7
Quercus sp.	5	3
Larix europaea	30	0.1-2
Larix europaea	10	2-8
Larix europaea	5	12
Picea abies	30	0.1-2
Picea abies	10	2-8
Picea abies	5	12

Table 9: Pioneer species on burned sites

Shrubs, grasses and herbaceous species form a dense understory beneath the canopy of pioneer species. *Pteridium aquilinum* is a characteristic species establishing on burned sites after fire, which dominates the understory. It was found to be abundant in all locations. Table 8 shows the main grass species present on all sites. Shrubs present on the sites are included in table 9. Table 10 shows the most frequent grasses and herbaceous species on all sites as well as along the route.

Species	**Cover (%)**	**Height (m)**
Bromus erectus	80-90	0.8
Bromus inermis	70-90	0.6-0.8
Nardus stricta	70-90	0.8
Festuca ovina	60-90	0.5-0.8
Festuca rubra	60-90	0.5-0.8
Dactylis glomerata	60	0.6
Pteridium aquilinum	70	0.8

Table 10: Main grass species on the burned sites

The fuel load consisting of live plant material was found to be high in all four sites as well as in the adjacent old growth forest. The high amount of grasses and herbs present on the burned sites as well as the dry snags found on all sites add to the increased fire risk on the plots. It can be assumed that fuel loads in the forests along the active track are similar to the fuel loads assessed along the inactive route. This means that the fire risk along the whole route is extremely high in case fire escapes from the boundary of the embankments and that measure to significantly reduce the risk along the railway route are indispensable. The fire risk along the route has shifted from trains as the only reason for fire ignition to other anthropogenic reasons related to human activities along the hiking trail.

Damages in the sites

After 24 years not much evidence about the extent of the damage has been found. The stands have probably been destroyed completely by the fire and the soil has burned down to the mineral soil to a great extent. At the same time some tree individuals present on the sites have been damaged less severely so that they have been able to resprout. Grasses, herbaceous species and pioneer species have been able to establish after the fire creating deciduous stands in an area otherwise dominated by old growth stands composed of *Larix europea* and *Picea abies*. Most of the species have established through seedlings, although some trees have been able to resprout after the fire.

Snag residues of *Larix europaea* and *Picea abies* indicate that the fire has killed the old growth present on the sites. In some locations the rows of snags reached as close as 15 meters to the former track. This indicates how close the old growth forest reached down to the embankment, which has made it susceptible to a fire outbreak. Scorched trees and trees with fire scars are located at the boundary of the burned sites. Mainly *Larix europaea* was found to be the damaged species. This species has a thick bark helping it to survive up to certain fire intensity. No crown damage has been found on scorched trees or trees with fire scars. The fire scars on the trees and the damaged bark makes the trees susceptible to follow-up diseases caused by beetles, viruses, bacteria or fungi. Studies have shown that certain susceptibility is present and that the follow-up damage is significant, even though trees might seem to be healthy. Damages to the soil have certainly been severe after the fires and soil conditions have been altered. Figure 25 shows the snags on one of the sites burned in 1982.

Figure 25: Snag residues on burned site

Formation of new habitats

The four burned sites are a practical example for the significance of succession regarding habitat requirements for game and other animal species. Forest succession has formed manifold habitat structures on the burned forest sites in the past 24 years. The old growth of the area is dominated by *Picea abies* and *Larix europaea* with an age over 100 years.

This forest structure offers a good quality habitat in terms of shelter. However it does not offer a high-quality food source for terrestrial wildlife species. Besides some open spots within the forest no structure with a high quality food source is available. Due to the fact that the burned sites have been mainly left to succession the vegetation present on the sites represent a high-quality food source for the game of the area. Intensive browsing damage is found throughout the whole site. Besides the significance of the burned sites as a habitat in terms of a food source the sites are important as a habitat for invertebrate species as well. Grasses and herbaceous species found o the burned sites provide and excellent food source for insects. Vipers and snakes get hold of an ideal habitat. Figure 26 shows the browsing damage on the burned sites.

Figure 26: Bark peeling and browsing damage on burned sites

As for the microfauna and other soil organisms it can only be assumed that habitat conditions have become ideal after the soil has recovered after the fires at this site. The removal of nutrients from the soil, ash deposition and erosion activity might have played a role on the sites after fires. Soil microorganisms and soil fauna has found ideal living conditions in the newly established forest stand. Due to the lack of data for the time after the fires this can only be assumed. Studies about soil conditions after forest fires have shown that fire has a significant impact on soil condition.

Susceptibility of vegetation to fire

The assessment of the four sites along the inactive route has revealed a high susceptibility of the stands composed of *Larix europaea* and *Picea abies* and its understory for fires. Even though not enough data have been available on the extent of the damage the fires have caused, the assessment of the sites revealed a complete destruction of the stands and the soils through high fire intensities. The high fuel loads present on the sites due to the high stand densities represent a high susceptibility of the sites and the surroundings for repeated fires for an extended period of time. Fire risk has shifted from trains as a reason for a fire outbreak to human activities related to car passage, hiking during the summer months and other related activities and therefore is still present along this part of the route.

State of maintenance

Since this section of the route is not in use by trains anymore, the need for a regular maintenance for the reduction of fire risk through train traffic is not given anymore. However the need of a regular maintenance is still given due to the regular use of the trail for hiking purposes in summer, access road for the housing along the route as well as the use as rescue road for the tunnel.

Fire Risk Factors and Values at Risk

The Fire Risk Factors and Values at Risk assessment indicates that the sites themselves as well as the area and the values located directly around them are subject to an increased fire risk. It is therefore necessary to take measures in order to reduce the fire risk. The fire risk evolves due to the fact that the vegetation covers reaches down to the road. Especially the high density of grasses and herbaceous species on the boundary of the road and the burned plots increases the fire risk for the forests. Table 11 shows the Fire Risk and Values at Risk Rating for the four sites with the kilometre mark found along the former railway route. The risk points shown here have been obtained by assigning point values to attributes characteristic for the sites. These point values are listed in the Point Rating tables in the Appendix.

Sites (km)	Fire Risk	Values at Risk
48.1-48.3	25	41
48.6-48.9	25	42
48.9-59.3	25	43
51.3-52	25	45

Table 11: Fire Risk and Values at Risk Rating

Even though train traffic has been removed as a reason for a fire outbreak along this section of the route, a fire risk for the sites studied and their surroundings is still present in the form of hikers and residents passing on the road. Rescue activities for the tunnel need to be considered as an influence of a fire risk for the area as well, if only on a short-term basis. Especially negligence plays a role in this context. In some places along the trail glass bottles were found, which act as a lighter when sun rays hit them. Together with the aspect of the area a longer period of hot and dry weather makes the site susceptible for a repeated fire outbreak.

Situation between Kaponig and Pussarnitz

Thirteen points of interest have been selected along the route based on the ÖBB fire statistics from 1997 to 2005, which have been subject to frequent fire outbreaks throughout the year.

The aspect of the route is south- to southwest facing and mainly runs from east to west. Conditions on a southern aspect are hotter and drier than on other aspects. The snow cover is melting sooner in early spring than in the valley or on other aspects of the valley. The extreme microclimate along the route enhances the effect of the aspect on the conditions of the area directly adjacent to the track. The vegetation and the soil dry out faster leaving a high fuel load and increasing the fire risk along the route.

The figure of the embankment and the slope are changing along the whole route on both sides. Rocky slopes with a gradient of more than 90 percent with no or little vegetation change with areas with a slope gradient of around 70 to 80 percent. Most rocky features are found along the uphill slope.

At regular intervals the embankment is technically reinforced by a wall with a slope gradient of 90 percent. In the cracks of the reinforcing walls and of the rocks trees, shrubs and grasses have established supporting the spread of a fire to the forest beyond the reinforcement. Bridges lead over gullies, stream beds or depressions especially in the mountainous part of the route so that the embankment only extents on the uphill slope of the track. The forest or agricultural area along the downhill side of the track is located 30 meters below the bridge. However old growth trees reach up to the track from the downhill side in several locations. Branches reach well into the track at several locations. Loose brakeshoes have been falling down the bridges causing damage in the forest. The lower part of the route running along the valley bottom and is bordered by pastures and fields. Lanes run along the track connecting it to the nearest road. Along this part of the route settlements and agriculture are bordering the route. Table 12 shows the tree species composition along the forested part of the route.

Species	**Cover (%)**	**Height (m)**
Betula pendula	60-70	7-12
Corylus avellana	30-70	7-10
Sambucus nigra	40	7
Sorbus aucuparia	20	7-12
Salix sp.	15	5-7
Quercus sp.	20	3
Larix europaea	30	10-18
Picea abies	20	12

Table 12: Tree species close to the track

No clear boundary is given between the embankment along the upslope section and old growth or managed forest. The species composition, cover and age of the old growth are given in table . Along some sections old growth forest with a dense grassy understory reaches as close as five meters to the track without a break. The further one moves away from the track the denser the forest and its understory gets and the amount of dead fine and coarse woody debris is increasing. The pioneer species grow as close as ten meters close to the route.

Together with the steep topography of the surrounding terrain the high amount of living plants and woody debris adds up to an increased fire risk for the surroundings. Old growth conifers, mainly *Larix europaea* and *Picea abies* are growing into the overhead system and over the track. Towards the valley bottom deciduous trees are leaning over the track and into the overhead system as well. Grasses and herbaceous species dominate the embankments and the understory of the forest stands adjacent to the track to a great extent. The grass species found along the route are listed in table 10. Table 13 shows the main herbaceous species found along the route.

Species	**Cover (%)**	**Height (m)**
Trifolium alpestre	30-90	0.3-0.4
Calamagrostis varia	70	0.2
Potentilla rectal	70	0.3
Fragaria vesca	50	0.15
Urtica urens	40	0.6
Geranium dissectum	40	0.4
Reseda lutea	30	0.3
Hieracium sylvaticum	30	0.5
Achillea millefolium	20-30	0.3
Anthyllis vulneraria	30	0.3
Digitalis grandis	20	0.6
Trifolium alpestre	20	0.3
Lotus corniculatus	20	0.15
Euphorbia cyparissias	20	0.2
Hedysarum hedysarioides	20	0.3

Table 13: Dominating herbaceous species

During fieldwork construction works have been going on along the route in order to straighten the curves and level the track so that the braking frequency will be reduced in the long run. The embankments will be remodelled and planted and roads are constructed along the embankments for maintenance purposes. The roads can be used for firefighting purposes as well. A part of the construction works has already been finished so that it is possible to provide management options to further reduce fire risk along the whole route.

Road access to the route is not given along the major part of the route. Especially in the mountainous part of the route no direct road access is available, which could be used for firefighting activities in case of a larger fire outbreak. Due to the construction works along the track especially in the middle part of the route roads will be present in the future for maintenance purposes, which can be used for firefighting purposes. In the lower part of the route lanes can be used in case of a fire outbreak. No direct water source is available along the whole route. Together with the lack of a decent infrastructure this poses a significant problem for firefighting activities in case of a big fire outbreak.

According to the ÖBB fire statistics the fires are mostly limited to the embankments and are mainly extinguished right away without having the chance to escape into the adjacent forest. According to the ÖBB fire statistics from 1997 to 2001 fire occurrence was found to be highest from January to March for most years. Some years however do not show any fire occurrence during this phase. In the period from May to September fire frequency was found to be moderate for some years, whereas in some years obviously no fire occurred at all. In 2003, which had a remarkably hot and dry summer, forest fires peaked in July and August, whereas the ÖBB fire statistic did not reveal a significant occurrence of fires on embankments during this period.[128] The period from October to December shows no fire incident for the route. Obviously the small quantity of winter fires occurred in years with no snow cover along the route. Table 14 shows the fire frequency for the period between 1997 and 2001 for the course of one year. The years from 2002 to 2005 are not shown, since fire occurrence and frequency was found to decline remarkably after 2001. Summing up the numbers of fires of the five years assessed February was found to be the month with the highest fire occurrence. This indicates that fire risk is significantly increased in late winter when fuel loads on the embankments and therefore ignition probabilities are high.

[128] Gossow and Hafellner, 2006

	1997	1998	1999	2000	2001	Sum
Jan.	-	7	2	4	1	14
Feb.	3	18	7	7	4	39
Mar.	-	5	7	2	1	15
April	15	2	-	2	-	19
May	3	7	-	2	-	12
June	3	3	-	5	2	13
July	3	2	5	1	2	13
Aug.	3	-	-	1	-	4
Sept.	5	-	4	1	1	11
Oct.	3	-	-	-	-	3
Nov.	1	-	-	-	-	1
Dec.	-	-	1	-	3	4

Table 14: Fire occurrence and fire frequency per month from 1997 to 2001 (ÖBB fire statistics 1997 to 2005)

The frequency of fires is quite different for the embankments assessed along the route. It was found that fires occurred more frequently along the higher sections of the route, whereas it decreases significantly as soon as the railway route reaches the valley bottom. This is linked to a better accessibility of the route on one hand and the existence of settlements and agriculture along the route. Figure 27 shows the fire frequency along the route from 1997 to 2005.

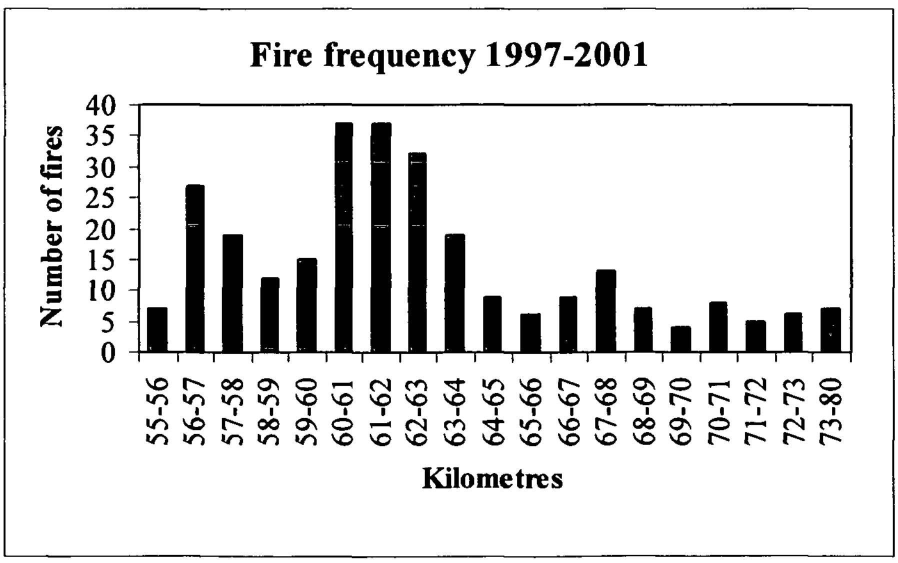

Figure 27: Fire frequency per kilometre (ÖBB fire statistics 1997-2005)

Two main periods for fire occurrence on embankments could be distinguished during the day. The afternoon is clearly the time of day with the highest fire occurrence during the day. Another peak was found during the night, whereas morning and early evening showed a low fire occurrence. Climatic conditions during the day together with the extreme microclimatic conditions along the track certainly influence the fire frequency during the day. As for the reason of fires it needs to be said that passenger and cargo trains are to be equal in causing fires during the day, whereas the fires ignited through the night are caused by cargo trains, which pass along the route during the night. It was not possible to investigate this detail any further, since cargo trains do not follow any timetable. Figure 28 illustrates the distribution of fires during the day for the years 1997 to 2005.

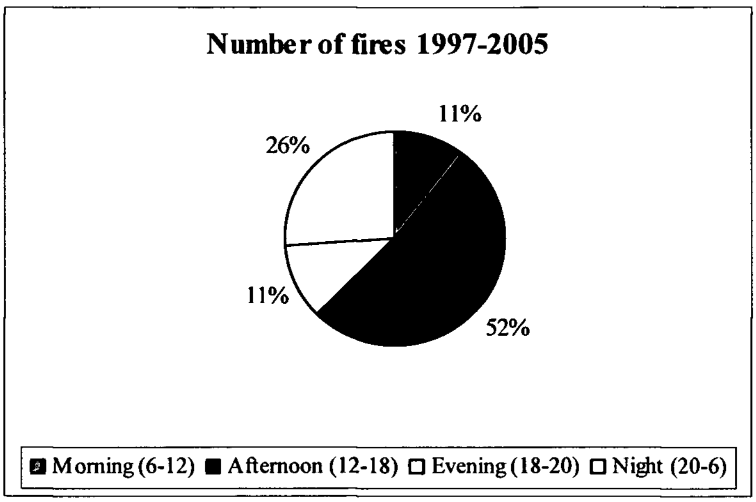

Figure 28: Fire occurrence during the day (ÖBB fire statistics 1997-2005)

Along parts of the route the ÖBB regularly conducts controlled fires on the embankments in order to reduce the fuel load and therefore also the fire risk. Even though the permit obliges the ÖBB to conduct controlled fires in early spring and in late summer, controlled fires are only conducted in late winter between February 15th and April 15th.

