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Criticalities of CH landscapes for landslides, flash floods, wind storms and fire

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1. Introduction

This document reviews physical and managerial aspects which make the specific cultural landscape categories (e.g. terraced coastal landscapes, mountainous hamlets, parks & gardens) susceptible to the selected hazards. It should be underlined that cultural landscapes can also contain built heritage objects sensitive to the hazards. Having already analyzed such objects and their predisposition to damage in the Interreg CE project ProteCHt2Ssave, they are here omitted.

Cultural landscapes possess another specific and rather fragile value which is not treated in detail in this document. In fact, cultural heritage landscapes enrich the society with their esthetic values combining intrinsic natural qualities with inherited cultural contributions. Natural and man-made hazards represent also a danger for esthetic characteristics and values of cultural landscapes. Nevertheless, the esthetic values of cultural landscapes deserve more attention and their damage should be identified and studied.

The document is composed of four paragraphs describing natural and man-made dangers for cultural landscapes, natural hazards in cultural landscapes associated with selected natural dangers, risk of damage of cultural landscapes due to natural or man-made hazards and the main identified criticalities of CH landscapes for landslides, flash floods, wind storms, wild fires and man-made hazards. The criticalities are identified on the basis of personal experience of the authors as well as on literature review.

2. Natural and man-made dangers for cultural landscapes

Cultural landscapes represent a wide variety of historical, geomorphological, hydrological, climatic and biotope situations, which together with their management and use substantially influence their sensitivity to natural and man-made dangers. In the future prospects, also the envisaged climate change impact must be considered in an assessment of such dangers.

Naturally the landscape typology reduces the general critical landscape characteristics decisive for planning measures enhancing the landscape resilience against natural hazard actions and impact. In the STRENCH project the following typologies have been selected for detailed studies: terraced (coastal) landscapes, hamlets in mountain areas, (i.e. small rural mountainous villages), parks & gardens. Hamlets frequently include ruined or partly ruined buildings. They possess different vulnerability features when facing natural and man-made dangers and with them the associated natural hazards.

The STRENCH project builds on the previous research into the problems of natural hazards related to cultural heritage and mainly focused on river floods or sea surge as well as drought. It widens this scope with addition of other selected important hazards, namely windstorms, flash floods, landslides and fire due to drought. However, the formerly studied danger of the high water or on the other hand drought cannot be excluded because they may contribute significantly to the ultimate damage of cultural heritage.
Similarly, man-made dangers must be included in the list due to their prevailing impact on the occurrence of heavy failures as well as on defects initiating loss of cultural heritage assets in longer time prospects.

2.1. Danger of water action

Water acts on historic materials and structures in all phases of its state. It represents their most harmful and dangerous enemy which can, together with temperature or other factors, cause deterioration to or even destroy a monument very quickly. Water acts in its solid phase as ice or snow, and in the fluid phase it attacks as rain, condensation or water trapped in depressions or voids, also as underground water which can moreover flow and carry corrosive substances or compounds. A possible erosion of soil under foundations represents another very dangerous phenomenon. In the gaseous state, the water increases the relative humidity of the air and creates conditions for the increase of moisture content of materials as well as for the life of biotic agents.

Cyclical changes of moisture content in materials, namely in the case of a material containing soluble salts (crystallization and hydration pressures generated at reversible changes of phases or crystal phases of salts) or clay materials (swelling of clay) are among the greater threats to building materials in historic structures. In many cases, a relatively high but stable content of moisture in the building is less harmful than a fluctuating even lower moisture content. In some cases, drying of permanently humid materials may be very dangerous, (e.g. disintegration of marlstone due to a quick loss of freely bound water or fast drying of adobe after flooding).

High water situations have further mechanical effects, namely hydrostatic pressure, buoyancy, washing out, jetting stream destructions, transportation of soil materials and objects, additional settlement.

2.2. Dangers of wind action

Wind primarily causes loading and mechanical damage of structures; nevertheless, it also increases or decreases the chemical action of water and gases on cultural heritage objects. The flow around monuments substantially influences the deposition of pollutants, biological colonization, cycles of drying and wetting, as well as mechanical wear of the attacked surfaces. Wind transports water, salts, dust and gases to the object or building or can conduct them away.

2.3. Danger of subsoil or particle layer instability

Subsoil instability is strongly related to the water saturation of some soils, which changes pore pressure and can mobilize transport of large mass of soil generating landslides or excessive settlement. Change of subsoil conditions causes loss of support for buildings and structures, which initiate structural damage or even failures. Moving soil mass may also load or even bury other buildings or structures. The forces are usually so large that any effective strengthening of existing buildings is impossible at reasonably acceptable costs.

Similar dangers may be created by various types of avalanches – snow, debris or mud flows. Here the loading by moving mass of snow or soil particles represents the main danger for buildings and some landscape shapes.

2.4. Danger of fire

Climate change, by inducing long dry periods and high temperatures, increases the danger of fires. Fires were historically more dangerous in settlements than nowadays, however, every year there are still losses of important monuments due to fire. In fire, the combustible materials, objects and structures may be totally destroyed in a very short time in the range of minutes. Therefore, the inflammability of cultural heritage assets is their most critical characteristics as well as their accessibility to igniting.

Other damage of cultural heritage may be caused during fire extinguishing when inappropriate fire-fighting methods are applied, e. g water for water sensitive materials.

Specific problems occur during wild fires over large territories when forests are burning. Here the danger of rapid and uncontrolled fire propagation exists and increases a danger for historic buildings and structures in both the countryside and settlements as well as for the historic gardens and parks.

2.5. Man-made dangers

Man-made dangers in cultural landscapes are typically associated with the mode of their management, modes and intensity of their exploitation and use, policies and financial support of their protection and unwanted or intentionally destructive human interventions.

3. Natural hazards in cultural landscapes associated with selected natural dangers

Under specific circumstances, usually in combination with geomorphological, hydrological and weather situations present in a given place, natural dangers are intensified to catastrophic extents in the form of natural disasters. In the STRENCH project only small water catchment floods, especially flash floods, landslides, wind storms and fires are discussed in detail.