Damages along the route

The ÖBB fire statistics reveals that fire has escaped from the embankment only occasionally and has only caused minor damage to trees or a meadow in the direct vicinity. Most damages are limited to the track and the embankment, since fires have been extinguished soon after discovery. Damages occur along both sides of the route. Fires along the uphill slope of the route have been caused both by flying sparks and glowing brakeshoes, whereas the fires along the downhill embankment have been mainly caused by glowing brakeshoes. Damages caused by flying sparks are not limited to one portion of the embankment, but are rather found along a major part of the route. This means that a braking train causes several small fires by flying sparks at once, whereas a fire caused by a glowing brakeshoe is limited to one spot.

The fires on the embankment and in the areas directly adjacent to the embankment have been only surface fires with a rather low impact on the soil and the vegetation. The release of nutrients to the soil has helped the understory consisting mainly of grasses and herbs to recover fast. Evidence of damage cannot be found on most sites, since grasses and herbs tend to colonise the very fast due to the release of nutrients, especially after a surface fire, where the soil cover has not been damaged seriously. Fire scars on trees giving evidence of fire damage are found on sites where a fire has been caused through a glowing brakeshoe. Trees damaged by the fires are subject to follow-up diseases caused by fungi, bacteria, viruses or beetles. On the sites, where the trees are standing along the uphill embankment caution needs to be taken, since the damaged trees are standing less than 50 meters away from the track. Besides the risk of infecting the adjacent stand the trees are at risk to fall down onto the track and cause significant damage to the overhead system.

During fieldwork a glowing brakeshoe has started a fire above a reinforcement wall. Sparks have been able to mount the wall along the herbaceous vegetation growing in the cracks of the wall and start the fire in the shrubs above the wall. In case the fire does not get detected and extinguished right away, the adjacent forests are at great risk of escaping fire. Figure 29 illustrates the damage above a reinforced embankment.

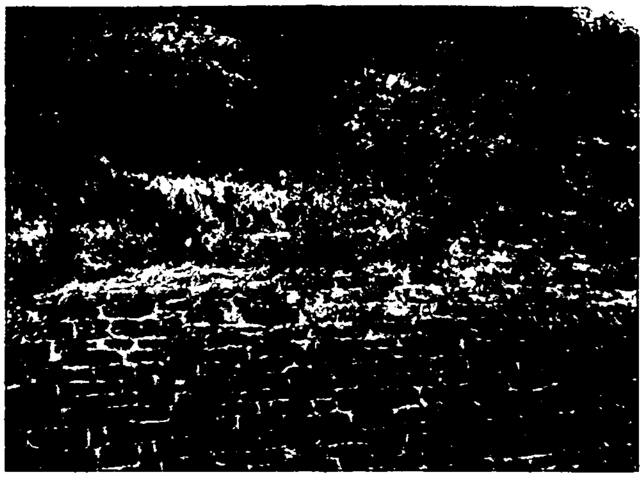

Figure 29: Fire caused by glowing brakeshoe above reinforced embankment

The downhill side of the embankment is susceptible to fire as well. Loose glowing brakeshoes have rolled downhill in the past and have started fires on the downslope side of the track. According to statements of ÖBB employees fire spread only took place upslope. Damage assessment along the downslope section of the route confirmed this report. Only few old growth *Larix europaea* have been damaged. The fuel load present at the time of the fire has lead to flames reaching as high as approximately four meters. However fire severity has not been strong enough to kill the larch, since the fire has been extinguished fast. Due to the thick bark the damage through fire has remained low. Nevertheless a follow-up damage by fungi, viruses, bacteria or other diseases entering the tree through the wound could weaken the tree in the long run. In figure 30 fire marks on *Larix europaea* are visible on the stem base. They have been caused by a fire, which has been caused by a glowing brakeshoe some years back.

Figure 30: Fire marks on *Larix europaea*

Close to stations embankments along the route are subject to frequent fires caused by sparks from braking trains are recurrently damaged. An example is the embankment north of the station Penk. The frequent surface fires burn down to the mineral soil and so disable a permanent vegetation cover to persist. Frequent fires enable plant species adapted to the harsh conditions as well as certain rare species to persist on this site. An example is the rare plant species *Iris variegata*. *Anethum graveolens* is an example of a cultivated plant growing wild. On frequently burned sites *Pteridium aquilinium* is found abundantly as well. This species is perfectly adapted to the harsh conditions on burned sites and is a good indicator of frequent fires. Figure 31 displays the embankment close to Penk, which is subject to frequent fires throughout the year.

Figure 31: Frequently burned embankment close to Penk

State of maintenance

Along a great extent of the route no embankment is present between the track and adjacent forest. At some places the forest reaches up to five meters close to the track. Deciduous and conifer trees are at risk of catching fire by sparks from braking trains causes fire or damaged brakeshoes. The grass layers next to the track as well as the understory of the forests are dense and pose a significant fire risk, because no break is present between the track and the vegetation.

Old growth *Larix europaea* frequently leans over the track and the branches reach into the overhead system along some sections of the route. The branches are at a critical distance to the track so that they are susceptible to sparks and therefore at risk for crowning. The reinforcements of the slopes are not cleaned from trees, shrubs and grasses growing in the cracks posing a significant fire risk to adjacent forests.

The mesh of the railing of the bridges is damaged on a major part of the bridges. It is corroded and has holes and is too weak to keep brakeshoes from falling down the bridge into the adjacent forest, when they are falling off the train with a high force. A replacement of the mesh needs to be considered.

The embankments along the part of the route running along the valley bottom are merely vegetated with grasses. Along this section of the route fire risk is still significant, however grasses do not support a significant fire spread. Since a road access adequate for firefighting purposes is given along the valley bottom, the fire risk is significantly reduced along this part of the route. As displayed in figure 27 the fire frequency is high for the area along the mountainous part of the route, whereas the fire frequency is significantly reduced along the section of the route running along the valley bottom.

Together with the high fuel load present along the mountainous part of the route and the lack of respective infrastructure along this part of the route this indicates an increased fire risk for the area adjacent to the railway route in case of a fire outbreak beyond the embankments. This makes management measures and the establishment of a respective fire management plan for this section of the route extremely necessary.

The construction works create a significant fire risk along the route, since the vegetation on the embankments is cleared before construction works. The dead woody debris is left on the embankment instead of being removed. This fine and coarse woody debris forms a high fuel load and is located less than one meter away from the track in most places. Sparks as well as loose brakeshoes directly fall into the debris and start a fire, which can easily spread to the surroundings. Settlements, managed forest and agriculture are located less than 100 meters away from this area. The south-facing aspect of the route, the special microclimate of the track and its direct surroundings, the slope of the embankment and periods of dry weather facilitate fire spread together with the high fuel load present. Figure 32 shows the high fuel load caused by woody debris left behind by construction works.

Figure 32: Woody debris caused by construction works

At this point it is unknown, how the embankments will be maintained after construction works will be finished, especially since by then most of the route will be accessible by means of a maintenance road running next to the track. Proposals for risk reduction measures will be given at a later point of this paper.

Formation of new habitats

The high frequency of fire along the route has formed numerous small habitat patches, which host species adapted to frequent disturbances, among them also many rare species, which are not found elsewhere along the route or in any other habitat in the area.

The vegetation on sites subject to several is subject to a change in species composition. Species not adapted to the high frequency of fires are replaced by species being more fire resistant or adapted to fire. Species are immigrating from sites close by. Often rare species, which are only found on this particular spot are colonising the area. Examples are *Iris variegata* and *Anethum graveolens*, which have become savage.

The embankments are suitable habitats for different animal species as well. Species such as lizard and snakes are adapted to hot environments such as along railway routes. The microclimate particular for railway routes promotes living conditions for those animals. Grasses and herbs are the ideal food source for insect species. Soil flora and fauna was not analysed for this study, even though fire has a significant impact on soil flora and fauna as well.

Susceptibility of adjacent forests to fire

The fires along the active route have been small so far and have not destroyed extensive areas beyond the embankments. Nevertheless a certain susceptibility of forest types exists along the route. The "*Tauernbahn*" is mainly surrounded by old growth conifer forests. At some points along the route small patches of managed private conifer forests are present among the old growth. In case of a fire outbreak the conifer forests are subject to complete destruction. The susceptibility of both forest types to fire is quite different in case of an escaping fire. *Larix europaea* resist low-intensity fires through their thick bark. However in the spots a fire has been caused by glowing brakeshoes the damage usually has been confined to a limited area causing fire scars on individuals of *Larix europaea* and making them susceptible to follow-up diseases. *Picea abies* shows a medium susceptibility to fire, whereas the planted *Pinus sylvestris* stands are highly susceptible to any fire intensity due to their thin bark. Young deciduous forests with a high stand density are to be found on several patches along the route. Together with a high density of the understory and a dense grass layer those stands hold high fuel loads, which increase the risk of a fire being carried into the adjacent old growth conifer forests.

Plant species not adapted to a high fire frequency do not get established on the sites in first place. On the other hand frequent fires would give way to invasion of the area through non-native species, which change the ecosystem structure to a great extent.

Fire Risk Factors and Values at Risk

The Fire Risk and Values at Risk Rating was found to exceed the threshold values defined for the Fire Risk and Values at Risk Rating significantly. This indicates that measures need to be taken in order to reduce the fire risk.

For assessing the fire risk factors for the kilometre sections listed in table 15 the topographical and the fuel situation of the embankment and the adjacent area was assessed as well as the risk of ignition by lightning, person, railway, and traffic. Additionally the proximity of roads and water sources were assessed. Both are not available abundantly, especially in the mountainous part of the route.

As for the Values at Risk Rating the risk of an escaping fire for life and property, timber values, habitat for plants and wildlife, visual and aesthetic elements as well as cultural values along the route were considered as well as visual and aesthetic values. Along the mountainous part of the route the consequences of fire especially for timber values as well as habitat values and visual and aesthetic values were found to be of significance. The risk for human life was found to play a role as well, since the area around the route is highly frequented by hikers. Around the part of the route running along the valley bottom fire risk is significant for values rather connected to agriculture, settlements and human life rather than to timber, habitat or aesthetic values.

However it needs to be mentioned that the sites along the route on the valley bottom are embankments with a grass cover, which means that a fire risk proceeding from woody debris is not given. Nevertheless grass can also pose a significant fire risk. Even though some sections of the embankment show a value clearly below the threshold value for both the fire risk and the values at risk rating because of the absence of woody debris there is a clear need for risk reduction measures along the whole route. Table 15 shows the Fire Risk and Values at Risk Rating for the single positions along the route.

Site (km)	Fire Risk	Values at Risk
54.4-54.5	26	44
55.1-55.2	26	38
56.4-56.6	25	22
56.9-57.2	26	25
57.7-57.9	24	20
59.7	25	20
59.220-59.250	27	29
60.4-60.5	19	23
64.070-64.100	21	25
67.1-67.3	21	18
70.4-70.6	24	29
71.1-71.2	26	40
71.7	24	45

Table 15: Fire Risk and Values at Risk Rating

Risk assessment for the route

According to the ÖBB fire statistics only small fires on the track or the directly adjacent embankment have occurred around the active route between Kaponig and Pussarnitz since 1998. If damage has occurred to the directly adjacent areas, damages were kept small, since all fires have been extinguished right away. Nevertheless the forests, agriculture and settlements as well as areas frequented by tourists along the route are highly susceptible to forest fire in case the fire escapes beyond the boundaries of the embankment.

Especially when considering the topography and the dominating south-west aspect of the whole route and the resulting climatic conditions, the microclimate along and directly adjacent to the track, the fuel load on the embankments and in the forest as well as the fact that along a major part of the route no real break is present between embankment and the adjacent areas, fire risk can be regarded as severe. Mainly in the area between Kaponig and Penk access to the route and the adjacent forests is difficult. No direct road access is available for firefighting activities so that especially those areas are at a high risk. Table 14 indicates the Fire Risk and Values at Risk Rating for the chosen sites along the route between Mallnitz and Pussarnitz.

Situation along the route Villach-Arnoldstein

In July 2006 ten hectares of community forest along the route between Villach and Arnoldstein has been destroyed by a fire after a short period of extremely hot and dry weather. The forest consists mainly of planted *Pinus sylvestris*, which has been severely damaged. The fire obviously has been a surface fire, which has caused considerable damage to tree stems. During site assessment a high number of trees was found with considerable fire scars and ruptured bark. The soil beneath the conifer trees has burned down to the mineral soil completely. The extent of damage on the deciduous trees present on some spots throughout the site has not been as significant as beneath the conifer forest due to the different burning characteristics of the different stands. The soils beneath the deciduous trees show a lower damage as well. These characteristics are going to be described at a later instant.

Figure 33 shows the extent of the damage in the burned forest stand in deciduous trees and conifers respectively.

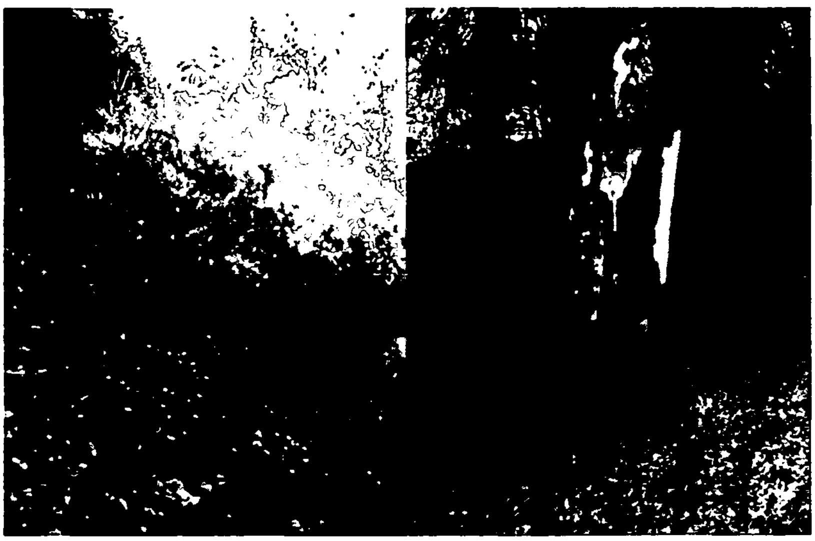

Figure 33: Extent of damage on trees and soil

The understory and the young trees beneath the mature stand have been burned completely. Apparently the understory has been high and dense enough to cause the considerable fire scars on the conifer stand.

No information was available on the situation in the forest stand before the fire. However the fuel conditions observed in adjacent unburned forest stands suggest that a fairly high amount of grasses and herbaceous species can be assumed for the deciduous forest stand. As for the conifer stand it can be assumed that fuel loads present before the fire have been moderately high. The higher ignition probability of conifer fuels has influenced the damage on the trees to a great extent.

The condition of the embankments close to the site indicates that the state of maintenance has been quite poor along this section of the route. It is not possible to identify the situation along this section of the route before the fire, since no further information has been available. Along this route no controlled burning or other measures have been conducted and it is not likely that any management measures are conducted on the embankment in order to keep the fire risk for the surrounding area low.

Accessibility to the forest stand is relatively good. Road access is given through a forest road leading into the stand as well as a forest road leading along the railway track. As far as it is known, a forest road is leading along the upper edge of the forest stand as well. Firefighting activities can be carried out properly. An important point to be considered is that the access to a reasonable water source is not given. Only an open water source in a nearby swampy area close to the railway track was helpful in the acute firefighting efforts in July 2006. However on one hand the swampy area is subject to nature conservation and therefore not very useful as a water source for firefighting purposes in the long run. On the other hand this swampy area is at risk to dry out completely during long lasting hot and dry periods so that it is not a reliable water source in the long run. Other water sources need to be explored and measures need to be found to transport water to the area in case of a repeated fire.

As far as an assessment was possible no measures have been taken on the embankments so far to reduce the increased fire risk for the adjacent forest. However no further information was available for this railway route.

Styria

Situation between Bruck and Frohnleiten

The route between Bruck an der Mur and Frohnleiten was chosen, because sparks from damaged freight train have caused major forest fires between Übelstein and Laufnitzdorf in February 1998. These fires have been the only fires between 1997 and 2005 according to the ÖBB fire statistics. There have been some small fires in 1997 and 1998 along this route, but they have not been as devastating. Figure 34 shows the fire occurrence along the route as stated in the ÖBB fire statistics. However it needs to be mentioned that the devastating fires of February 27th to 29th 1998 have not been included in the fire statistic for some reason. A reference site close to Mixnitz has been chosen to show the risk of a repeated fire for the whole route.

The route follows the valley bottom and has various curvy sections. The main aspect along the route is west-facing. Due to many curves along the route the route is characterised by a frequent change of aspects ranging from north facing over west facing to south facing. Together with topographical, climatic and fuel aspects this fact influences the fire risk and fire susceptibility of the embankment as well as the adjacent sites to a great extent.

The microclimate characteristic for the track and the directly adjacent embankment has a significant influence on fire risk and susceptibility along the route as well. Fire risk and susceptibility are frequently changing due to the frequent change in the exposure to the conditions described above.

Moisture conditions on the embankment are changing along the route. Especially the embankments directly bordering the floodplain of the meandering Mur River are influenced by the wet conditions in the floodplain. It can be assumed that theoretically the risk of a fire to escape along these parts of the embankment is low. The slope of the embankment amounts to 40 percent and has a height of around eight meters.

The eastern embankment is influenced by the adjacent slopes and amounts to 80 to 90 percent. Along a major part of the route forests are found along the mountains bordering the track. The inclination of the embankment bordered by settlements or agricultural areas is between 30 and 60 percent. The route is running through the plain, so that the embankment has a upslope character along this part of the route.

Bare soil is not found throughout the whole route and vegetation cover on the embankments amounts to 100 percent. The vegetation is dominated by tree and shrub species as well as grasses and herbaceous species. The dominant tree and shrub species found on the embankments along the route are listed in table 16. Even though the species found along a major part of the route are broadleaved species, fire risk is still significant due to the increased fuel loads present on the embankments.

Species	Cover (%)	Height (m)
Sorbus aucuparia	60	7
Fraxinus excelsior	60	7
Robinia pseudoacacia	60	7
Betula pendula	40	7
Populus nigra	30	7
Acer platanoides	40	7
Salix sp.	50-60	4-7
Malus sylvestris	50	3
Pyrus achras	50	3
Rubus fructicosus	70	2
Rubus idaeus	70	1.2
Clematis vitalba	60	8
Picea abies	40	15
Evonymus europaeus	40	5
Ulex europaeus	30	1.5
Ligustrum vulgare	30	5
Reynoutria japonica	30	2
Quercus sp.	20	4-5

Table 16: Dominating tree and shrub species

Along some sections of the route planted coniferous forest mainly consisting of *Pinus sylvestris* and *Picea abies* were found to reach directly down to the track without any gap in-between. Along these sections of the route the fire risk is increased significantly due to the specific ignition characteristics of conifer litter and fuel. A dense layer of grasses and herbaceous species adds up to the increased fire risk along the route. The main grass and herbaceous species are listed in table 17.

Species	**Cover (%)**	**Height (m)**
Dactylis glomerata	100	1
Lolium multiflorum	100	1
Agropyron repens	100	1
Poa pratensis 1	00	1
Poa nemoralis	100	1
Festuca gigantea	100	1
Festuca ovina	100	1
Festuca rubra	100	1
Bromus erectus	100	1
Bromus incana	100	1
Impatiens noli-tangere	60	0.8
Impatiens parviflora	60	0.6
Impatiens glandulifera	70	1.5

Table 17: Dominating grass and herbaceous species

As indicated by the ÖBB fire statistics the track and the embankments have neither been subject small fires nor do them show any damage from the big fires in 1998. The vegetation has developed without any sign of disturbance. Therefore the high fuel load found on the embankments adds up to the increased fire risk for the embankment and its surroundings. Ignition probability and fire intensity are enlarged to a great extent. The significance of the "*Murradweg*" as a fuel break between the embankment and the adjacent forests is therefore significantly decreased. In order to use the road as a fuel break it is therefore necessary to apply maintenance measures along the whole route.

Damages along the route

The big fires of February 1998 caused by a damaged brakeshoe have destroyed 37 hectares of forest and embankments along the route between Übelstein and Laufnitzdorf, specifically between the route kilometres 162.2-164.1 and 167.0 and 176.1. Around 31 hectares of private forest were affected and six hectares of embankment in the property of the ÖBB. The extensive damage the fire has caused on all forest sites is visible throughout the whole valley. It will take a long time until forest has reoccupied the sites to such an extent that the damages will not be as evident anymore. Figure 34 shows the burned forest stand in the Gabraungraben.

Figure 34: Gabraungraben

Extreme climatic conditions together with fuel load, aspect and topography have influenced fire spread and fire behaviour and therefore the degree of the damage to a great extent. Due to the steep and rugged terrain the fire has spread into several directions and has destroyed the forests on the sites completely. There were no respective data available for the route between Bruck an der Mur and Frohnleiten. Therefore the data obtained through the analysis of fire frequency along the route between Mallnitz and Pussarnitz were used, because it can be assumed that general conditions were the same for both routes. The precedent fall and winter have been exceptionally dry and the snow cover in the preceding winter has been low. This has obviously facilitated fire ignition.

Due to the lack of respective data for the route between Bruck and Frohnleiten fire occurrence for the route between Mallnitz and Pussarnitz from 1997 to 1998 are shown in figure 35 instead. Respective numbers of fires for the period shown are listed in table 14. February 1998 shows an increased fire occurrence compared to February 1997. This can be related to the preceding winter, which has been remarkably dry and low in precipitation.

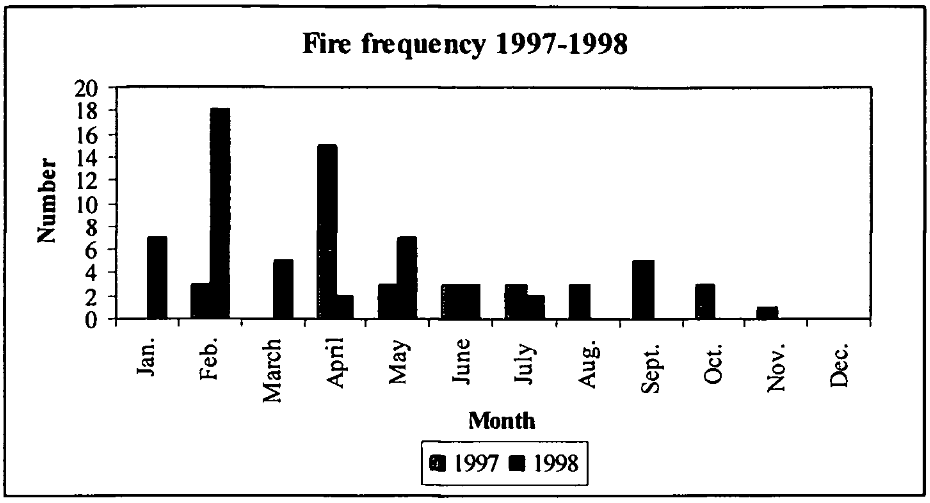

Figure 35: Fire frequency 1997-1998 (ÖBB fire statistics 1997-2005)

Documentation provided by the *Guts- und Forstverwaltung Schloß Pernegg* has revealed different intensities of destructions of forest stands and forest soil. It was found that fire especially affected young stands up to 30 years and conifers, whereas deciduous stands showed less damage. The intensity of soil destruction depends on the forest type as well. Table 18 shows the extend of the damage to different forest stands and soils at different ages. Additionally to the damage to the forest stand 3.8 kilometres of the forest road, which is leading through the site has been damaged as well.

Species composition	**Age**	**Damage to stand**	**Damage to soil**
P. abies	40	30 %	25 %
P. abies	70	10 %	20 %
P. abies	20	100 %	20 %
P. abies/L. europaea	11	100 %	40 %
P. abies/L. europaea/ B. pendula	12	100 %	30 %
P. abies/F. sylvatica/ L. europaea/P. sylvestris	2	100 %	40 %
P. abies/Larix europaea/ P. sylvestris/F. sylvatica	20	100 %	40 %
F. sylvatica/Larix europaea/ P. sylvestris/P. abies	80	10 %	20 %
P. abies/L. europaea/ F. sylvatica	55	30 %	40 %
P. abies/F. sylvatica	40	10 %	20 %
P. abies	70		20 %
P. abies/L. europaea/ P. sylvestris/F. sylvatica/ Q. species	60	10 %	30 %
P. abies/P. sylvestris	90	10 %	20 %

Table 18: Extend of damage to forest stand
(Guts- und Forstverwaltung Schloß Pernegg)

The site is dominated by pioneer species and shrubs. As the site is used for timber production especially conifer species have been planted, whereas other species have grown on the site by self-seeding. Shrub species form a dense understory and grass and herbaceous species form a dense layer. The main tree and shrub species found on the site are listed in table 20. Grasses and herbaceous species found on the site are the same as the ones found on the embankments along the route. They are found in table 19.

Species	Cover (%)	Height (m)
Picea abies	60	5-7
Quercus species	20	2-6
Betula pendula	40	2-6
Fagus sylvatica	30	5
Acer pseudoplatanus	20	6
Quercus sp.	< 5	18
Larix europaea	< 5	15
Rubus idaeus	80	1.2
Rubus fructicosus	80	2

Table 19: Tree and shrub species in the *Gabraungraben*

There is still a significant number of dry snags and dead woody debris left on the plot that cannot be removed due to the difficult terrain. The snags are an indication for the extent of the damage that has occurred on the site. At the same time they pose a significant risk to the newly established vegetation in case of a repeated fire outbreak on this site. Figure 36 shows the present conditions on the site.

Figure 36: State of the site in the Gabraungraben

Some local erosion has taken place directly after fire due to the lack of vegetation and the protecting humus layer, but obviously the severity has not been remarkably high. The soil layer on exposed parts at the top of the site is low due to the rocky terrain and erosion processes. Some wind erosion might have taken place directly after the fire causing an additional loss of soil and leftover organic matter. Figure 37 shows minor erosion occurring on the site.

Figure 37: Local erosion

As noticeable in figure 35 the site is made accessible by three forest roads on the upper part of the area. A lane leading to the near "*Murradweg*" is running along the lower part of the site. The next water source is the Mur, which is approximately 800 meters away from the lower part of the site. Industrial sites as well as agricultural sites are not close to the site. The next settlement is around one kilometre away from the burned site.

The expert opinion carried out on the site soon after the fire has discovered several cost factors related to the direct damage done by the fire to the forest stand and the forest road as well as to the re-establishment of the forest stand.

The ÖBB has paid compensation for the decreased soil value, the direct damage to the forest stand in terms of clearing costs, reduced yield due to fire damage as well as for indispensable harvest and immature cutting of the stand. Additionally the costs for the reconstruction of the forest road have been refunded. As for the follow-up costs compensation has been assigned for the restoration of the stand as well as to the treatment of the newly established stand.

An increased maintenance of the newly established stand has been necessary as well. Therefore a reimbursement has been assigned as well. The specific cost factors related to the damage in the site are listed in table 20 together with the amount of compensation reimbursed by the ÖBB. The analysis of other expert opinions reveals that the fire has caused more or less similar damages on all sites affected. Damages and follow-up costs for the re-establishment of the forest stands have been reimbursed by the ÖBB in the same way. Due to the limited possibility to refer to the respective documentation the analysis is not included. Therefore the cost factors listed serve as an illustration of costs that arise after a fire and the respective compensation.

Cost factor	Compensation (%)
decreased soil value	10
clearing costs	3
reduced yield (fire damage)	15
indispensable harvest	11
immature cutting	8
reconstruction forest road (3.8 km)	9
restoration costs	7
treatment costs	22
increased maintenance costs	15

Table 20: Cost factors and compensation
(Expert opinion Guts- und Forstverwaltung Schloß Pernegg)

The damage on and close to the embankments is minimal compared to the damage that has occurred in the forest stands. At present no damage can be found on the embankment along the track anymore. Due to the steep topography of the location and the convex shape of the site fire has spread in an upslope direction and into different directions causing extensive damage in the forest site. The damaged area along the embankments has been overgrown in the meantime and no evidence of damage can be found anymore.

State of maintenance

No measures are taken at present for the reduction of the fire risk and no permits allowing controlled burning or proposing other measures to reduce the fire risk along this route are available. As indicated by local residents controlled burning as well as other measures such as mowing and grazing have been in use on the embankments into the 1960'ies to keep vegetation low and therefore reduce the chance of ignition through sparks from trains along the route. These measures have kept fuel loads small and have prevented trees and shrubs to invade and become established on the embankments. By introducing new engines and new wagons those measures have been stopped and the vegetation on the embankments has been left unmanaged. No evidence has been found that any measures have been continued up to present times in order to keep fire risk low.

The embankment is in a rather neglected state on a large part of the route. The trees grow into the overhead system and the shrubs, grasses and herbs are already spreading onto the railway track. Trees are dangerously leaning towards the track and large piles of fine and coarse woody debris produced during maintenance activities are present along some parts of the route. The high amount of living and dead plant material along the embankment specifies a significant fire risk for the adjacent area. Especially during long periods of drought with no or low precipitation the high fuel load present dries out to a great extent and therefore becomes highly susceptible to fire. The state of the embankment is shown in figure 38.

Figure 38: Fuel load on the embankment

Since the route is surrounded by private forests, agricultural areas and settlements, the need for measures for a well maintained embankment are extremely necessary for the whole route. Local residents ask for management measures to be conducted along the whole route in order to reduce the damage and to avoid a repetition of the 1998 forest fires.

Consequence of fires and susceptibility of sites to fire

The fires have destroyed the forest in the study site completely. The removal of the humus layer prevents some plants to become established and grow. Artificial regeneration has been conduced over a big part of the site, since the forest is commercially used. Natural regeneration and shrubs, grasses and herbaceous species have established on the site as well. The resulting high accumulation of fuel creates a significant fire risk for the site. Shrubs, herbs and grasses compete with the trees present for nutrients and water.

In some places the ash layer deposited after the fire was found to have a thickness of more than one meter. In those places trees form a dense stand and even have a growth advantage compared to trees growing on places with a small or no ash layer. Eight years after the fire the stands were found to be taller compared to other trees of the same age on the site. Erosion problems were found to be of minor importance, since the site has been replanted right away. Figure 39 shows the ash deposition in a depression on the site.

Figure 39: Increased vegetation growth due to ash deposition

As for the game in the area the fires escaping from the embankments into the adjacent forest have negative consequences in terms of short-term habitat loss. Rare and endemic plant species present throughout the whole forest along the route are endangered by a fire outbreak as well. An example is *Gentiana asclepiadea*, which is found in all undamaged forests along the route.

The burned sites are at a high fire risk through a repeated fire due to the increased fuel load present. In case of a repeated fire outbreak the newly established stand is going to be destroyed completely causing a recurring damage to the stand and the soil causing follow-up damages in terms of erosion and diseases respectively. Plant species composition is influenced by the fire to a great extent.

Climate change is going to trigger a change in plant species composition as well as fire frequency and fire behaviour so that all sites are at a high fire risk. A higher fire frequency on the site means a shift in plant species composition from the forest to shrubs, grasses and herbaceous species in the long run as well.

Formation of new habitats

Along this route fire has formed new habitats as well. Due to the fact that conditions on the study site are extreme, pioneer species, which are adapted to the harsh environment, have established. It has been impossible to assess the whole site due to its inaccessibility, but most probably rare plant species have been able to establish as well. Tree species found in the surrounding forests re-establish on the site by dispersal so that the vegetation occurring naturally on the site will return after a period. The mountainous character of the site influences species richness on the site as well. Species richness and diversity on the site is increased due to the south aspect.

Insect species, which use flowering grasses and herbs as a food source are present abundantly on the whole burned site. The pioneer species are a food source for game as well. The site acts as a habitat for the different game species in the area as well. It was not possible to find any evidence in terms of browsing damage, but the conditions in the surrounding old growth suggest that game uses the species on the burned area as a food source. Bird species might have been affected by the fire as well. Especially tetranoid species might have found a suitable habitat due to the open structures frequently found on recently burned sites.

Fire Risk Factors and Values at Risk

Fire Risk Factors and Values at Risk are located well above the threshold values for both the embankments as well as for the burned and unburned site assessed for this study. This indicates the extreme need to take measures to reduce the fire risk. The areas along the route are heavily used for timber production as well as for recreation and settlements as well as habitat for wildlife. This results in the high values in the Fire Risk and Values at Risk Rating. Table 21 shows the Fire Risk and Values at Risk Rating for the embankments along the track as well as for the chosen sites.