3.1. Flash floods

3.1.1. Conditions and triggering mechanisms

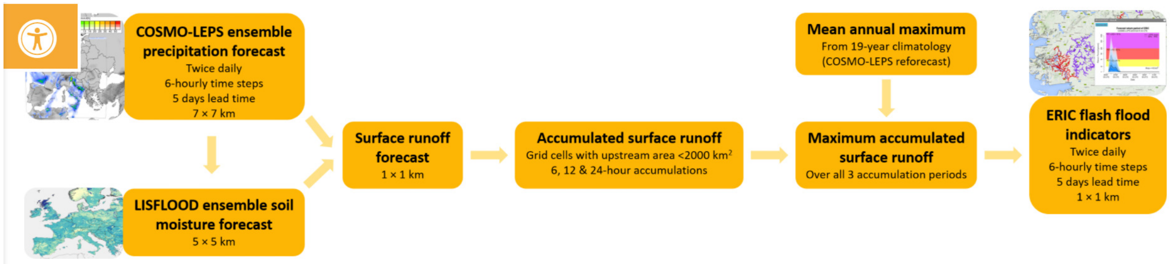
Flash floods typically occur in a rather limited catching basin drained with a rather small river or creek during intensive water precipitation. The effect is intensified after long term rainy periods when the soil is saturated with water and has no capacity to further absorb the rain water. The reduction of water soaking can be also a result of inappropriate agricultural activities or extensive pavements in a territory. In such situations a very heavy rain may initiate a flash flood, even in narrow steep valleys without any brook in the country side or in settlements and without previous long term rain

3.1.2. Mapping of the hazard

The EC Directive 2007/60/EC regulates the production of risk maps concerning river floods [1]. The maps should include position of important cultural heritage objects, however, involvement of cultural landscape assets has not been explicitly demanded. The content of flood risk maps is thus left on individual country policies, which gives an opportunity for *transnational amendments*.

For flash flood no maps are available. However, the danger can be estimated and published. One service of the Copernicus Emergency Management Service (CEMS) - the European Flood Awareness System (EFAS)[2], provides different flash flood indicators based on two main concepts: 1) ERIC, generated from high-resolution numerical weather predictions with a lead time of up to 120 hours, and 2) ERICHA, based on radar-based precipitation monitoring and nowcasting for the next 6 hours [3].

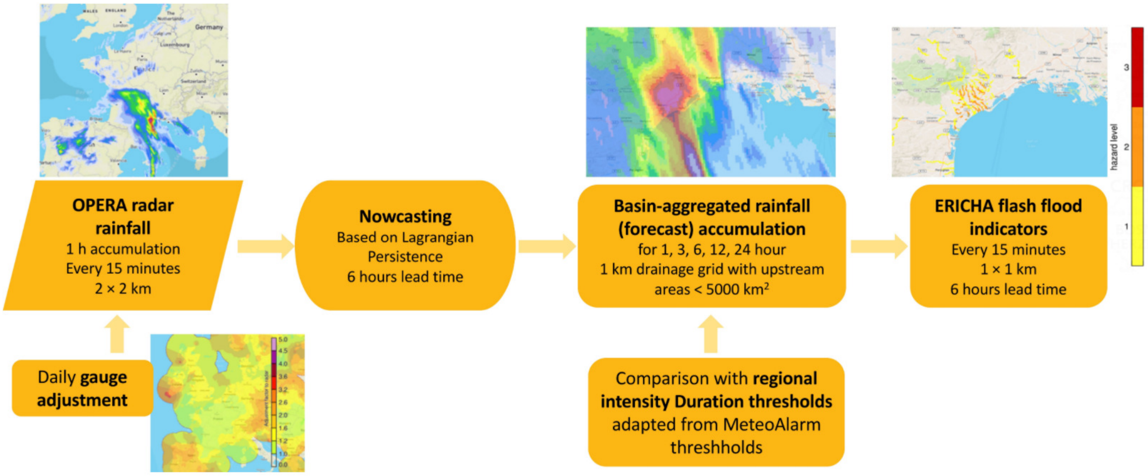
The *ERIC flash-flood indicator* is generated by comparing the forecasted surface runoff accumulated over the upstream catchment with a reference threshold. It is based on the 20-member COSMO-LEPS ensemble precipitation and soil moisture forecasts from the LISFLOOD hydrological model and provides indicators for the next 5 days for catchments smaller than 2,000km^2.



The ERIC flash flood indicators modelling chain

Two ERIC products exist:
Reporting points ("ERIC Reporting Points" layers): points in the river network highlighted because their flash flood forecast probability over the next 5 days meets certain criteria:
1. probability of exceeding a 5 year return period magnitude of the surface runoff index is forecasted to be greater than or equal to 10%
2. forecasted start of the event is < 48 hours in a region for which an EFAS partner exist
Affected area ("ERIC Affected Area"): river network which contributes to each ERIC reporting point, i.e. areas at risk from flash flooding ("ERIC Affected Area")

The *ERICHA flash-flood indicator* is generated from radar-based precipitation monitoring and nowcasting product, based from the European OPERA radar composite. This aims to capture very localised events difficult to predict from numerical weather prediction systems, but only provide information up to 4 hours.



The chain of the updated ERICHA system producing precipitation and flash flood hazard nowcasts.

Three ERICHA products exist:
Hourly precipitation maps: Hourly precipitation totals from the OPERA radar composite, updated every 15 minutes ("ERICHA hourly accumulation precipitation" layer).
Flash flood hazard maps: Sections of the river network highlighted because their flash flood forecast probability over the next 4 hours meets certain criteria. The thresholds are based on regional climatic characteristics and river basin upstream area as published by the MeteoAlarm consortium ("ERICHA - FF hazard levels forecasts" layer).
Daily precipitation maps: Daily gauge-adjusted radar rainfall accumulation over the last 24 hours ("ERICHA 24-h accumulations" layer).