Site (km)	Fire Risk	Values at Risk
Embankment (159-180)	34	53
Gabraungraben (166.1-166.2)	33	53
Mixnitz (175-177)	25	40

Table 21: Fire Risk and Values at Risk Rating

The Fire Risk and the Values at Risk Rating for the embankment result in relatively high values for all three sites assessed. The reasons lie in the proximity of forests used for timber production, recreation areas as well as settlements. The high values obtained in the Gabraungraben can be explained by the use of the site and the adjacent forest for timber production. The fact that the site has already been burned once, increases the risk of the site for a repeated fire.

As for the assessed site close to Mixnitz the Fire Risk Values were found to be low due to the northern aspect of the site and the rather moist conditions. However the site is still susceptible for a future fire outbreak, especially when considering changing climatic conditions. Values at risk were found to be high for the surveyed site as well as the adjacent area, since the forest is of significance for timber production and as wildlife habitat as well as for recreation.

It can be assumed that all other sites along the route show similar values for the Fire Risk and Values at Risk Rating indicating the strong need for management measures along the whole route, since the embankments and the area surrounding the railway route are at high risk to be damaged or even destroyed by a fire escaping from the boundaries of the embankment.

Risk assessment for the route

The embankments as well as the affected areas adjacent to the track have only been once subject to major fires caused by a loose brakeshoes of a train so far. Nevertheless the risk for a repeated fire outbreak and the susceptibility of the adjacent area is high. The whole route runs through a densely populated area with major forestry and agriculture as well as recreational values, which are highly susceptible for a fire outbreak. Damages to forestry, agriculture, settlements and tourism would be immeasurable.

Topographic conditions, the influence of the mainly west to south exposure of the route, the curviness of the route and the specific microclimate on the track and the adjacent surroundings are factors influencing the fire risk for the forests adjacent to the route. The above mentioned conditions highly influence the high fuel load on the embankment and it is only a matter of time until another spark from a braking train causes the next big fire. Experiences from the past have shown that the "*Murradweg*" is not sufficient enough to act as a fuel break for the adjacent areas, if measures to reduce the fuel load along the embankments will not be conducted. Even though the accessibility along the whole route is good and the Mur River provides a good water source for firefighting, a reduction of the primary risk is absolutely necessary.

As for the other sites assessed during fieldwork a significant fire risk is present as well. Even though they are influenced by a western to northern aspect longterm climatic conditions together with topography and fuel conditions – especially on the embankments – are capable to trigger significant economical damage to the forest after a fire. Figure 40 shows unburned site along the route close to Mixnitz in the property of the *Forstverwaltung Mayr-Melnhof-Sarau*.

Figure 40: Site at risk in the Forstverwaltung Mayr-Melnhof-Sarau

State of maintenance of brakes of engines and wagons

Due to the lack of information about the construction of engines and wagons used by the ÖBB as well as about the maintenance of the brakes only assumptions could be made about the condition of the brakes. However it could be discovered that damaged brakes pose a significant problem regarding the fire risk along Austrian railway routes. It is not known what has caused the decline of fires on the embankments according to the ÖBB fire statistic since 2001. It can be only assumed that the decline of fire frequency is related to the exchange of the types of brakeshoes. Engines do not seem to be the reason for fire outbreaks, since they are not involved in the active braking process as stated by an ÖBB employee. The engine only seems to send out the braking impulse to the wagons, which carry out the braking process. Consequently the type of brakes on the wagons might be essential in causing fire outbreaks. However a more precise investigation concerning the role of engines, wagons and especially the type of brakes in use has not been possible due to the lack of appropriate documentation.

Investigations have proved that in other countries such as Canada, the USA or Russia forest fires caused by braking trains do not seem to play a significant role along railway routes. The reason might be that trains in other countries are kept in a rather good condition so that sparks or loose brakeshoes do not seem to occur.

Discussion

A discussion of the literature analysis has been included in this chapter for a better understanding of own findings. The literature cited in this context is not directly related to the findings in this study. However the results of the various studies cited were used to support the outcomes of the underlying study. Literature research has been linked to own findings as far as it supports own results.

Literature analysis

Fire and soils

Fire has both positive and negative effects on soil structure, soil chemistry, microclimate, soil life and soil life beneath the stands depending on the dominating vegetation type and fire intensity. The soil beneath conifer forests generally is destroyed completely, whereas the extent of soil damage beneath deciduous stands and grasslands is much lower. The reason is that conifer foliage and wood contains substances, which cause higher fire intensities. Foliage and wood in deciduous forests do not cause as high fire intensities as foliage and wood in conifer forests. Grasslands are rather subject to fast surface fires causing lower fire intensities so that soil damage is restricted to the upper soil layers.[129] The different fire intensities resulting from the different vegetation types dominating the various sites assessed have lead to diverse types of destruction along all railway routes assessed.

The forest fire caused by a braking train close to Arnoldstein has revealed the damage a relatively intense fire is causing to forest soil. The damage has been more severe beneath the conifer stands than beneath the deciduous stands.[130]

As for the conifer old growth forests along the route between Mallnitz and Pussarnitz the extent of damage can be expected to have been high due to the high fuel loads present and the characteristics of conifer foliage and fuel.

[129] Gorbachev and Popova, 1996; Mälkönen and Levula, 1996; Pietikänen, 1996; Fuller, 1991; Carcaillet et al., 2001; Feller, 2001; Thonicke et al., 2001; Fonda, 2001; Schmidt et al., 2003; Russel-Smith, 2003; National Wildfire Coordinating Group, 2004; Hart et al., 2005
[130] Carcaillet et al., 2001

No documentation has been available on the extent of damage in the burned forest stands between Mallnitz and Kaponig, but findings in the field confirm the findings of literature analysis that the forest soils have been destroyed completely and that nutrient loss after fire has been significant. Findings on the burned sites between Übelstein and Laufnitzdorf and the analysis of documentation confirmed the findings of literature analysis as well. They revealed a complete destruction of conifer forests and an entire destruction of the soil.

Due to time constraints and the long time elapsed after fire it was not possible to measure the nutrient losses - especially that of nitrogen - in the sites. However, based on literature findings it can be assumed that nitrogen losses have been considerable. [131]

Due to the temporary loss of vegetation cover on all sites assessed erosivity of the remaining soil has been quite high. Outcomes of the assessment of the burned forest close to Arnoldstein reveal the formation of hydrophobic layers. The formation of hydrophobic soil layers has certainly occurred on the other burned sites as well. Together with the steep topography dominating the area along all assessed railway routes the hydrophobic soil layers lead to an increased erosivity of soil, which can turn into massive erosion and extensive overland flow on all sites.[132]

On the other hand the soil on all burned sites has been affected positively through the deposition of ashes. This ash deposition has facilitated the re-establishment of vegetation to a great extent. Findings during fieldwork revealed spots on the burned sites, where vegetation growing on fertilized soil showed a growth advantage compared to vegetation at the same age growing on unfertilized soils. The re-establishment of grasses on the burned site close to Arnoldstein just days after the fire confirm the findings in the literature that ash deposition aids vegetation to become re-established on a burned site within a short period of time.[133]

Even though it was not possible to reveal all positive and negative effects on the burned sites during fieldwork due to the lack of information concerning the situation directly after fire it can be assumed that the soils of the embankments along all railway routes as well as of the burned sites have been destroyed as described and that soil fertilisation has aided vegetation to become re-established.

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[131] Feller, 1988; Goldammer et al., 1998; Fuller, 1991; Mälkönen and Levula, 1996; Pietikänen and Fritze, 1996; Harden et al., 2000; Müller, 2001; Russel-Smith et al., 2003

[132] Coelho et al., 2000; Thonicke, 2001; Müller, 2001; Camia et al., 2002

[133] Fuller, 1991; Henig-Sever et al., 2000; Coelho et al., 2000; Thonicke et al., 2001; Wang et al., 2001; Goto, 2004; Bond-Lamberty et al., 2004

The analysis of the results shows that in case of a repeated fire on the already burned sites the damage of the soil is going to be particularly severe. For the still unburned sites along all three railway routes fire poses a significant risk for forest soil depending on the vegetation type as well. Management measures need to be found to reduce the risk of a fire escape beyond the boundaries of the embankments in order to reduce its mainly negative effects on forest soils.

Fire and vegetation

The formerly railway-related burned sites in Carinthia as well as in Styria were destroyed completely by the devastating forest fires. However recovery has occurred quickly. Literature analysis confirms that the recovery after fire occurs relatively quick.[134] Nevertheless all burned sites are still detectable from a considerable distance.

Climate, aspect, topography and vegetation composition have significantly influenced fire intensity and therefore the extent of the damage on all sites. As for the climatic it was impossible to exactly reconstruct the climatic conditions for the forest fires between Mallnitz and Kaponig and between Übelstein and Laufnitzdorf, but long dry periods before the fire, inversions and the frequently changing wind direction during the fire have lead to an increase in fire intensity.[135] Since all sites assessed are dominated by a southern aspect fuel moisture tends to be lower on all sites and has therefore lead to an increase in fire intensity. Due to a significant change in climatic conditions however the role of aspect for the fire regime needs to be recalculated, since climatic warming has a significant influence on the fire regime, as it will become evident later.

Findings on all sites assessed confirmed once again that conifer stands show a higher ignition probability, higher fire intensities as well as higher damage than deciduous trees due to their higher contents of oils, resins and other substances facilitating ignition.[136] Even though hardly any information has been available about the forest fires along the route between Mallnitz and Pussarnitz, fieldwork confirmed that the old growth conifer stands consisting of *Larix europaea* and *Picea abies* have been destroyed completely.

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[134] Gossow, 1996; Goldammer et al., 1997; Goldammer et al., 1997; Goldammer and Page, 2000
[135] Fuller, 1991; Feller, 2001; Fonda, 2001; National Wildfire Coordinating Group, 2004
[136] Carcaillet et al., 2001; Fuller, 1991; Feller, 2001; Fonda, 2001; National Wildfire Coordinating Group, 2004

Documentation about the damaged forest stands along the route between Übelstein and Laufnitzdorf verify the findings in the literature as well. Also here the degree of damage to conifer stands has been significantly higher than in deciduous stands. The newly established stands on all burned sites show a rather high susceptibility of being destroyed completely by a repeated fire, since tree mortality caused by fire is known to be higher in juvenile plants up to a certain age than in mature plants.[137] Although it was not possible to determine the damage done by fire to symbiotic fungi or the condition of the root system it can be presumed that fire has reduced the presence of *mycorrhizae* in the soil for an extended period of time and that some time was required to pass until tree and grass species with *mycorrhizae* were able to become re-established.[138] In general non-native plants benefit from the increased nutrient availability on the burned sites. However no evidence has been found on the sites that invasive plants have established on the burned sites.[139]

Fieldwork has confirmed findings in literature that succession plays a considerable role on burned sites. All burned sites are dominated by pioneer species and a dense understory of shrubs, grasses and herbaceous species.[140] In contrary to the unburned surroundings the burned areas showed a high plant species richness as well as plant abundance. The increased presence of *Pteridium aquilinium* and *Calamagrostis epigeios* and other acidophilus plant species on the burned sites are an indicator for fire occurrence. They form a dense understory and therefore increase the fuel load of an area to a great extent. Especially the sites along the route between Mallnitz and Pussarnitz, which are subject to frequent smaller fires, are densely covered with *Pteridium aquilinium* and *Calamagrostis epigeios*. Due to the increase in fuel load the fire risk for the area adjacent to the burned site is increased.[141]

Trees are able to re-establish during succession by resprouting, immigration by seeds or doing both. Due to the intense damage that has occurred on the sites assessed however, re-establishment has occurred mainly by seeds and through artificial regeneration. Resprouting was found to play a minor role on the assessed sites as did the natural regeneration merely through conifers.

137 Vignolio et al., 2003
138 Fuller, 1991; Hartnett et al., 2004; Bruns et al., 2002
139 Elliot and White, 1987; Fuller, 1991; Henig-Sever et al., 2000; Radho-Toly et al., 2001; Goto, 2004; Hunter et al., 2006; Hunter et al., 2006
140 Ellenberg, 1996; Rice and Westoby, 1999; Harden et al., 2000; Wang et al., 2001; Thonicke et al., 2001; Wahren and Papst, 2001; Bond-Lamberty et al., 2004; Govender et al., 2006; Day et al., 2006; Laterra et al., 2006
141 Müller, 2001; Camia et al., 2002; Spencer and Baxter, 2006

Conifers were discovered to establish only by artificial regeneration, since they play an important role in timber production. It was not possible to assess sprouting vigour or competition between seeders and resprouters, but it can be assumed that both changed depending on site and climatic conditions. The vegetation type dominating the surroundings of the burned site was found to play a significant role in the process of re-establishment. However it needs a longer time period to observe re-establishment of the original plant cover.[142]

Artificial regeneration plays a significant role on the burned sites significant for timber harvest. Especially the private forests along the route between Bruck an der Mur and Frohnleiten are commercially used and therefore artificial regeneration is used to promote the re-establishment of the desired tree species. However time elapsed after fire is still short enough that grasses, herbaceous plants, shrubs and pioneer species are dominating in the dense understory. They compete with the planted tree species for water, nutrients and light so that it will take a long time until the desired tree species is going to dominate the site. It will take a long time period for succession to be completed and the vegetation type dominating the site before a fire has re-established.[143]

Time constraints did not allow measuring Net Primary Production or rooting density of the burned stands, since long-term measures would be necessary to verify it for the sites underlying the study. It can be assumed that Net Primary Production and root density for the sites between Mallnitz and Kaponig are high, whereas the Net Primary Production and root density for the site assessed near Pernegg are increasing. It can be presumed that the stands along both routes, which have been subject to succession, are significant carbon source.

[142] Fuller, 1991; Ellenberg, 1996; Gossow, 1996; Goldammer et al., 1998; Rice and Westoby, 1999; Pfab et al., 1999; Hong and Mladenoff, 1999; Carrington and Keeley, 1999; Higgins, et al., 2000; Calvo et al., 2000; Henig-Sever et al., 2000; Coops et al., 2000; USDA Forest Service, 2000; Müller, 2001; Jacobs and Schloeder, 2002; Clarke, 2002; Camia et al., 2002; Santalla et al., 2002; Clarke, 2002; Williams et al., 2003; Goto, 2004; Kupfer and Miller, 2005; Ojeda et al., 2005; Gurvich et al., 2005; Laughlin et al., 2005

[143] Ellenberg, 1996; Rice and Westoby, 1999; Laterra et al., 2006; Wahren and Papst, 2001

Due to the fact that the sites assessed have been subject to only one fire so far and no documentation of the fire history of the sites has been available, the influence of fire frequency and intensity as well as season of fire on plant abundance and density as well as on vegetation composition and species richness could neither be confirmed during fieldwork nor through research. However, with a future increase in fire frequency and fire intensity linked to climate change might have a significant influence on all forest stands along railway routes.[144]

A shift from fire-sensitive to more fire-tolerant species is likely to occur on all sites along the railway routes. Due to the mountainous terrain and the wide range of different habitats available within a small area along all three routes assessed fire frequency would cause speciation and selection processes in species. Certain species might be killed by fire in one habitat type present on the sites while surviving in the other or becoming adapted to the changed fire environment. Rare species present in unburned forests along all railway routes are vulnerable to fire due to their restricted distribution range and their increased sensitivity to conditions altered by fire.[145]

Trees damaged by fire are a major concern for follow-up diseases along all three routes assessed. Fire scars and split bark as well as signs of beetle attack were found on all burned sites along the three routes to a great extent. Damaged trees on all burned sites are susceptible to all types of damage by insects, bacteria, viruses and fungi. The stands directly adjacent to the burned sites and therefore to the infected trees are susceptible to an outbreak of diseases, if the damaged trees are not removed. This is a fundamental concern especially in commercially used forests along railway routes. This makes management measures along the railway routes extremely necessary.[146]

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[144] Condit, 1998; Goldammer et al., 1998; Williams et al., 2001; Mouillot et al., 2002; Wotton et al., 2003; Camill et al., 2003; McKenzie et al., 2004; Brown et al., 2004; Brunetti et al., 2004; Grigulis et al., 2005; Czimczik et al., 2006; Carrer and Urbinati, 2006; Chapin et al., 2006; Scholze et al., 2006; Fuhrer et al., 2006; Sibold and Veblen, 2006

[145] Goldammer et al., 1998; Condit, 1998; Easterling et al., 2000; Parmesan et al., 2000; Carcaillet et al., 2001; Mouillot et al., 2002; Walther et al., 2002; Beniston, 2003; Camill et al., 2003; Wotton et al., 2003; Brunetti et al., 2004; McKenzie et al., 2004; Brown et al., 2004; McKenzie et al., 2004; Calef et al., 2005; Taylor and Beaty, 2005; Calef et al., 2005; Grigulis et al., 2005; Carrer and Urbinati, 2006; Czimczik et al., 2006; Sibold and Veblen, 2006; Broennimann et al., 2006; Carrer and Urbinati, 2006; Calanca, 2006; Gobbi et al., 2006; Thuiller et al., 2006; Jump et al., 2006

[146] Fuller, 1991; Babintseva and Titova, 1996; Kalinin, 1996; Matveev and Usoltzev, 1996; Andersen and Müller, 2000; Müller, 2001; Goto, 2004

The above mentioned significance of burned areas as a food source for especially ungulates leads to considerable browsing damage. Also small mammals play an important role in the re-establishment of forest stands after fire. This is especially of importance in forests used for timber production. Planted trees are often the first available food source on burned sites, so that tree establishment and growth is reduced. The high browsing damage found on all burned sites during fieldwork confirms this hypothesis.

Significance of fire for grasslands

Findings based on literature analysis verify that frequent fires influence the vegetation community of grasslands to a great extent. Trees and shrubs are prevented to become established in grasslands through reduced growth and competition for water and nutrients. Frequent fires keep grasslands open and fuel loads low. Grass species adapted to a high fire frequency generally replace the original plant community.[147] The aspect of low fuel loads along embankments is an important point to be considered for future management measures on embankments. Controlled burning is an ideal measure to keep embankments free of trees and shrubs and fuel loads low. The situation along the route between Mallnitz and Pussarnitz confirms the findings of literature analysis. Along this route controlled burning has obviously been conducted on a regular basis so that fuel loads are low. However it was not possible to make out the parts of the embankment, where controlled burning has taken place, since information regarding the detailed location and method of controlled burning could not be obtained.

No evidence could be found for the destruction of native grassland communities and the related symbiotic life forms by fires and the invasion of exotic and non-native species on any of the embankments along the routes assessed.[148] However *Impatiens sp.* were found to be invasive on the embankments along the route between Bruck an der Mur and Frohnleiten. The invasion of those species might be somewhat related to climate change and the lack of maintenance rather than to fire. Due to the high fuel loads these species create together with the trees, shrubs and grass species on the embankments the risk of ignition, the fire regime and fire severity is increased without doubt.

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[147] Elliott and White, 1987; Ellenberg, 1996; Rice and Westoby, 1999; Higgins et al., 2000; Wahren and Papst, 2001; Bond et al., 2003; Butler and Fairfax, 2003; Florentine et al., 2003; Mistry and Berardi, 2005; Grigulis et al., 2005; Laterra et al., 2006; O'Reilly et al., 2006

[148] Cione et al., 2002; Rossiter et al., 2003; Butler and Fairfax, 2003; Setterfield et al., 2005; Kupfer and Miller, 2005; Mistry and Berardi, 2005; Grigulis et al., 2005

With trains remaining a major reason for fire outbreak and an increase in fire frequency, intensity and behaviour in the future invasive species might play a more important role in the future. A longer observation period would be needed in order to be able to verify theses findings in literature and to investigate the significance for the future development of the fire frequency, intensity and risk caused by braking trains along railway routes.

Altogether the embankments were an ideal retreat for rare and endangered species, which are not adapted to current land use practices. However some places are present, where frequent fires reduce the habitat quality for those endangered plant species. A shift has taken place to rare plant species adapted to fire caused by braking trains or its use as management tool.[149] Along the embankments a variety of rare and endangered species were found during fieldwork, which are adapted to the extreme conditions along railway tracks. On one hand species composition was found to be made up by species solely adapted to the extreme climatic conditions on the embankments, on the other hand species composition was found to be composed of species adapted to frequent fires. This needs to be considered when using controlled burning as a management tool on embankments.

Fire and wildlife

Wildlife is influenced through the modification of its habitat through fire on the sites burned to a great extent. Literature research has found that certain species intolerant of fire leave the affected area and do not become established again. For most species this was found to be true only during a short period of time. During fieldwork evidence has been found that quite the opposite is true for all burned sites assessed. Fire has increased habitat quality on all sites especially in terms of high-quality food sources.

The importance of a habitat as a food source is especially important in old growth forests such as along the route between Mallnitz and Pussarnitz, where food sources are limited due to the low understory and the dominating tree species. Animals with a flexible habitat were found to re-colonize the burned sites as soon as vegetation became established again.

[149] Goldammer et al., 1997; Goldammer et al., 1997; Goldammer and Page, 2000; Gillespie and Allen, 2004; Beyers, 2004; Kruse et al., 2004; Hunter et al., 2006; Hunter et al., 2006; Maccherini, 2006

So called "*Edge effects*" play an important role in all burned sites, since the burned areas are surrounded by old growth forests. Even though no evidence could be found for an increase in species richness on any of the burned sites assessed, species richness is certain on all sites burned. Predators were found to be increasing on and close to the burned sites as well due to the increased number of existing prey.[150]

Browsing and bark peeling play an important role on burned sites due to the increased availability of plant material. Ungulates as well as small mammals were found to be an increased strain on burned sites. This is of importance especially on sites used for timber production. In most cases artificial regeneration is the first vegetation found on the site so that it is subject to extensive browsing damage if protection measures are not in place.

Extensive browsing damage found on the burned sites between Mallnitz and Kaponig gives evidence about the significance of the pioneer stands as a food source for ungulates such as the roe deer. Even though it was not possible to locate browsing damage on the burned site in the "*Gabraungraben*", it can be assumed that browsing damage by ungulates can be found there as well. Without doubt a change of habitat conditions would be of interest for the ibex population found close to the "*Röthelstein*" along the route between Bruck an der Mur and Frohnleiten. Even though enough food sources are available in the area, the significance of burned sites as a food source is high due to the increased nutrient status of the plants, which means a benefit for ibex. The increased browsing pressure and the resulting damage on the burned sites are especially important in forests used for timber production.

Literature analysis has shown that small animals are negatively affected by fire on all sites burned.[151] However sufficient time has passed on all burned sites except the site close to Arnoldstein so that populations have been able to recover.

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[150] Fuller, 1991; Gossow, 1996; Johnson, 1997; Andrew et al., 2000; Vernesi and Hayden, 2001; Radho-Toly et al., 2001; Santalla et al., 2002; Moretti et al., 2002; Moretti et al., 2004; Ratchford et al., 2005; Zavala and Holdo, 2005; O'Reilly, 2006; Spencer and Baxter, 2006; McEntire and Fortin, 2006

[151] Fuller, 1991; Johnson, 1997; Vieira, 1999; Monamy and Fox, 2000; Green and Sanecki, 2006; Moretti et al., 2000; Moretti et al., 2002; Moretti et al., 2004

Experiences verify that small mammals can cause massive damages in forests. This is especially true for burned sites with newly established vegetation, which signifies a high-quality food source for small mammals as well. Browsing damage by small mammals is of great significance especially on sites used for timber production, since artificial regeneration often means a readily available food source on many recently burned sites. Browsing and root damage by small mammals on trees is, besides the browsing damage and bark peeling done by ungulates one of the most important negative longterm consequences and adds up to the follow-up damage caused by escaping fires.

Invertebrate communities have certainly been influenced by fire on all sites assessed. With a future change in fire frequency and fire intensity along railway routes a change in composition, density and species richness of invertebrate communities can be predicted. Pyrophilous species attracted by the smoke of a fire were found to play an important role on all sites assessed. As mentioned above damaged trees signify a good food source for these species, which pose a significant risk in forests used for timber production.[152] Evidence of damage by pyrophilous species has been found on all sites assessed. However no evidence was found that those insect species have spread to the forests adjacent to the burned sites so far. Nevertheless it is likely that damage by insect species is going to occur in the future, especially when an escaping fire affects a large forested area. The area adjacent to the burned site close to Arnoldstein is a good example for such a situation. It is going to be subject to damage by pyrophilous species to a great extent, since damaged trees are found abundantly on the burned site. It is necessary to remove the damaged trees from the site. The burned site and its surroundings should be inspected in the future in order to eliminate any damage.

Bird diversity was found to be high during. However fire might have caused a shift in species composition on the burned sites due to the change in plant species composition to species adapted to more broadleaved forests.[153]

As for the embankments no bird species were found to live directly along the railway routes. However it is possible that the embankments along railway routes are indirectly profiting birds as a food source, since grasses and herbaceous species provide a habitat for various insect species.

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[152] Andersen and Müller, 2000; Radho-Toly et al., 2001; Orgeas, 2001; Müller, 2001; Parr et al., 2004; Kiss et al., 2004; Ratchford et al., 2005; Arnan et al., 2006

[153] Fuller, 1991; Gossow, 1996; Moretti et al., 2004; Yallop et al., 2006; Green and Sanecki, 2006

From other settings it is known that controlled burning aids in maintaining the habitat for certain bird species. At this point in time it is unknown, which significance controlled burning along railway routes has on the local bird community. It needs to be proved, if controlled burning directly or indirectly aids to enhance living conditions for certain bird species.

Rare animal species adapted to extreme habitats were found to be present along all railway routes.[154] It was only possible to observe rare animal species and the respective habitats along the route between Mallnitz and Pussarnitz. Without doubt rare animal species and endangered habitats are present along the route between Bruck an der Mur and Frohnleiten as well. They might be at risk by fires as well. On the other hand controlled burning is known to form and maintain habitats for endangered species, which are somewhat adapted to regular disturbance. This means that management measures need to be considered to protect both habitat types present along railway routes. Major fires occurring in the future along all routes would have the same effect on wildlife as the sites assessed during fieldwork.

Fire and climate change

There have been phases in earth history where naturally occurring climate change has caused a shift in vegetation composition, structure and diversity across all ecosystems in the world. This in turn has lead to a change in fire frequency, extent, severity and risk. Nature has been able to deal with naturally induced climate change quite well so far. Anthropogenic climate change however has lead to a serious modification of ecosystems and fire regime over the past 150 years. Together with the increase of severe weather events in the future anthropogenic climate change is expected to lead to an increase in fire severity and intensity as well as to a longer fire season.

Heat waves and droughts are going to increase in the future causing an extensive change in ecosystems in terms of vegetation composition, structure and diversity, the population dynamics as well as a shift in seasons. The fire cycle is going to change as well. Mountain regions such as they are dominant in Austria are one of the most sensitive regions of the world regarding climate change and the therewith connected severe weather events, since the various ecosystems are located next to each other within a small area.

[154] Goldammer et al., 1997; Goldammer et al., 1997; Goldammer and Page, 2000; Martin, 2001; Moretti et al., 2004; Means et al., 2004

The restricted ability of mountain ecosystems to react to a change in climate increases the susceptibility of those ecosystems to the altered fire regime. Wet years occurring prior to dry years were found to be the reason for an increased fire severity through an increased accumulation of fuel. This is especially significant on embankments along railway routes as well as for mountain regions.[155]

Together with the effects of climate change on ecosystems and the fire regime of a region braking trains are becoming increasingly important as a reason for fire outbreaks along railway routes. In this context the significance of the microclimate specific for railway routes and its surroundings is growing. The increasing frequency of extreme events such as droughts influences the effects of the microclimate along railway routes to a great extent. The already hot and dry conditions along railway routes are going to become even hotter and drier in the future. Together with an increasing aridity of the surroundings the likelihood for a higher fire frequency and more intense fires in the future is given.

Condition along the routes

The railway routes between Mallnitz and Pussarnitz and between Bruck an der Mur and Frohnleiten are part of two major international transit routes between Northern and Southern Europe and therefore subject to intense train passage.

The railway route between Villach and Arnoldstein is subject to intense traffic due to the proximity of the cargo station, which is posing a significant fire risk on the route and the adjacent area due to the high frequency of train passage and the necessity of frequent braking.

Fires caused by sparks from braking trains were found to be the reasons for minor as well as major fires along all routes primarily during descend travel, whereas glowing brakeshoes have caused fires during ascend as well as during descend travel. Sparks have caused several fires along the route at the same time, whereas fires caused by glowing brakeshoes merely caused local fires.[156]

[155] Condit, 1998; Goldammer et al., 1998; Easterling et al., 2000; Carcaillet et al., 2001; Williams et al., 2001; Mouillot et al., 2002; Clarke, 2002; Wotton et al., 2003; Camill et al., 2003; Fensham et al., 2003; Beniston, 2003; McKenzie et al., 2004; Brown et al., 2004; Brunetti et al., 2004; Calef et al., 2005; Grigulis et al., 2005; Taylor and Beaty, 2005; Thuiller et al., 2005; Taylor and Beaty, 2005; Meehl and Tebaldi, 2006; Fuhrer et al., 2006; Sibold and Veblen, 2006; Ohlemüller et al., 2006; Scholze et al., 2006; Czimczik et al., 2006; Carrer and Urbinati, 2006; Chapin et al., 2006; Scholze et al., 2006; Jump et al., 2006; Stephenson et al., 2006; Bradley et al., 2006; Sibold and Veblen, 2006; Calanca et al., 2006; Stoy et al., 2006; Camill et al., 2003; Felderhof and Gillieson, 2006

[156] Mißbach, 1964; Cowles, 1972; Lex, 2002

All three routes are located within or next to steep mountainous terrain with a large number of curves. The local topography, local and regional weather, the high fuel loads present along the embankments and the microclimate specific for railway routes as well as the disturbance of the local wind field by passing trains considerably influence on the fire regime along all three railway routes. The steep slopes of the embankments and the adjacent terrain along the three routes evaluated facilitate an escape of fires beyond the boundary of the embankments. Especially the upslope areas were found to be subject to increased fire risk, since fire travels upslope faster at a greater speed than downslope. The traditional left-hand traffic along all three routes was found to be a further factor influencing the greater tendency of fires starting on the upslope side and therefore escaping rather upslope than downslope. A comparison of the fuel loads present on the embankments of the surveyed routes are listed in table 22 together with a mean of the fire risk and values at risk the conditions on the embankment produce for the surrounding area.

The different types of embankments found along the three different railway routes were found to create different levels of fire risk to the route as well as to its surroundings. All types of embankments influence the microclimate and the local wind field to a great extent. Besides wind channelling along the route and the intensification of the microclimate the embankments were found to influence the short-term turbulences caused by passing trains as well.

On several locations the embankments cause a tunnel effect forcing the wind into one direction and increasing the turbulences caused by passing trains. Together with the type of vegetation present on the embankments those characteristics intensify the fire risk for the adjacent areas along the routes. Due to the traditional left-hand traffic along Austrian railway routes the uphill embankment is slightly more susceptible for damage through sparks from braking trains than the embankment along the right-hand track as a result of frequent braking.

Loose brakeshoes were found to frequently cause fires on the right-hand side of the track. This problem needs to be considered when choosing appropriate management measures and plants suitable for the reduction of fire risk.

Due to time and organisational constraints before and during fieldwork it was not possible to obtain clear measurements of the effects of embankments and passing trains on the local wind field or the microclimate along the railway routes assessed. For that reason the assumptions on the change of the local wind field are solely based on literature research as well as subjective perceptions during fieldwork.

There is a strong need to further investigate the above mentioned effects along Austrian railway routes, since they are important factors influencing fire regime and fire risk along railway routes. This is important, since the consequences of escaping fire for the various landscape types and uses along the railway routes may become disastrous.

The embankments along the railway route between Mallnitz and Pussarnitz were found in a reasonably good state of maintenance. Obviously a regular treatment of the embankments is taking place. However a regular inspection of the route is necessary, since the route is running along the mountain slope and the embankments are quite narrow along a major part of the route. This means that virtually no boundary is given between the track and the adjacent area. At the same time it implies that fire risk for the area adjacent to the railway route is even higher than if embankments would create a gap between the track and its surroundings. Especially the microclimate characteristic for railway routes as well as the turbulences within the natural wind field caused by passing trains influences the forested area adjacent to the track in particular, since the vegetation composition is dominated by conifers and the high fuel loads directly adjacent to the tracks and in the forests support a severe fire.

It is obvious that it is not possible to construct an appropriate embankment along the mountainous part of the route, but at least a gap with no fuel would be necessary in order to suppress any fires caused by braking trains or glowing brakeshoes.

The vegetation in the cracks of reinforced embankments found along the route increases the fire risk for the adjacent forests due to its ladder effect. A reinforced embankment cleaned from any type of vegetation would decrease the fire risk for the area to a great extent. Figure 41 shows a reinforced embankment with fuel in the cracks, which might act as ladder for fire.