In the Czech Republic, the Flash Flood Indicator system has been developed and launched in 2018 [4]. It consists of three tools: a) an assessment of the water saturation degree in a daily step based on precipitation volume, drainage and current evaporation – *water saturation indicator*; b) determination of *potentially risky precipitation amount* during a given period, which can in present water saturation conditions in the territory generate surface drainage of a given importance; c) determination of a *risk of occurrence or potential origin of flash flood* on a given territory based on current data of fallen precipitation and its short term forecasting. The *potentially risky precipitation amount* is calculated over the territory of 3 km x 3 km. It is an amount which might cause superficial surface drain off the given territory with a repetition period of 2-5 years. In urban territories or slope agricultural fields where inappropriate farming is applied the values could reach substantially lower values and increase the potential risk of flash floods. The web application shows results of the above described procedures https://www.arcgis.com/apps/webappviewer/index.html?id=1159f13d2f034424be2fb2d88d73723f. Both Copernicus and the national flash flood warnings do not include any cultural heritage exposure. However, the hydrogeological land surface data are used in the systems.

3.2. Landslides

Landslide phenomena in relation to climate effects have been studied in [5], [6] and the most important findings are presented below.

3.2.1. Conditions and triggering mechanisms

Landslide event are usually caused by a combination of different factors, the most important are:

Material properties of soil/rock massif. In general, more susceptible to failure are fine-grained soils which are characterized by significantly lower friction angles (Φ) compared to coarse grained materials (the typical critical state friction angle of clay is of the order of 22°, whereas of sands it is 35°). Friction angle of clays further reduces in the case of previous deformation (pre-existing slip surface, stabilized old landslide) up to the residual value of approx. 6°. In theory, the critical state friction angle Φ is related to the "angle of repose" of the soil (α), an inclination of the slope under stable conditions. In dry homogeneous material $\alpha = \Phi$, in water saturated state with ground water table on the surface $\alpha = \Phi/2$.

Geological composition. The stability of the slope may be further reduced by unfavorable geological conditions. A typical unfavorable example is flysh material, with interchanging layers of sandstone and clay stone. During rainfall the sandstone layer quickly saturates due to high permeability, which causes decrease of effective mean stress in the impermeable layer of clay stone, which is than susceptible to failure. Another example of geological conditions pre-defining slope collapse is a rigid rock stratum lying on a highly plastic fine grained material. Rigid blocks load a slope which fails in the case of high precipitation.

Precipitation, water saturation. It is one of the most important aspect causing landslides. Increasing of water table causes an increase in pore pressure. According to Terzaghi's principle of effective stresses, increase in pore pressure causes decrease of the mean stress p, while the shear stress q remains unchanged (water cannot sustain shear stresses). Consequently, stress state moves towards Coulomb's failure envelope (defined by a friction angle Φ) which may lead to slope failure. More problematic from the point of view of landslide hazard is an extreme climatic event (strong rainfalls, quick snow-melting in spring) which causes sudden increase of the pore pressure and may be reason for reaching Coulomb's failure criterion. Annual average changes are less important.

Slope inclination. An important factor influencing susceptibility of the slope to failure. In general, slopes with medium inclination (15°-30°) are the most problematic. Slopes with a smaller inclination are usually stable due to small shear stresses acting in the ground (with the exception of slopes with pre-existing slip surfaces, where residual friction angle has been reached, see “material properties”). On the other hand, it turns out statistically that slopes with higher inclination than about 35° are usually also stable. If such a slope was susceptible to failure, it would have already failed in the geological history. Nevertheless, recently created slopes in parks and gardens may represent such type of problems. Slopes with high inclination are often made up from rigid rocks, where other types of instabilities, such as rock falls, may be expected.

Technical disturbance of the slope. It is an important factor which may be influenced by taking correct protective measures. The probability of failure is increased by cuts (unloading) in the slope toe and loading of the crest, insufficient water drainage which causes infiltration of water and increase of pore pressures, retaining wall without sufficient drainage, etc. The majority of such disturbances are not predictable from the general management point of view.

3.2.2. Mapping of the hazard

Individual countries of regions develop *maps of the landslide danger* based on the slope inclination, geological characteristics and historic experience. Such maps represent basic data for the hazard assessment; they should be published and compared to maps of cultural heritage assets. Their scale must take into account the fact that landslide prone areas may be rather small with dimensions in a range of hundred meters. The current danger is then estimated according to the current precipitation in rainy periods. Studies of landslide activities show that the trigger factors are the *rainfall amount at the day of landslide* as well as the *total rainfall for previous two weeks*. Of course, in the combination with the soil type (at least sandy versus cohesive, or soil permeability) and the slope inclination.

3.3. Wind storms

3.3.1. Triggering mechanisms

Wind storms result mainly from global atmospheric phenomena and, therefore, are predictable from monitored atmospheric situations. Some regional events may occur in sudden situations influenced by a combination of geomorphological features, surface cover with plants or large water areas as well as urban areas generating heat islands. There is a difference between synoptic winds which typically lose their force due to contact with barriers and thermal winds which may increase after contacts with barriers. In any case, the windstorms are dependent on climate conditions and their occurrence is expected to change due to climate development.

3.3.2. Mapping of the hazard

However, there are attempts to predict the windstorm danger and impact from statistical analysis historical data on wind storms and the generated insurance claims. For example, in France the country is divided into wind zones, mostly for the purpose of insurance [8]. The division exploits a newly developed *wind storm index* based on the wind index [9] and the number of risks in the insurance portfolio (exposure for the given region). The index is studied over a longer period than damage data, it presents less non-stationarities and can exploit a finer spatial resolution. It takes into account the size of the damaged area (geographic aggregation), the duration of the storm event and the number of active stations for day of the event. The maximum and not the sum of daily indexes for the temporal clusters associated to each storm has been chosen. Similar approach could be applied for cultural heritage risks from wind storm actions provided the data on damage are available.

3.4. Wild fire

3.4.1. Triggering mechanisms

Wild fires originate naturally by ignition due to lightning or self-ignition in suitable conditions, usually during long term dry periods and relatively high temperatures, and in forests with highly flammable plants or their leaves, e.g. eucalyptus or pine trees. Many wild forests fires are also a result of arson´s activities, which has been experienced e.g. in Bulgaria in recent decades [9]. Then they belong in the category of the man-made dangers.

3.4.2. Mapping of the hazard

The Copernicus EMS On Demand Mapping provides on-demand detailed information for selected emergency situations that arise from natural or man-made disasters anywhere in the world. The European Forest Fire Information System (EFFIS) monitors forest fire activity in near-real time. EFFIS supports wildfire management at the national and regional level for EU member states [10]. However, wildfires are strongly dependent on the winds, precipitation / drought and naturally on the land surface conditions. Therefore, occurrence of danger situations can be forecasted from climatic data in combination with land surface data describing forest and bush flammability in wildfire prone areas as well as a possible danger of flammable soils. Involvement of public thus can bring about positive results for preventive and early activities. Such a decentralized approach has been studied together with transnational cooperation in the running Italian-Greek Interreg project OFIDIA [11].

4. Risk of damage of cultural landscapes due to natural or man-made hazards

Three typologies of cultural landscape are studied - terraced landscapes, hamlets in mountain areas, (i.e. small rural mountainous villages) and parks & gardens. Their risk of damage - partial or critical – is dependent on their susceptibility to damaging factors of the above discussed dangers and hazards. In the previous projects Noah´s Ark and ProteCHt2save the cultural heritage assets were ranked according to their vulnerability in five categories. The ranking helps to select appropriate preventive or mitigating measures because it is focused on specific weak characteristics of the typologies under discussion in regards to the damaging forces or actions. Possible synergies, e.g. mass tourism, are also taken into account, as well as other man-made hazards associated with management issues.

4.1. Terraced landscapes

Terraced landscapes are typical in hilly or mountain regions. They may suffer from all four types of natural hazards listed in the previous paragraphs with some extensions involving mud or debris flow and rock fall.

4.1.1. Ranking of terraced landscapes

L0 – Robust landscapes – include resilient landscapes which proved to sustain historical harming events without substantial damage or modification.

L1 – Landscapes prone to loss of biological cover – are represented by areas with fragile biological cover sensitive to windstorms, wild fires, drought or frost.

L2 –Landscapes prone to superficial damage – include terraces endangered by erosion of soil, mostly due to unsuitable agricultural exploitation, areas with topsoil unstable in heavy rain situations, places exposed to mechanical damage by movement of cattle or human visitors.

L3 – Landscapes prone to partial structural damage – include areas endangered by local flash flood, mud or debris flow or rock fall impact, areas with inefficient retaining walls made of sensitive materials or not properly constructed.

L4 – Landscapes prone to devastating damage – include terraces built on slopes endangered by landslides.

4.2. Hamlets in mountain areas

Hamlets in mountain areas mainly suffer from the risks generated by flash floods, landslides, wind storms and avalanches as far as the natural hazards are concerned. However, their sustainability is substantially influenced by man-made hazards, namely the tendency to abandon such places and leave them unmaintained, which creates specific damaging conditions. From the cultural heritage point of view, hamlets may be built on territories with important archaeological remains – buried or standing as ruins.

4.2.1. Ranking of hamlets

H0 – Robust hamlets – include resilient hamlets which proved to sustain historical harming events without substantial damage or modification.

H1 – Hamlets prone to loss of inhabitants – are represented by settlements with fragile socio-political and economic stability sensitive to natural disasters.

H2 – Hamlets prone to loss of buried archaeological remains – include areas endangered by erosion of soil, flash floods or man-made interventions.

H3 – Hamlets prone to partial structural damage – include areas endangered by local flash flood, avalanches, mud or debris flow or rock fall impact, areas with buildings made of sensitive materials or not properly constructed, unmaintained ruins or places exposed to intensive use for mass tourism.

H4 – Hamlets prone to devastating damage – include hamlets built on slopes endangered by landslides.

4.3. Parks & gardens

Parks and gardens in mountain regions suffer from the problems similar to the terraced landscapes. In flat country sites they are usually not affected by landslides. Next to the abiotic factors also biotic ones must be taken into account. They are strongly influenced by climate conditions and weather situations as well as by the quality of management.

4.3.1. Ranking of parks and gardens

P0 – Robust parks and gardens – include resilient parks and gardens which proved to sustain historical harming events and situations without substantial damage or modification.

P1 – Parks and garden prone to loss of biological cover – are represented by areas with fragile biological cover sensitive to windstorms, wild fires, drought or frost, as well as floods. Moreover, in this category we consider also parks and gardens which suffer from managerial errors or massive attack of biotic agents.

P2 – Parks and gardens prone to superficial damage – include parks and gardens endangered by erosion of soil, mostly due to unsuitable biological cover and a shortage in its maintenance, areas with unstable topsoil layer in heavy rain situations, places exposed to mechanical damage by movement of human visitors or intensive use for mass tourism.

P3 – Parks and gardens prone to partial structural damage – include areas endangered by local flash flood, mud or debris flow or rock fall impact, areas with trees sensitive to windstorms and gardens with buildings or artificial landscape elements made of sensitive materials or not properly constructed or stabilized.

P4 – Parks and gardens prone to devastating damage – include areas created on or under slopes endangered by landslides.

4.3.2 Examples of risks and damage

Climate change factors strongly influence sustainability of parks & gardens in the most significant way. Therefore, this CH category is treated in detail and distinguishes actions of abiotic and biotic agents. The *abiotic action* is mainly caused by extreme weather fluctuations and manifests in physical as well as physiological impacts. They include:

Long term increase of temperature

It affects mainly initiation of phenology phases of plants especially for trees and bushes important for garden and landscape arts. It impacts propagation of detrimental pathogenic organisms such as infection carriers or fungi towards North and in higher altitudes. It further causes shift of vegetation steps with changes in ecology bindings and species composition, size and quality of plants, their vegetation periods (usually prolongation), propagation of invasive species and shortage of the winter season.

Solar overheating and excessive radiation

The temperatures above 35°C in the CE latitudes decrease efficiency of CO_2 fixing. Many plants suffer photo-destruction effects at extremely intensive visible or UV irradiation. High temperatures also damage plants by dehydration associated with a high transpiration.