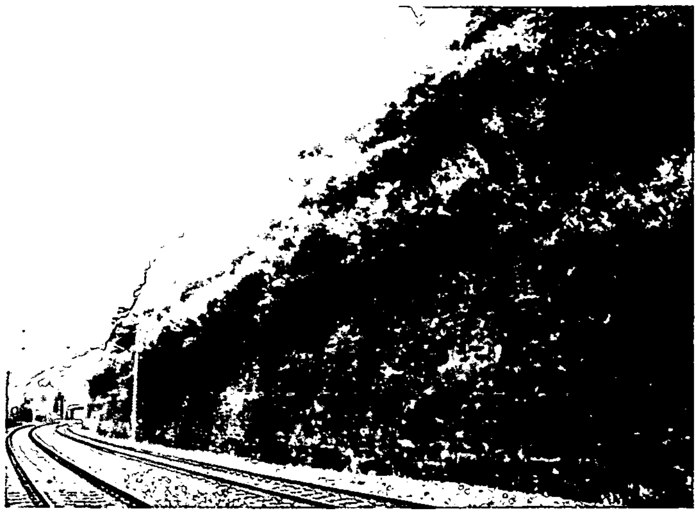

Figure 41: Fuel on reinforced embankment

The lack of appropriate access to the upper part of the track indicates that measures need to be found to reduce the fire risk for the adjacent area to such an extent that a fire outbreak is small. As for the part of the route that is running through agricultural and settlement areas management measures need to be found for the embankments as well. Here the embankments are differentiated from the surroundings and the state of maintenance is quite well and accessibility is sufficient. However appropriate management measures need to be found to avoid a fire outbreak in order to reduce the risk for agriculture and settlements. As a consequence of the fact that the route is leading through steep mountainous terrain and major parts of the routes are hardly accessible for most firefighting purposes, measures other than controlled burning, need to be considered as well. These measures will be discussed in the management considerations.

Due to the lack of documentation it was not possible to find out, which particular measures have been taken in the past and to what extend they have been carried out. Available information indicated that permits for controlled burning existed for the years 2005 and 2006. The allowed time periods for controlled burning were between February and April 15th as well as between August and September 15th. Treatment measures such as mowing and controlled burning in a controlled environment are necessary in order to reduce the grass cover on the embankments along all railway routes and therefore also the fire risk along the route.

The embankments along the route between Bruck an der Mur and Frohnleiten were found to be in a relatively poor state of maintenance. This route is an example of how the lack of maintenance measures changes the image of the embankment. The high density of trees and shrubs along the embankment together with grasses and herbaceous species signifies a high fuel load, which in turn implies an increased fire risk for the adjacent area. Acidophilus species such as *Impatiens glandulifera* were found to be the dominating non-native plant along the route. Together with trees, shrubs, grasses and herbaceous species the increased presence of non-native plants along the route has lead to an increased fuel load on the embankments. When considering the microclimate typical for embankments along railway routes, the steep topography along the route as well as local and regional weather this signifies a considerable fire risk for the forests and other landscape uses adjacent to the route.

In the past maintenance measures such as mowing, grazing and controlled fire have kept grasses and herbaceous species on the embankments low and have eliminated trees and shrubs. They have therefore lead to a significant reduction of the ignition probability through sparks from braking trains in the past. It is incomprehensible why maintenance has stopped some decades ago. Due to the devastated state of the embankments and the high accumulation of fuels along the route the surrounding area is highly susceptible for a devastating fire outbreak. Fires that have escaped from the embankments to the adjacent area along both railway routes in the past have lead to significant economic and temporary ecological damage to forests along the route. A repeated fire outbreak would cause significant damage to the already burned sites as well as unburned forests, settlements, agriculture and the tourism industry. This makes management measures extremely necessary.

In this context it needs to be mentioned that it would be greatly appreciated by the communities, the local fire departments and the private forest owners along the route that measures are taken to significantly reduce the fire hazard proceeding from the neglected embankments. As for the development and performance of management measures - such as for instance firefighting measures – a longterm cooperation with the ÖBB would be greatly appreciated by all parties affected.

According to the ÖBB fire statistics noticeable damage to agriculture has not occurred so far, but the chance is elevated along all three routes. Furthermore the high likelihood of fires escaping from the embankment into settled area puts people and property at risk.

Moreover tourism was found to be of great importance along the railway routes between Mallnitz and Pussarnitz and Bruck an der Mur and Frohnleiten. Hiking trails are located close to the route between Mallnitz and Pussarnitz and the "*Murradweg*" runs along a major part of the route right next to the railway route between Bruck an der Mur and Frohnleiten. With the "*Rothleiten*" and the "*Bärenschützklamm*" two major tourist attractions are present close to the railway routes, which makes the area highly frequented. Therefore a fire risk needs to be considered for the local tourism industry as well. The four main landscape uses forests, agriculture, settlements and agriculture are crucial elements, for which fire risk is high along all three routes.

Health problems such as visibility and respiratory difficulties caused by the smoke of escaped fires are another important point to consider in densely populated areas as they occur along all three routes assessed. With a future increase in fire frequency these health problems are going to increase. Firefighting activities in mountainous terrain poses a threat to life as well, if the main factors of fuel, weather and topography are not considered.[157]

The Fire Risk Factor and Values at Risk Rating for all three routes resulted in high values, which confirm the findings in the field. The high and frequent traffic along the three routes as well as the areas burned by previous fires in 1982, 1998 and 2006 generate a significant fire risk for all landscape uses existing in the surrounding area. The high values imply that management measures are necessary and give rise to management considerations discussed in a later chapter.

In many cases perennials such as *Solidago virgaurea* or *Impatiens sp.* as well as acidophilous species such as *Pteridium aquilinum* are generally considered as plants increasing the fire risk on sites exposed to an increased ignition probability. However those plants were not found in such abundant amounts that they would play a significant role as singular reason for an increased fire risk. *Pteridium aquilinum* was found only in insignificant amounts along the route between Mallnitz and Pussarnitz, whereas *Solidago virgaurea* was not found at all. *Impatiens sp.*were found to increase the fire risk between Bruck and Frohnleiten in combination with the increased presence of other herbaceous species, grasses, shrubs and trees on the embankments. A comparison of fuel loads as well as fire risk and values at risk values of the embankments along the three railway routes surveyed is given in table 22.

[157] Mißbach, 1965; Cowles, 1972; Fuller, 1991; Cheney, 1997; Pernegg News, 1998; Feller, 1999; Lex, 2002

Characteristics	Mallnitz-Pussarnitz	Bruck-Frohnleiten	Arnoldstein
grasses/herbs (%)	80-100	80-100	(100)
trees/shrubs	60-80	90	80
Conifer forest (%)	60	40	80
Deciduous forest (%)	70	80	20
total fuel load	high	high	high
Fire risk	25	34	
Values at risk	33	53	

Table 22: Comparison of fuel loads, fire risk and values at risk

The sites along the railway routes burned by forest fires in 1982 between Mallnitz and Kaponig in Carinthia and in 1998 between Übelstein and Laufnitzdorf in Styria are susceptible to a repeated fire in the future due to the high fuel loads present on all sites. Literature research has shown that fire-related plant mortality is size-dependent and found in juvenile plants rather than in mature plants.[158] This suggests that the high fuel loads on the formerly burned sites are at risk of a repeated fire, which would lead to a complete destruction of the newly established stands and therefore to significant economic damage for the forest owner. Due to the relatively short time passed since fire especially the trees were not able to outgrow the fire-sensitive phase and establish a certain fire resistance. They add up to the high fuel loads on the sites consisting of shrubs, grasses and herbaceous species.

The surrounding embankments close to the burned site near Arnoldstein indicate that the state of maintenance has been quite poor along this section of the route as well. As far as an assessment was possible no measures have been taken so far to reduce the increased fire risk for the adjacent forest. The fire has been intense enough to destroy the understory and young trees and damage mature trees. The fire remained a surface fire over the whole stand with no crowning. The forest reaches too close to the railway route without any distinct embankment acting as a fuel break.

The fire risk on the embankments and for the area surrounding the railway route was found to be influenced and increased by the same characteristics along all three routes surveyed. Table 23 shows a list of factors influencing the fire risk of the area starting from the railway track and the embankments together with the degree of influence. All factors listed influence each other to a great extent. Therefore all factors need to be observed together in order to determine the fire risk for an area.

158 Vignolio, 2003

Characteristic	Fire Risk		
	high	Medium	low
Weather conditions			
hot and dry weather	X		
high precipitation			X
low precipitation	X		
Track			
curviness	X		
long/steep descends	X		
left-hand traffic along mountain slope	X		
influence on wind field	X		
Microclimate	X		
Embankment			
smooth topography		X	
steep topography	X		
tunnel effect (wind field)	X		
Vegetation type on embankment			
grasses and herbs		X	
grasses/herbs/shrubs/trees	X		
forests close to track	X		
high fuel load	X		
medium fuel load		X	
low fuel load			X
dry fuel	X		
moist fuel			X
no maintenance	X		
Appropriate maintenance			X
Forest stand characteristics			
conifers	X		
broadleaved		X	
understory	X		
young stands	X		
medium aged stands		X	
old growth			X
Slope characteristics			
convex topography (chimney effect)	X		
concave topography		X	
steep slope	X		
smooth slope		X	
Firefighting accessibility			
good road access			X
poor road access	X		
adequate water availability			X
inadequate water availability	X		

Table 23: Factors increasing fire risk

State of maintenance of brakes of engines and wagons

Since no detailed information has been available about the conditions of engines and wagons used by the ÖBB no details about the concrete state of maintenance or any maintenance measures being accomplished at present could be revealed. However it is obvious that the condition of brakes needs to be observed and maintenance measures need to be developed. It is apparent that damaged brakes are the main reason for fire outbreaks on embankments. Since wagons by other Federal Railway Companies are used in trains as well it is essential to make sure that cooperation between the railway companies becomes established so that maintenance measures can be established.

It was not possible to determine the role of the construction type of the engine in causing fires on embankments along railway routes. On one hand oral comments were made that the new "*Taurus*" engine, which is in use since some time are the reason for the decline of fire occurrence on embankments. Other remarks however state that the engines do not play a significant role in the braking process. Only the braking impulse is sent out by the engine-driver to the wagons, whereas the braking process itself is carried out by the wagons. Detailed information would have been needed in order to analyse the role of engines and wagons and the respective condition of the brakes.

Investigations in other countries such as in Canada, the United States and Russia have shown that fires caused by braking trains are obviously not of that importance as in Europe. It is believed that maintenance of engines and wagons and especially the brakes takes place much more frequently. However there is no detailed knowledge available so that only assumptions can be made.

Critique

Before and during data collection for this thesis several deficiencies occurred. Due to the restrictions before and during fieldwork it has not been possible to accomplish all objectives that have been developed beforehand. Therefore many issues could only be treated as assumptions and not as facts.

To begin with there has been a hold-up prior to the start of the thesis. Due to unidentified difficulties the promised free ticket for the transfer to the sites assessed was not issued until the middle of June 2006. Therefore it was not possible to start fieldwork until this time. As a result data acquisition in the field had to be abbreviated significantly. The delay has been the reason for an extension of the studies for one semester, which has not been very desirable.

Originally it was planned to include an analysis about the construction of engines and wagons and the brake types used. However this was not possible, since respective documentation could not be obtained. Additionally information about the type and regularity of maintenance of the brakes would have been helpful. This documentation would have been particularly necessary to clarify the role the various brake types and their state of maintenance play a role as a reason for fire along railway routes. However it was not possible to obtain the required data.

In terms of the documentation of fires that escaped from the embankments into the adjacent forested area it needs to be stated that no detailed information has been available about the forest fires of 1982 between Mallnitz and Kaponig. It would have been useful to obtain detailed information about the reason for the fires as well as extend and duration. Additionally information about firefighting activities and parties involved would have been useful. As for the extend of the damage the fires have caused to the forests and the successive silvicultural measures information would have been helpful.

As for the documentation provided by the Österreichischen Bundesbahnen reluctance was present concerning the use of the information for scientific purposes. Yet a minimum of analysis of basis information is necessary to support the findings of research. Therefore it would have been decent to get hold of the authorization to analyse the data obtained a little bit earlier. Contrary to the documentation provided by the ÖBB there was no problem to analyse and cite documentation and correspondence provided by private forest owners and the respective communities. Therefore those data have been analysed and used for supporting the findings about the burned sites.

Controlled burning has obviously not taken place along the assessed route between Mallnitz and Pussarnitz or it has not been considered to inform about the performance of this important management measure. Therefore it was not possible to include information about how controlled burning is carried out on embankments along Austrian railway routes and how efficiency controls are exhibited.

During research, fieldwork and writing it has been somewhat disappointing that there was not much interest in the progress of the work from the side of the ÖBB as the consignor. Some interest in the work would have been nice. Private forest owners owning forests along the routes as well as representatives of communities located along the route, showed more interest in the investigation of the fire risk along railway routes.

Management recommendations

Research has provided evidence that the embankments along many Austrian railway routes are in need of maintenance measures to reduce fuel loads. Subsequently suggestions for the future management of embankments along railway routes are provided.

For all embankments along railway routes in Austria a comprehensive and detailed management plan should be developed in order to significantly reduce the fire risk and potential damage resulting from escaping fire for the adjacent area. The construction works going on along the route between Mallnitz and Pussarnitz is an ideal opportunity to develop and implement such a management plan. It is desirable to use such construction works to apply management measures and to restructure the embankments in order to reduce fire risk. A particular focus should be placed on embankments, which have not been subject to any regular maintenance measure in the past. An example is the route between Bruck an der Mur and Frohnleiten, which is in a poor state of maintenance. For those routes it is necessary to develop a management plan for the maintenance of embankments. In this context a cooperation with affected forest and landowners and communities is desirable.

As a rule, ***controlled burning*** and ***mowing*** are clearly the most appropriate measures to reduce the fire risk along railway routes. Both measures ought to be carried out on a regular basis in order to be effective.

Besides the reduction of accumulated fuel loads the repeated use of ***controlled burning*** prevents trees and shrubs to become established along railway routes. Consequently a high accumulation of live and dead fuel is avoided and therefore the fire risk is significantly reduced as well. Studies have shown that the best period to carry out controlled burning for fuel reduction is late winter to early spring. Temperatures are still low, the fuel and the soil are still relatively moist from winter and new vegetation has not established yet. Little damage and only a slight danger of an escaping fire are to be expected. In addition to the reduction of fuel loads on embankments controlled burning is a useful measure to preserve habitats for rare and endangered plant and animal species along railway routes. Especially along railway embankments such habitats can be found.

However the special climatic characteristics of mountain regions need to be considered when applying for and issuing a ***permit***. Railway routes passing through high mountains might be still covered with snow in late winter. Experiences from the winter 2006 have proved that it has been necessary to postpone controlled burning due to the long lasting winter and the high snow cover along the railway routes. However the high accumulation of dead fuel over the winter makes controlled burning necessary. To be able to realize controlled burning in late winter a higher flexibility of the time frame for controlled burning in mountainous regions is therefore recommended. Assuming the time between February 15th and April 15th as time frame for controlled burning, as stated in the burning permit for the route between Mallnitz and Pussarnitz, this would either mean to extend the allowed time frame to six or eight weeks or transfer the allowed time frame to the period between April 15th to May 15th of a year in order to be able to conduct controlled burning.

For the ***performance of controlled burning*** climate, topography, accessibility, fuel conditions on the embankments as well as in the surrounding area and the availability of resources need to be considered. A steep embankment and the surrounding mountainous terrain with high fuel loads and certain climatic conditions facilitate the escape of a fire. Regarding the climatic conditions care must be taken in the choice of the appropriate time for conducting controlled burning. A sufficient personnel needs to be present in order to carry out the measure properly.

Regular mowing during the vegetation period is an appropriate measure along railway routes as well. Especially along railway routes, which are hardly accessible or no embankment is present between the track and the adjacent forest mowing is a suitable option to reduce fuel loads. An example is the route between Mallnitz and Pussarnitz, where parts of the route are either to inaccessible to conduct controlled burning or embankments are not present so that the risk of the escape of the fire into the forest is too high. Along routes and route sections, where ***controlled burning*** is applied for fuel reduction the ***parallel application*** of regular mowing during the vegetation period is highly recommended in order to avoid an excessive accumulation of fuel on the embankments, especially when longer lasting snow loads prevent the use of fire for a long period.