Long term drought

It decreases resilience of vegetation elements against action of other stress factors, e.g. pests, air pollution etc. It also changes resilience of environment, ability of its appropriate reaction and adaptation. It increases risk of wild fires at simultaneous worsening of their extinguishing due to a shortage of water. It decreases water flow in garden and park rivers, artificial channels, ponds and lakes. It causes a decrease of underground water table level under the reaching of tree roots, drying of vegetation elements and shortage of water for irrigation. It increases the risk of propagation of detrimental pathogenic organisms and non-indigenous invasive species.

Inundation and high water presence

It includes various floods, high underground water table and heavy rain periods. It decreases physiology of root activity. Short and long term inundations cause various types of damage on trees including their loss due to root system instability. Water flow initiate erosion or transport of sediments and trash in gardens as well as harmful organisms. High water may mobilize landslides in parks and gardens, even local ones on artificial decorative hills or earth structures. In parks and gardens, especially if located on sloping land, the heavy rains concentrated in a short time can compromise the water regulating network (ditches and drains) and the pathways (roads with natural ground, grass paths or dirt), with considerable damage due to the erosion of the substrate, the deterioration of artifacts, the impracticability of the paths and the consequent need for important interventions to restore the state of the places and the use of green areas.

Frost

The most dangerous are early spring frosts, winter frosts without snow cover and long term decrease of temperature under -20°C. The early spring frost of about -3°C to -5°C damage young sprouts, winter frosts damage bark and phloem and late spring frosts up to -5°C damage buds, sprouts and blossoms. Sensitive are sculptures and fountains in parks.

Snow and icing

Extreme snow precipitation and icing typically overload trees and cause mechanical damage such as breaking of branches or even whole trees. With regard to snow, evergreen woody plants suffer the most damage, since the foliage intercepts greater volumes of snow. "Out of season" snowfalls are particularly damaging on deciduous wood species, when they occur in late autumn or early spring, due to the presence of leaves increasing the load of snow on the tree tops.

Hail

It damages assimilation apparatus, blossoms, fruits as well as thin branches. Major damage is observed on new plantations.

Wind and windstorms

Vegetation cover is damaged or even destroyed by movement of air mass. Especially for separate trees located in open space or on higher terrain waves are very sensitive. The most dangerous for gardens and parks are gust winds with sudden changes of force and direction of the wind. The most serious damage is caused by hurricanes with the wind velocities above 100 km/hour. In the parks and gardens with built romantic ruins, pavilions, summerhouses, sculptures are frequently damaged by wind due to their inappropriate or temporary construction or exposed location. In urban areas, sometimes special air circulation conditions occur ("canyon effect") which expose trees to greater turbulence. It follows that, with the same average wind speed, trees undergo bending conditions higher than those located in rural or forest contexts.

Lightning

Lightning may totally kill trees or seriously damage trunks and branches. Some species of trees attract lightning more than others probably due to their height and electricity conductivity. The tall ones are more attractive than trees with oils content. The impact includes further creation of lightning rings, i.e. damage of surrounded trees by the discharge transmission trough roots. Lightning may also initiate wild fires. In historical parks and gardens, in particular, lightning often strikes the monumental tree heritage with consequent impairment or loss of the most valuable plant component of the green area. A similar situation also applies to wind and snow.

The biotic agents caused enormous damage on parks and gardens in recent years and their activity is more and more considered in relation to the observed climate change tendencies.

Pests deteriorating branches and trunks of coniferous trees

Spruce (*Picea* spp.) is especially sensitive to harmful action of the bark beetle (*Ips typographus*), however, pine (*Pinus* spp.) or larch (*Larix* spp.) can also attacked. The dangerous situation occurs when several factors coincide, namely temperature, long term precipitation in the area, site, composition of species in the park and the reproduction cycle of the beetle. Such synergies may cause total loss of trees.

Fungicide diseases of leaves, buds and sprouts

For ash trees the Hymenoscyphus pseudoalbidus fungus is the most dangerous pest causing necrosis of such trees (*Chalara fraxinea*).

Pests deteriorating leaves

Some beetles are responsible for significant loss of trees in the gardens and parks. It is mainly *Cameraria ohridella* which attack chestnut trees (*Aesculus hippocastanum*) and *Cydalima perspectalis* seriously deteriorating box trees and bushes (*Buxus* spp.).

Parasitic plants

In this category the mistletoe (*Viscum album*) represents the most important as well as the most known plant. It preferentially consumes water and may gradually kill the tree.

Invasive or expansive plants

Invasive plants are those which are non-indigenous in the territory and have a high ability of fast colonization of new sites. Expansive species are indigenous plants, however, similarly fast propagating and creating rather large populations. They involve many herbs and also trees e.g. *Rubus*, *Sambucus nigra*. Nevertheless, their effect is manageable. Examples of invasive plants:

Locust tree (*Robinia pseudoacacia*) is the most spread introduced tree in the Central Europe, Tree of heaven (*Ailanthus altissima*) is a very aggressive sub-tropic plant colonizing rather warm areas and its future propagation is dependent on the climate change.

Synergic biotic and weather effects

A set of different causes, such as the action of pathogenic fungi, the activity of harmful insects and changed climatic conditions, in particular the increase of drought periods, are at the basis of the "decline of the oak" *(decline of Quercus sp.)* which manifests itself through the decay of adult, and in some cases monumental, individuals - in forest and rural contexts, but also in parks and gardens. The result is partial desiccation of the foliage of the trees, which in some cases lead to the sudden death of the plants.

Mature and aging trees

With regard to this type of trees, belonging to both native and exotic species, various problems are encountered that compromise their vegetative and phytosanitary conditions and cause an acceleration of the senescence processes, causing partial desiccation up to the death of the specimens. The causes are related to the greater receptivity of senescent trees towards biotic damage agents and to their poor adaptability and resistance to current environmental conditions, aggravated in the urban environment by the known stress conditions to which the trees are subjected. In historical parks and gardens, in particular, the monumental tree heritage can be compromised, with the consequent loss of the most valuable plant component of the green area.