Due to the significance of many sites as habitat for rare and endangered species the ***application of herbicides*** is not recommended for fuel reduction. Other reasons for staying away from the use of herbicides and other pesticides comprise the undesirable probability of spread beyond the embankments into adjacent forests, agriculture or settlements. Besides the risk for forestry and agriculture an extensive application of herbicides might cause health problems in and close settled areas.

Investigation has confirmed that controlled burning as well as mowing are essential tools to reduce the fire risk along the embankments of all railway route. At this point the ***cost factor*** of maintenance measures needs to be considered. Weighed against the costs arising from the damage fire would cause to forestry, agriculture or settlements and through the expenses for firefighting activities the expenditure of the proposed treatments are considerably lower.

During research the lack of ***burning permits*** for embankments along Austrian railway routes has been observed. In total only two permits have been on hand, which have expired by the end of 2006. At this point in time it is not known, if any further burning permits will be issued and to what extent. As controlled burning is an indispensable measure to reduce fire risk, permits for controlled burning are required in order to be able to maintain fire risk low along Austrian railway routes.

Considering the devastated ***state of embankments*** and the ***high fuel load*** found along some railway routes across Austria management measures need to be conducted in order to significantly reduce the fuel loads before controlled burning is conducted. Measures include mowing and the cutting of trees, wherever trees are growing on the embankments.

Recommendations for maintenance measures for embankments along railway routes are presented in the following. They can form the basis for a detailed management plan, which should be developed and carried out on the embankments especially along fire-risky railway routes across Austria. The ***aim of a management plan*** should be the establishment of relatively fire-resistant plants by bio-engineering measures and, where possible an establishment of an adequate infrastructure for management purposes. A rapid spread of a fire on the embankment as well as an escape beyond the embankment should be avoided.

As a first step the complete removal of trees and shrubs from the embankments is proposed. Next the implementation of controlled burning is required in order to remove the roots of trees and shrubs. Controlled burning should be conducted in late winter to early spring, since climatic conditions and fuel conditions slow down fire spread so that controlled burning can be controlled. After clearing and controlled burning operations ***bio-engineering measures*** need to be carried out in order to establish more fire-resistant vegetation and therefore to generate fire-safer embankments. Grasses and herbaceous species are seeded first in order to prepare the soil for the successive vegetation and to prevent soil erosion until the permanent vegetation community is established. Various bio-engineering measures are suitable for establishing grasses and herbaceous species. They are presented in the following.

An adequate bio-engineering measure for embankments along railway routes is the so-called ***mulch-seeding***. This method is suitable for sites such as embankments, which are subject to climatic extremes such as frost, heat or aridity. The most common mulch material used are straw and hay. On steep and windy sites the mulch covers need to be fixed in order to keep in place. The best method to be used is the bitumen-straw cover-seeding, where a straw cover with a height of three to four centimetres is applied above the seeds and fertilizer and fixed with an instable bitumen mixture. The glue and the straw operate as a greenhouse. On very steep embankments the straw mulch is secured by a mesh consisting of coconut or other material. Due to the extreme microclimatic conditions along the track, the use of straw and hay as mulch material and the elevated ignition probabilities of straw and hay and later also of grasses and herbs a proper distance to the track should be maintained. The gap between the track and the vegetation should not be less than two meters so that the chance of fire ignition from sparks from braking trains and glowing brakeshoes is kept at a minimum.

Another bio-engineering measure suitable for steep embankments along railway routes is ***hydro-seeding***. Seeds, fertilizer, mulch material, fixing paste and water are brought out with a special sprayer at the same time. In case of steep and inaccessible terrain this mixture can be applied with a helicopter or a train as well. This method is comparatively cheap and easy to apply along railway routes considering the high train frequency along a major part of Austrian railway routes.

However this method is not very suitable for the direct surroundings of the track due to the existing extreme microclimatic conditions. It should be used in a greater distance to the track, where the extreme climatic influences do not affect vegetation growth. For this method the same is valid as for the first method. A reasonable gap of at least two metres should be maintained to the track in order to reduce the risk of ignition through sparks or glowing brakeshoes.[159]

The third bio-engineering measure appropriate for particularly steep embankments along railway routes is the ***shelter crop seeding***. Here a shelter crop is applied to the embankment in order to protect the valuable seed. First winter roe and barley are worked into the ground followed by the application of the remaining seed. In higher regions *Seeale multicule* is suitable as shelter crop as well. On lower sites the shelter crop at a maximal height of 30 centimetres through well-timed mowing. Additionally the removal of the shelter crop is necessary. Otherwise the shelter crop suppresses the desired vegetation community and leaves big blanks after dying away. In case the immigration potential of seeds from the surroundings is satisfactory, it is not necessary to buy additional seed mixtures. In this case the mowed shelter crop is to be left on site as seed trap and for erosion protection. However the mowed plant material increases the dead fuel load on embankments along railway routes until the desired vegetation becomes established. The mowed plant material creates a high fuel load on the embankment. Considering the microclimatic characteristics of railway tracks and the adjacent embankments the fuel is at risk of drying out quickly, especially when general weather conditions become hot and dry. This implies a higher ignition probability of fuel and therefore a higher fire risk for the surrounding area. Observations during fieldwork have shown that a reduction of fuel loads do not always take place in a satisfactory way. Therefore the application of prepared seed mixtures and the early removal of the mowed shelter crop is strongly recommended in order to accelerate the establishment of vegetation and reduce the fire risk caused by dead fuel. An appropriate distance to the track needs to be maintained along with this method as well in order to significantly reduce the risk of ignition of the vegetation through sparks or glowing brakeshoes. The maintenance of a gap of two meters is recommended.[160]

[159] Florineth and Kloidt, 2005
[160] Florineth and Kloidt, 2005

The ***mulching method*** was found to be the most suitable bio-engineering method for embankments along railway routes, since it is most appropriate for extreme climatic conditions as they exist along railway routes. Due to the use of straw or hay as mulching material however the risk of ignition by sparks from braking trains may be present, if a safe distance to the track is not maintained. Studies have shown that mulching and seeding significantly reduced the establishment of tree seeds on the treatment sites. Due to the reduced establishment of trees on embankments fuel loads are kept at a low level. However it needs to be made sure that the mulch does not contain any non-native plants, which may become dominant in the vegetation community and lead to an undesirable increase in fuel load.[161]

A list of the quantities of required material and seed mixtures to be used for the various bio-engineering methods is provided in the Appendix. As to the seed mixtures to be used for all bio-engineering methods recommended it is important to utilize only seed mixtures composed of native plants in order to avoid the introduction of non-native plants. The reason for this is that non-native plants easily become dominant in grasslands such as on embankments along railway routes. This leads to an increase in fuel loads, which in turn increases the fire risk along railway routes.[162]

As ***subsequent measures*** on the embankments along railway routes the ***planting*** of fire-resistant herbaceous species as well as shrubs is recommended in order to reduce the fire risk along railway routes. The reduced ignition probability of herbaceous plants and shrubs is leading to a lower fire risk along railway routes. Especially through the ***presence of shrubs*** the amount of fine fuels, which consist mainly of grasses, is significantly reduced. This in turn leads to a decreased ignition probability, since woody material dries out slower.

As to the choice of shrubs to be planted it is suggested to choose species with a rather low height, especially close to the track. High shrubs represent an increased risk of ignition in case they grow into the overhead system or into the track. Between the track and the lowest boundary of the vegetation on the embankments bare ground is recommended to be reserved in order to prevent vegetation to become ignited by sparks from braking trains and glowing brakeshoes. The recommended distance between track and vegetation depends on the total height of the species chosen. It is recommended to adjust the distance to the height of the chosen shrubs.

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161 Kruse et al., 2004
162 Silva and Raventos, 1999; Cione et al., 2002; Beyers, 2004; Kruse et al., 2004

A choice of shrub species recommended is given in the Appendix together with a proposed minimum distance to the track. The list of recommended species could be certainly extended as needed. It is essential to maintain the recommended minimum distance of the vegetation to the track in order to prevent sparks to ignite the fuels present. In order to keep the ignition probability low, a regular maintenance of the embankments is extremely necessary as well. In addition to a regular height reduction of herbs and shrubs it is strongly recommended to keep the gap between the track and the planted embankment clear of vegetation.

A list of recommendable herbaceous species and shrubs with respective distances between track and vegetation is given in the Appendix. This list is only a selection of species suitable for the extreme microclimatic conditions dominant along railway routes and serves as suggestion. Without doubt it is possible to expand the choice of species to be planted along railway routes.

As for the route sections, where no or little gap is found between the track and the adjacent forest or where the forest reaches directly to the track ***silvicultural measures*** are necessary in order to reduce the fire risk for the adjacent forests. Silvicultural measures should be carried out in order to restructure the forests directly adjacent to the railway track. As the ignition probability of conifers is higher than that of deciduous forests it is strongly recommended that conifer forests along the route should be replaced by deciduous forests or forest edge zones.[163]

Studies have shown that the likelihood of sparks flying a high distance is rather elevated. Damages caused to the forest stand as well as to the soil were found to be highest in pure conifer stands. The highest distance sparks were found to fly into forested areas was 30 meters.[164] Therefore a ***change in vegetation composition*** 40 meters alongside track from conifer to deciduous forests is strongly recommended in order to reduce ignition probability of fuels and to avoid a spread of fire into conifer forests. This is especially important where forests used for timber production primarily consist of conifer species or where protection is one aim of the forest stand. In case of protection forests next to railway routes a change to more mixed forests is considered to be favourable as well.

[163] Fuller, 1991; Feller, 2001; Carcaillet et al., 2001; Fonda, 2001; Vignolio et al., 2003; National Wildfire Coordinating Group, 2004

[164] Mißbach, 1965; Cowles, 1972; Lex, 2002

Broadleaved trees alone are certainly not capable of preventing damages by snow or rock avalanches, but it is without doubt of use to include broadleaved trees into the silvicultural plan for a protection forest. The reason is that compared to conifers most broadleaved trees are capable of resprouting. This is especially beneficial in case the complete stand is destroyed by fire or any other disaster, since resprouting plants are more capable than conifers to become established on a damaged site. This needs to be considered as protection measure of railway routes against any kind of natural or human-caused disaster.

With regard to the ***state of maintenance of the brakes*** of both engines and wagons a regular maintenance is strongly recommended in order to significantly reduce the occurrence of damaged brakes and therefore reduce the fire risk for railway routes. In this context it needs to be mentioned that often wagons from foreign railway companies are used in train sets. Therefore an international cooperation with regard to the state of maintenance of brakes is recommended as well as in order to reduce the fire risk along railway routes. However it is not possible to provide any additional suggestions in this context, since the provision of information regarding engines and wagons has been inadequate.

In order to sustain a satisfactory state along Austrian railway routes it is strongly recommended that the ÖBB considers cooperation with communities, local structural and volunteer fire departments as well as private forest and other landowners along the railway routes in Austria. This is especially important for the implementation of the management plan as well as in terms of assistance during controlled burning and potential assistance in case of a fire outbreak.

As for the public it is recommended that the ÖBB considers regular events in order to inform the public about the reason for maintenance measures on embankments along railway routes as well as about the purpose and usefulness of sufficiently controllable burning on the embankments. Generally the public should be involved in the fire management activities and processes, since it is the public, which is most concerned by the consequences of a fire outbreak.

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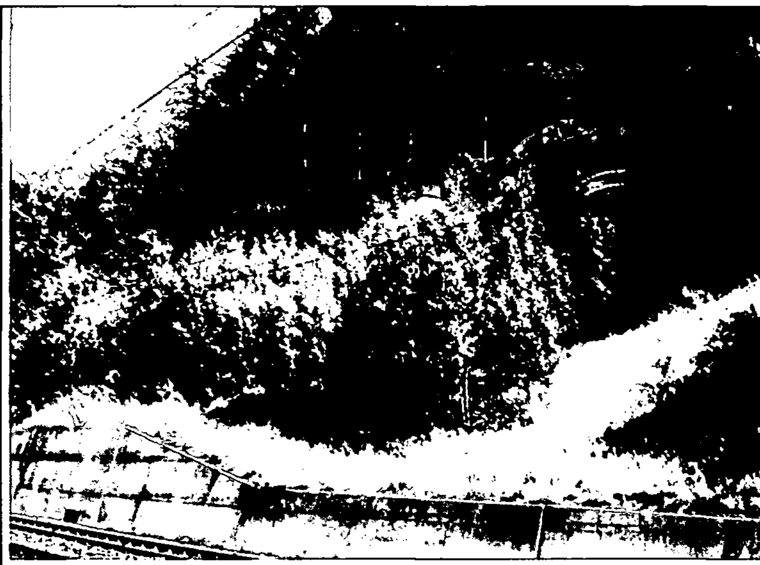
Field Forms

Railway situation assessment form

Route	Kaponig-Pussarnitz
Section (km)	56.4-56.6
Aspect	SW
Elevation (a.s.l.)	~ 850
Landform	GMF
Slope	75%
Vertical slope	LI
Horizontal slope	CV
Size of area (ha)	N/A
Road access (Y/N)	Y
Distance to major road	300 m
Distance to settlement	400 m
Distance to forestry	0 m
Distance to industry	-
Distance to agriculture	-
Distance to water	-



Dist. fr. track / Type	0-5 m	5-10 m	10-50 m	50-100 m	> 100 m
Vegetation					
Grass	X	X	X	X	X
Shrubs	X	X	X		
Trees		X	X	X	X
Density					
High (71-100%)	X_{grass}	X_{grass}	X_{grass}		X_{tree}
Medium (35-70%)			X_{tree}	X_{tree}	
Low (0-35%)	X_{shrub}	X_{shrub}			
Topography					
Slope (%)	0%	75%	75%	75%	N/A
Aspect	SW	SW	SW	SW	SW
Rocky features	N	N	Y	-	-
Soil					
Dry	X				-
Fairly moist		X	X	X	-
Wet					-

Plot Description

Geology and Soils	
Primary surfacial Geology	SEDI
Secondary surfacial Geology	DOLO/LIME
Soil texture class	SIL/SL
Erosion type	S
Erosion severity	0
Vegetation Fields	
Trees	
Total tree cover	80
Seedling tree cover	20
Sapling tree cover	30
Pole tree cover	40
Medium tree cover	50
Large tree cover	-
Very large tree cover	-
Shrubs	
Total shrub cover	20
Low shrub cover	0
Medium shrub cover	10
Tall shrub cover	10
Herbaceous	
Grass cover	40
Herb cover	30
Fern cover	10
Moss & lichen cover	-
Vegetation Composition	
Upper dominant species 1	Grasses & herbs
Upper dominant species 2	BET PEND
Mid dominant species 1	LAR EU
Mid dominant species 2	N/A
Lower dominant species 1	SORB AUC
Lower dominant species 2	PIC AB

Potential Vegetation	
Potential vegetation type ID	X
Potential life form	CW
Ground cover fields	
Ground cover	
Bare soil ground cover	0
Gravel ground cover	0
Rock ground cover	5
Litter & duff ground cover	80
Wood ground cover	80
Moss & lichen cover	10
Charred ground cover	0
Ash ground cover	0
Basal vegetation ground cover	15
Water ground cover	0
General fuel characteristics	
Stand height (m)	12
Canopy fuel base height (m)	0.4
Canopy cover (%)	98

Species Composition

Item code	Status	Size class	Cover (%)	Height (m)	Notes
BET PEND	L	PT	40	10	
SORB AUC	L	PT	30	10	
LAR EU	L	LT	40	12-15	Fire scars
PIC AB	L	PT, MT	20	7-15	
QU ROB	L	PT	3	7	
RO CAN	L	MD	0.5	0.5	
RUB FRUCT	L	MD	60	1	
VERB THAP	L	MD	30	0.6	
CHAM REC	L	LW	30	0.4	embankment
MAT MARIT	L	LW	30	0.5	embankment
DIG GRAN	L	MD	30	0.7	
VIC VILL	L	MD	20	0.6	
CENT JAC	L	MD	10	0.7	
ANT VUL ALP	L	LW	40	0.3	embankment
HEL NUM	L	LW	20	0.3	
ORO TEU	L	SM	0.3	0.15	
BER INC	L	MD	0.3	0.6	
SCAB LUC	L	MD	0.3	0.6	
SAL OFF	L	LW	0.3	0.3	embankment
PLAN MA	L	LW	40	0.3	
TET MARIT	L	MD	0.3	0.4	
BERT INC	L	MD	10	0.8	
VIC VILL	L	MD	10	0.8	
PRUN GRAND	L	LW	3	0.3	
BRO IN	L	MD	100	0.8	Grass
BRO ER	L	MD	100	0.8	Grass
NARD STR	L	MD	100	0.8	grass
FEST OV	L	MD	100	0.8	grass
FEST RU	L	MD	100	0.8	Grass
BRO ER	L	MD	100	0.8	Grass
ATEN	L	MD	100	0.3	Grass

Fuel load

A specific fuel load assessment has not been done or this area due to the steep slope and the proximity of the railway track. It would have been too dangerous to climb up the embankment.