Climate change and adaptation of plant species

The changed climatic conditions are affecting the capacity of the different plant species to adapt to the different geographical contexts in which they grow, with different effects depending on the characteristics of each species (geographical and altitude distribution, ecological characteristics, environmental needs). In natural forests, for example, we are witnessing the migration of thermophilic and xeric species from south to north and from minor to higher altitudes; at the level of plant species, therefore, climate change can determine migration, or the displacement of the distribution area, generally from the most southern to the northern latitudes and from the lowest to the highest altitudes. This trend also affects the species present in parks and gardens, especially in urban areas, characterised by the loss of less adaptable essences and the increase of new species that are more tolerant and resistant to changed environmental conditions and typical stresses of the urban environment. The choice of plant essences to be introduced in the future in green spaces must take this aspect into account.

In the area around Bologna, for example, the scarce adaptability of the beech (*Fagus sylvatica*) should be noted, a mesophilic species typical of cool-humid environments and higher altitudes, often used in the past as a component of parks and gardens. Many of the specimens present in urban greenery are showing widespread suffering with partial or total desiccation, including those of the characteristic "beech wood" within the Villa Ghigi Park.

Wildlife

The increasingly widespread presence, in recent years, of wildlife, including medium-large size animals such as wild boar *(Sus scrofa)*, roe deer *(Capreolus capreolus)*, hare *(Lepus europaeus)*, badger *(Meles meles)*, represents a serious problem for the management of parks and gardens, including those in urban areas. The consequences are debarking and removal of shoots in shrubs and young trees, damage to lawns due to the removal of bulbs and tubers (including rare and protected plant species), damage to fences, paths and artefact's. Also noteworthy is the presence of the porcupine *(Hystrix cristata)*, a species well present in the Mediterranean area, which in recent decades is growing in number, has colonized the hilly territory of the Emilia-Romagna region and is expanding towards the plain and the coastal strip.

Finally, it should be emphasized that porcupine and badger, both mammals with a fossor habit, dig burrows along the river banks, making them unstable and causing breakage of the embankments, with consequent increase of floods.

4.4. Man-made risks

In this paragraph harming situations generated by human are listed. They act in synergy with the natural hazards and risks and in many cases worsen conditions for damage. MC stands for *Managerial Criticality*.

4.4.1. MC1-Quality of information on cultural landscapes.

Shortage in data on cultural landscape assets prevents designing and implementing effective measures for safeguarding them in all stages of natural disaster. Land surface data are indispensable for an efficient cooperation with remote sensing tools.

4.4.2. MC2-Funding availability

Development and implementation of efficient preventive, rescue and repair or restoration measures in cultural landscape strongly depends on the availability of financial resources in necessary amounts as well as in appropriate time.

4.4.3. MC3-Knowledge and awareness

Awareness and understanding of cultural landscape assets represents one of the most important quality for public involvement in the resilience and restoration interventions and activities.

4.4.4. MC4- Policy and regulation

Development of protection and resilience improvement plans is still underestimated and lacking.

4.4.5. MC5- Resilience and protection of cultural landscape planning

Policies and regulations frequently ignore specific requirements of cultural heritage protection and resilience or implement them in practice with significant delay.

5. Criticalities of CH landscapes for landslides, flash floods, wind storms, wild fires and man-made harming actions

In the ProteCHt2save project an approach of identification of critical elements or conditions decisive for an effective resilience and risk management planning has been developed and adopted. A critical element has been defined as an adjustable/changeable factor or aspect of a CH system, intended as the ensemble of its physical and managerial characteristics, which proves to be crucial for the determination of its resilience against natural disasters and climate change actions. Critical elements therefore set the priorities which resilience and risk management policies should address.

For the sake of establishing a proper framework for the decision support tool which can be easy to use and accessible also to non-technical stakeholders, a simplified categorization of critical elements has been proposed.

This Deliverable endorses the involvement of stakeholders in the process of improvement of cultural landscape resilience. Nevertheless, not all criticalities are ready for a feasible treatment. Criticalities are listed in the tables below in which the possible mode and feasibility of their treatment is also indicated.

Illustrative examples of damage are presented in the Annex.

5.1. Terraced landscape (physical)

Criticality	*Hazard*	*Typical damage or consequence*	*Rank or type*	*Resilience feasibility*
Location of CH assets on slopes of the average inclination angle between 15° - 30° or at the foot of such slopes	landslide	Dislocation of the CH assets or their partial or total destruction or burying at the foot of slopes	L3-L4	Geotechnical engineering task
CH assets on slopes with pre-existing slip surface or stabilized old landslide of the average inclination angle between 6° - 15° or at the foot of such slopes	landslide	Dislocation of the CH assets or their partial or total destruction or burying at the foot of slopes	L3-L4	Geotechnical engineering task
Location of CH assets at the foot of slopes, e.g. at the foot of the descending hills of a valley	landslide flash flood	Caving of the CH assets in soil material slipped or transported by mud / debris-flow from the hill	L3-L4	Geotechnical engineering task
Terrace shaping made of fragile stone walls, e.g. water sensitive stone, clay mortar walls	flash flood mud flow	Partial destruction of terrace walls	L3	Skilled professional (do-it-yourself)
Landscape located on or under unstable rock cliffs	rock fall	Modification of landscape, damage of terrace walls	L3	Geotechnical engineering task
Presence of fall line water channels (creeks, narrow valleys, paths, …)	flash flood	Partial destruction of terrace walls	L3	Geotechnical engineering task
Sloped pasture lands with cattle or wildlife / tourist pathes	abuse	Local superficial mechanical damage, increased soil erosion	L2	Management (do-it-yourself)
Strong winds, solar overheating / frost exposed slopes	harsh weather drought	Loss of biological cover	L1	Protective measures against wind, solar heating, drying
Worsening condition of the walls	neglected maintenance	Partial destruction of terrace walls	L3	Repair (do-It-yourself or profi)