Nevertheless an appreciate fuel load assessment can be given here based on the observations made from the railway track.

The significant fuel load beneath the coniferous forest stand on the uphill embankment is mainly composed of hardly decomposed needles and coarse woody debris, which is mainly composed of *Larix europaea* and *Picea abies*. The forest begins around 20 meters away from the track.

The same is true for the downhill side adjacent to the embankment. Here the coniferous forest begins around 50 to 60 meters away from the track and is separated from the track by a meadow.

Coniferous forests are always subject to a high fire risk doe to slow decomposing material, especially in dry weather periods.

Fire Risk Factors

FIRE RISK FACTORS	POINT RATING
Site information	
Size of area	1
Aspect	4
Slope	3
Area information	
adjacent slash - %	6
Risk of ignition	
Lightning	2
Person (exclud. Industry)	1
Railway	3
Access (industry & recreation)	3
Proximity to road	2
Fire Risk assessment total	25

Values at Risk

VALUES AT RISK	POINT RATING
Life and property	
1) Distance from populated areas	8
2) Size of development (within 10 km)	8
Timber values	
1) Primary contributor to A.A.C.	0
2) Silviculture Investments (within 2.5 km)	0
3) Silviculture System	0
4) Slope position	2
5) Valley Orientation	1
Water quality (Downstream Domestic Use)	0
Habitat (within 2.5 km)	
1) Wildlife	0
2) Fish	0
3) Plants	0
Visual/Aesthetics	0
Cultural	3
Subtotal	22

Codes used for field forms

General landform codes (FIREMON)

Code	Landform
GMF	Glaciated mountains-foothills
UMF	Unglaciated mountains-foothills
BRK	Breaklands-river; breaklands-badlands
PLA	Plains-rolling; plains with breaks
VAL	Valleys
HIL	Hill-low ridges-benches
MOSL	Mountain slope
PLAT	Plateau
RIDG	Ridge
X	Did not access

Slope shapes (FIREMON)

Code	Slope shape
LI	Linear or planar
CC	Depression or concave
PA	Patterned
CV	Rounded or convex
FL	Flat
BR	Broken
UN	Undulating
OO	Other shape
X	Did not assess

Primary and secondary geological codes (FIREMON)

Primary code	Primary geology	Secondary code	Secondary geology
IGEX	Igneous extrusive	ANDE	Andesit
	Igneous extrusive	BASA	Basalt
IGIN	Igneous intrusive	GRAN	Granite
META	Metamorphic	GNEI	Gneiss
	Metamorphic	PHYL	Phyllite
	Metamorphic	QUAR	Quartzite
	Metamorphic	SCHI	Schist
	Metamorphic	SLAT	Slate
SEDI	Sedimentary	CONG	Conglomerate
	Sedimentary	DOLO	Dolomite
	Sedimentary	LIME	Limestone
	Sedimentary	SILS	Siltstone
UNDI	Undifferentiated	MIEXME	Mixed extrusive and metamorphic
	Undifferentiated	MIEXSE	Mixed extrusive and sedimentary
	Undifferentiated	MILG	Mixed igneous (extrusive and intrusive)
	Undifferentiated	MILGME	Mixed igneous and metamorphic
	Undifferentiated	MILGSE	Mixed igneous and sedimentary
	Undifferentiated	MIINME	Mixed intrusive and metamorphic
	Undifferentiated	MIINSE	Mixed intrusive and sedimentary
	Undifferentiated	MIMESE	Mixed metamorphic and sedimentary

Soil texture codes (FIREMON)

Code	Description	Code	Description
C	Clay	S	Sand
CL	Clay loam	SC	Sandy Clay
COS	Coarse sand	SCL	Sandy clay loam
COSL	Coarse sandy loam	SI	Silt
FS	Fine sand	SIC	Silt clay
FSL	Fine sandy loam	SICL	Silty clay loam
L	Loam	SIL	Silt loam
LCOS	Loamy coarse sand	SL	Sandy loam
LFS	Loamy fine sand	VFS	Very fine sand
LS	Loamy sand	VFSL	Very fine sandy loam
LVFS	Loamy very fine sand	X	Did not assess

Erosion type codes (FIREMON)

Code	Erosion type
S	Stable, no erosion evident
R	Water erosion, rill
H	Water erosion, sheet
G	Water erosion, gully
T	Water erosion, tunnel
W	Wind erosion
O	Other type of erosion
X	Did not assess

Erosion severity codes (FIREMON)

Code	Erosion severity
0	Stable, no erosion evident
1	Low erosion severity; small amounts (less than 25% of the upper 20 cm of soil surface) of material are lost from the plot.
2	Moderate erosion severity; moderate amounts (between 25 and 75% of the upper 20 cm of soil surface) of material are lost from the plot.
3	High erosion severity; large amounts of material (75% or more of the upper 20 cm of soil surface) are lost fro the plot.
4	Very high erosion severity; very large amounts of materials (all of the upper 20 cm of soil surface) are lost from the plot.
-1	Unable to assess

Canopy cover codes (FIREMON)

Code	Canopy cover
0	Zero percent canopy cover
0.5	> 0-1 percent of canopy cover
3	> 1-5 percent of canopy cover
10	> 5-15 percent of canopy cover
20	> 15-25 percent of canopy cover
30	> 25-35 percent of canopy cover
40	> 35-45 percent of canopy cover
50	> 45-55 percent of canopy cover
60	> 55-65 percent of canopy cover
70	> 65-75 percent of canopy cover
80	> 75-85 percent of canopy cover
90	> 85-95 percent of canopy cover
98	> 95-100 percent of canopy cover

Potential vegetation type ID (FIREMON)

Code	Potential vegetation type
AQ	Aquatic – lake, pond. Bog, river
NV	Non-vegetated - bare soil, rock, dunes, scree, talus
CF	Coniferous upland forest – Pine, spruce, hemlock
CW	Coniferous wetland or riparian forest – spruce, larch
BF	Broadleaf upland forest – oak, beech, birch
BW	Broadleaf wetland or riparian forest – e.g. cypress
SA	Shrub dominated alpine – willow
SU	Shrub dominated upland – sagebrush, bitterbrush
SW	Shrub dominated wetland – willow
HA	Herbaceous dominated alpine – dryas
HU	Herbaceous dominated upland – grassland, bunchgrass
HW	Herbaceous dominated upland or riparian – ferns
ML	Moss or lichen dominated upland or wetland
OT	Other potential vegetation type
X	Did not assess

Tree size class codes (FIREMON)

Tree Size Class Codes	Tree Size Classes
TO	Total cover
SE	Seedling (<2.5 cm DBH or <1.5 m height)
SA	Sapling (2.5 - <12.5 cm DBH)
PT	Pole tree (12.5 - <25 cm DBH)
MT	Medium tree (25 - <50 cm DBH)
LT	Large tree (50 - < 80 cm DBH)
VT	Very large tree (80+ cm)
NA	Not Applicable

Shrub, grass and herb size classes (FIREMON)

Shrub/Herb Size Class Codes	Shrub/Herb Size Class
TO	Total cover
SM	Small (< 0.15m height)
LW	Low (0.15 - < 0.5 m height)
MD	Medium (0.5 - < 1.5 m height)
TL	Tall (1.5 - < 2.5 m height)
VT	Very tall (+ 2.5 m height)
NA	Not Applicable

Dead woody class (FIREMON)

<table>
<tr><th colspan="3">Dead Woody Class</th><th>Piece Diameter (cm)</th></tr>
<tr><td rowspan="4">DWD</td><td rowspan="3">FWD</td><td>1-hr</td><td>0 to 0.6 cm</td></tr>
<tr><td>10-hr</td><td>0.6 to 2.5 cm</td></tr>
<tr><td>100-hr</td><td>2.5 to 8.0 cm</td></tr>
<tr><td>CWD</td><td>1000-hr and greater</td><td>8.0 cm and greater</td></tr>
</table>

Factors for calculating Fire Risk Rating

FIRE RISK FACTORS	FACTORS AFFECTING FIRE RISK7POINT RATING			
Site information				
1) Size of area	< 20 ha **1**	21 to 40 ha **2**	41 to 60 ha **3**	> 60 ha **4**
2) Aspect	N, NE **0**	NW, E **1**	W, SE **2**	S, SW **4**
3) Slope	< 20% **1**	20 to 35% **2**	36 to 45% **3**	> 45% **3**
Area information				
1) Adjacent slash	None **0**	< 15% **2**	16 to 40% **4**	> 40% **6**
Risk of ignition				
1) Lightning	Low **2**	Medium **6**	High **10**	Extreme **14**
2) Person (excl. industry)	Low **1**	Medium **2**	High **3**	Extreme **4**
3) Trains	None **0**	Freight trains **1**	Passenger trains **2**	All together **3**
4) Access	Foot **0**	Car/Foot **2**	Train **3**	All **4**
5) Proximity to road	> 5 km **0**	3 to 5 km **1**	1 to 3 km **2**	< 1 km **3**
Fire risk assessment subtotal				

The number of people-caused fires excluding industry caused fires has been grouped into following categories:

Number of fires	Rating	Points
0	Low	1
1-2	Medium	2
3-5	High	3
6+	Extreme	4

Values at Risk Rating

Values at Risk Factors	Factors affecting Values at Risk			
Life and Property				
1) Distance to populated areas	> 10 km **0**	3 to 10 km **4**	1 to 3 km **8**	< 1 km **12**
2) Size of Development	No dev. **0**	Rural home **4**	Rural subdivision **8**	Village **12**
Timber values				
1) primary contributor to A.A.C.	None or < 50 ha **0**	Over mature > 50 ha **2**	Mature > 50 ha **4**	Immature > 50 ha **6**
2) Silviculture investments	None **0**	< 20 ha **1**	21 to 50 ha **3**	> 50 ha **6**
3) Silvicultural system	None **0**	Clearing **2**	Revegetation/planting **4**	Old growth **6**
4) Slope position	Top 1/3 **1**	Middle 1/3 **2**	Bottom 1/3 **3**	Valley bottom **4**
5) Valley orientation	Back 1/3 **1**	Middle 1/3 **2**	Front 1/3 **3**	Main Valley **4**
Water quality				
Downstream domestic use	No use or agriculture use **0**	Single house **4**	Small resort Electricity **8**	Large Village Electricity **10**
Habitat	Beneficial/no concern	Low	Moderate	High
1) Wildlife	**0**	**1**	**3**	**5**
2) Fish	**0**	**1**	**3**	**5**
3) Plants	**0**	**1**	**3**	**5**
Visual aesthetics	Max. modification **0**	Modification **3**	Retention **5**	Preservation to retention **7**
Cultural	> 10 km **0**	3 to 10 km **1**	1 to 3 km **3**	< 1 km **5**

Comments on the values at risk assessment

Life and property: Information can be collected from existing plans (landscape unit, development, local community) or local knowledge.

Timber values:

1 – refers to stands that are free growing. This highest rate applies; e.g. if there is 750 ha of old growth forest and 250 ha of immature forest, point rating is 6.

2 – this only refers to stands that are not free growing. Forestry investments in stands beyond free growing are captured "immature" above.

5 – a secondary drainage is less than 10 km in length from its stream junction at the front of the drainage to the merchantability and/or accessibility line at the back of the drainage.

Water quality: Values only apply if they are downstream in the watershed or within 2.5 km upstream in the watershed.

Habitat: Significant risk of fire for habitats, especially regarding nature conservation.

Wildlife habitat rating:

High: Red-listed species
Moderate: Yellow-listed species
Low: Regionally significant species

Fish habitat rating:

High: Special rivers and lakes
Moderate: Regionally significant species
Low: sport fish not above

Visual/aesthetics

This section only applies where VQOs have been formally established by the district manager through some planning process. If this has not happened, the default VPO is "maximum modification".

Cultural

This refers only to inventoried and identified cultural heritage resources that have been used to formulate a development or higher-level plan.

Bioengineering measures

Material requirements

Material requirements for mulch seeds (Florineth and Kloidt, 2005)

Type of material	Quantity
Hay/long straw	500/700 g/m^2
Seed mixture	25 g/m^2
Organic fertilizer	100 g/m^2
Instable Bitumen	700 g/m^2
Colourless fixing material	20-100 g/m^2

Material requirements for net-straw cover seedlings (Florineth and Kloidt, 2005)

Type of material	Quantity
Long straw	700 g/m^2
Seed mixture	25 g/m^2
Organic fertilizer	100 g/m^2
Net (Coconut, and other material)	10 % more than the seeded area
Nails for fixation of the net	2.5 pieces/m^2

Material requirements for hydro seeding (Florineth and Kloidt, 2005)

Type of material	Quantity
Seeding	25 g/m^2
Organic fertilizer	100 g/m^2
Fibre or very short straw	80g/m^2
Organic fixing material	20-100g/m^2
Artificial fixing material	20-30 g/m^2

Material requirements for cover crop seeding (Florineth and Kloidt, 2005)

Type of material	Quantity
Winter roe/barely	10 g/m^2
Seeding material	15 g/m^2
Organic fertilizer	100 g/m^2

Seed mixtures

Seed mixture for steep embankments (Florineth and Kloidt, 2005)

Species	Quantity (%)
Agrostis tenuis	3 %
Deschampsia caespitosa	3 %
Deschampsia flexuosa	2 %
Festuca rubra	23 %
Festuca rubra	25 %
Festuca tenuifolia	10 %
Lolium perenne	5 %
Phleum pratense	3 %
Poa nemoralis	7 %
Lotus corniculatus	2 %
Onobrychis viciifolia	2 %
Trifolium hybridum	3 %
Trifolium pratense	2 %
Trifolium repens	10 %

Seed mixture for steep and acidic sites with additional planting (Florineth and Kloidt, 2005)

Species	Quantity (%)
Agrostis tenuis	1 %
Dactylis glomerata	3 %
Festuca duriuscula	8 %
Festuca ovina	15 %
Festuca rubra	15 %
Festuca rubra	20 %
Lolium perenne	4 %
Phleum pratense	2 %
Poa pratensis	7 %
Achillea millefolium	2 %
Lathyrus pratensis	1 %
Lotus corniculatus	4 %
Lupinus perennis	1 %
Medicago lupulina	2 %
Onobrychis viciifolia	2 %
Sanguisorba minor	2 %
Trifolium hybridum	3 %
Trifolium pratense	2 %
Trifolium repens	6 %

Seed mixture for steep and acidic sites without further planting

(Florineth and Kloidt, 2005)

Species	Quantity (%)
Agrostis tenuis	1 %
Dactylis glomerata	5 %
Festuca duriuscula	8 %
Festuca ovina	10 %
Festuca pratensis	10 %
Festuca rubra	10 %
Festuca rubra	15 %
Lolium perenne	5 %
Phleum pratense	3 %
Poa pratensis	7 %
Achillea millefolium	1 %
Lathyrus pratensis	1 %
Lotus corniculatus	4 %
Lupinus perennis	1 %
Medicago lupulina	1 %
Medicago sativa	2 %
Onobrychis viciifolia	2 %
Sanguisorba minor	2 %
Trifolium hybridum	3 %
Trifolium pratense	2 %
Trifolium repens	5 %
Vicia sativa	1 %
Vicia villosa	1 %

Species for longterm bio-engineering measures

Shrub species and minimum distance to track

Species	Distance to track (m)
Shrubs	
Salix alpina	0.3
Salix breviserrata	0.5
Salix reticula	0.4
Rosa gallica	0.8
Cotoneaster horizontalis	1
Dictamnus albus	1.2
Cotoneaster melanocarpus	1.5
Salix glabra	1.5
Rosa villosa	1.5
Reynoutria japonica	1.5-2
Rosa rugosa	2
Cotoneaster integerrimus	2
Rosa elliptica	2
Rosa pendulina	2
Rosa majalis	2
Salix serpilifolia	2
Sorbus chamaemespilus	2
Prunus spinosa	3
Amelanchier ovalis	3
Rosa canina	3
Rosa abresbis	3
Viburnum lantana	3
Pyracantha sp.	4
Sambucus racemosa	4
Ligustrum sp.	5
Hippophae rhamnoides	6

Grass species and minimum distance to railway track

Species	Distance to track (m)
Grasses	
Agropyron repens	1.5
Festuca ovina ssp. minuscula	0.4
Festuca rubra	0.8
Commutela sp.	0.8