5.2. Hamlets in mountain areas (physical)

Criticality	*Hazard*	*Typical damage or consequence*	*Rank or type*	*Resilience feasibility*
Location of hamlets on slopes of the average inclination angle between 15° - 30° or at the foot of such slopes	landslide	Dislocation of the hamlet buildings or their partial or total destruction or burying at the foot of slopes	H3-H4	Geotechnical engineering task
Location of hamlets at the foot of slopes, e.g. at the foot of the descending hills of a valley	landslide flash flood avalanches	Caving of the CH assets in soil material slipped or transported by mud / debris-flow or in snow avalanches falling from the hill	H3-H4	Geotechnical engineering task Building protection barriers preventing avalanches
Obsolete built infrastructure	any	Loss of inhabitants and gradual loss of built heritage	H1	Management on the authority level
Shallow located archaeological remains	flash flood tillage	Soil erosion with the loss archaelogical stratigraphy and/or assets/destruction or damage to CH assets	H2	Geotechnical engineering task
Ruins in abandoned hamlets	weather fire vandalism thefts	Damage or loss of built heritage, abuse of ruins	H3	Management on the authority or owner level
Archaeological assets in abandoned hamlets	weather vandalism thefts	Loss of archaeological assets	H2	Management on the authority level
Malfunctioning drainage	weather	Damage due to increase of water table level	H3	Repair or maintenance
Worsen condition of the hamlet objects	neglected maintenance	Partial destruction of hamlet buildings, objects and structures	H3	Repair (do-It-yourself or profi)
Ruins in redeveloped hamlets	neglected maintenance	Damage or loss of built heritage, gradual loss of ruins	H3	Management on the authority level

5.3. Parks & gardens (physical abiotic)

Criticality	*Hazard*	*Typical damage or consequence*	*Rank or type*	*Resilience feasibility*
Site exposed to intensive insolation	harsh weather	Plants exposed to solar overheating and excessive radiation suffer photo-destructionand dehydration	P1	Management by owners or site managers
Site with deep or higly fluctuating underground water table level	drought	Drying or loss of vegetation elements, increased risk of propagation of detrimental pathogenic organisms	P1	Management by owners or site managers
Sites occasionally inundated with long term duration	river flood	Initiation of instabilities of tree roots, landslide initiation (this aspect may not apply for tree species adapted to floodplains)	P1	Management by owners or site managers
Sites occasionally inundated with water stream	all types of flood	Initiation of instabilities of tree roots, landslide initiation, transportation of sand or gravel or garbage and fouling up with sediments	P2-P3	Management by owners or site managers
Small or pedestrian bridges	river or flash floods	Damage or destruction by undermining or direct stream force	P3	Specific measures of site management
Separated (detached) trees and sculptures	frost, icing, wind	Breaking of branches or even whole trees, material disintegration of porous sculptures, windthrow of trees	P1, P3	Management by owners or site managers
Romantic ruins, temporary buildings or pavillions	wind storm	Partial or total collapse of roofs or whole buildings or objects	P3	Management by owners or site managers
Tall trees with a high content of starch	lightning	Damage or breaking of trees, wild fire initiation	P1	Specific measures of site management
Sites on or under slopes endangered by landslides or massive rock fall	landslide rock fall	Devastating damage	P4	Geotechnical engineering task

5.4. Parks & gardens (physical biotic)

Criticality	*Hazard*	*Typical damage or consequence*	*Rank or type*	*Resilience feasibility*
Spruce tree compositions	biotic pests + climate	Branch or tree deterioration, loss of coniferous trees	P1	Management by owners or site managers
Ash or chestnut trees	fungi insect	Necrosis of ash trees, deterioration of leaves of chestnut – aesthetic damage	P1	Management by owners or site managers
Box trees or bushes	insect	Total loss of box trees	P1	Management by owners or site managers
Parasitic plants	presence	Gradual loss of trees	P1	Management by owners or site managers
Expansive plants, e.g. *Rubus, Sambucus nigra*	presence	Fast colonization and population destroying large parts of gardens or parks	P3	Management by owners or site managers
Synergic	presence + climate	Fast colonization and population destroying large parts of gardens or parks/ adverse effects on health of visitors	P3	Management by owners or site managers
Synergic biotic and weather effects	presence + climate	Decline and decay of adult oak, in some cases monumental individuals, desiccation of the foliage	P1	Management by owners or site managers
Mature and aging trees	presence	Acceleration of the senescence processes, causing partial desiccation up to the death of the specimens	P1	Management by owners or site managers
Adaptation capacity of plant species	climate change	Loss of less adaptable essences and the increase of more tolerant and resistant species, migration of sp.	P1	Management by owners or site managers
Wildlife	presence of wildlife	Damage of shrubs and young trees, lawns, protected plant species, damage to fences, paths and artefact’s	P1	Management by owners or site managers

5.5. Man made criticalities

Criticality	*Hazard*	*Typical damage or consequence*	*Rank or type*	*Resilience feasibility*
Missing updated databases (e.g. inventories, lists, atlas etc.)	All types	No risk assessment possible. Problematic or impossible evacuation and rescue action	MC1	Management by managers at local/regional/national level.
Lack of mapping of the site conditions	All types	No risk assessment possible. Problematic or impossible evacuation and rescue action	MC1	Management by managers at local/regional/national level.
Lack of data on the CH accesibility	All types	Problematic or impossible evacuation and rescue action	MC1	Management by owners or site managers.
Lack of funds	All types	Impeded maintenance and repair works	MC2	Management by managers at local/regional/national level.
Unsuitable exploitation of CH for commercial activities	All types	Low interest in object preservation	MC2	Management by managers at local/regional/national level.
Non-use or limited use of external sources of financing	All types	Impeded maintenance and repair works	MC2	Management by managers at local/regional/national level.

Lack of knowledge or experience with management of CH site	All types	Serious damage in case of disaster to site and occupants	MC3	Management by owners or site managers.
Lack of sense of belonging resulting in carelessness from communities	All types	Obstable to conservation of heritage values	MC3	Management by managers at local/regional/national level.
Low awareness and knowledge about the process of cultural heritage protection	All types	Inappropriate management and maintenance of CH site	MC3	Management by owners or site managers.
Incorrect technical solutions	All types	Even if not immediate, serious complications might be expected in the long term, with further increasing of the damage of the initiaiton of new degradation processes	MC3	Management by owners or site managers.
Misinformation	All types	Poor decision making	MC3	Management by owners or site managers.
Lack of communication and social engagement	All types	Poor decision making	MC3	Management by owners or site managers.
Incompatibility of large investment and conservation projects	All types	Loss of heritage values	MC3	Management by managers at local/regional/national level.
Lack of forecast and control system	All types	Impossible to implement early wasrning systems. Serious consequences might be expected in disastrous scenarios	MC4	Management by managers at local/regional/national level.

Inappropriate urban regulation for building and construction	All types	Damage to site characteristics and authenticity	MC4	Management by policy makers.
Presence of unregulated human activity	All types	Activation of multiple damaging processes	MC4	Management by policy makers.
Lack of official action (no enforcement)	All types	Inappropriate use of the site. Incompatible activities for CH preservation	MC4	Management by managers at local/regional/national level.
Unregulated attendance of the site by visitors and groups	All types	Effects of mass tourism	MC4	Management by owners or site managers.
Absence of the headquarters of the managing entity within the site area	All types	Slower and less effective intervention in case of emergency and in monitoring	MC4	Management by owners or site managers.
Lack of perimeter protection	All types	Vandalism	MC4	Management by owners or site managers.
Lack of regulations preventing the demolition or complete reconstruction	All types	Total loss of heritage values might be expected	MC4	Management by policy makers.
Incompatibility of standards and regulations resulting from building codes	All types	Inadequate interventions	MC4	Management by policy makers.
Lack of any risk mitigating measure	All types	High sensitivity to hazards	MC5	Management by owners or site managers.

Lack of emergency plans.	All types	Impossible to rescue artifacts or to preventively protect the site in case of emergency	MC5	Management by owners or site managers.
Lack of integrated tools for decision support.	All types	Poor decision making	MC5	Management by owners or site managers.
Lack of monitoring and risk evaluation methodology.	All types	Poor decision making	MC5	Management by owners or site managers.
Lack of inspection and maintenance schemes.	All types	Worsening structural heatlh conditions and possible significant damage in the long term	MC5	Management by owners or site managers.
Lack of participation in the decision making.	All types	Poor decision making	MC5	Management by owners or site managers.
Lack of a renewal plan.	All types	Poor decision making	MC5	Management by owners or site managers.
Lack of annual management plan, aimed at its reorganization and requalification.	All types	Poor decision making	MC5	Management by owners or site managers.

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7. Annex - examples of selected events & damage

Flash flood in the pilot site of Prague Troja – August 14, 2020. Water flow transported sand, gravel and stones in the neighbourhood under the hill, the traffic was blocked due to high water.

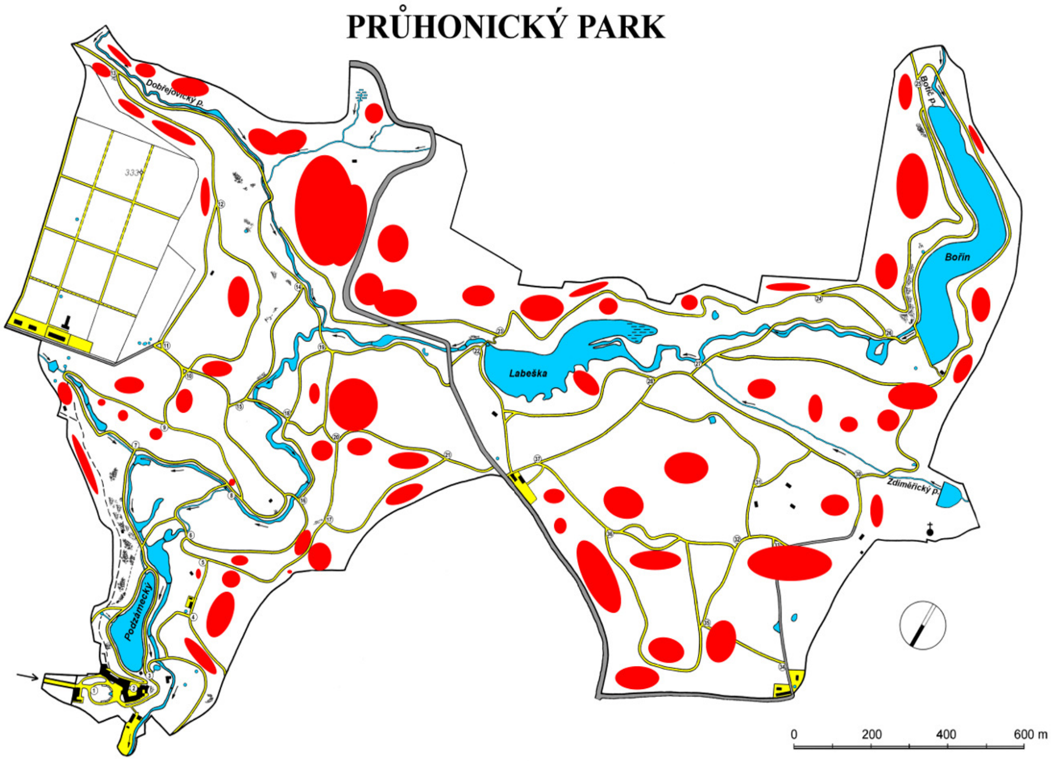
Kroměříž - Archbishop´s Château - UNESCO World Heritage protected garden monument. River flood in 1997 with the high water depth of about 210 cm in the duration of three weeks. Damage on the herbs and flower beds composition, loss of 105 trees – immediately fallen down or gradually deteriorated during the following years, loss of the bushes in the area of 2200 m^2. Structural elements (banks of water channels or ponds, paths) were seriously damaged. The effects manifested for another 20 years (fungi diseases, damage on root systems).

Kroměříž - Archbishop´s Château - UNESCO World Heritage protected garden monument. Long term heavy rain period in May 2019 initiated a localised gradually developed landslide on an artificial and steep so called “rabbit´s hill” which had insufficiently developed plant cover on the insolated slope – synergic effects of overheating and drying. The damage repair and recovery consumed 5 years.

Chateau Slatiňany – protected National garden heritage (altitude of 268 m. above the sea level). Damaged by summer windstorm in 2018 (with previous windstorms Herwart (2017) and Fabienne (2018)). Loss of 30 trees, many trees had broken branches. Falling trees damaged small architecture in the garden.

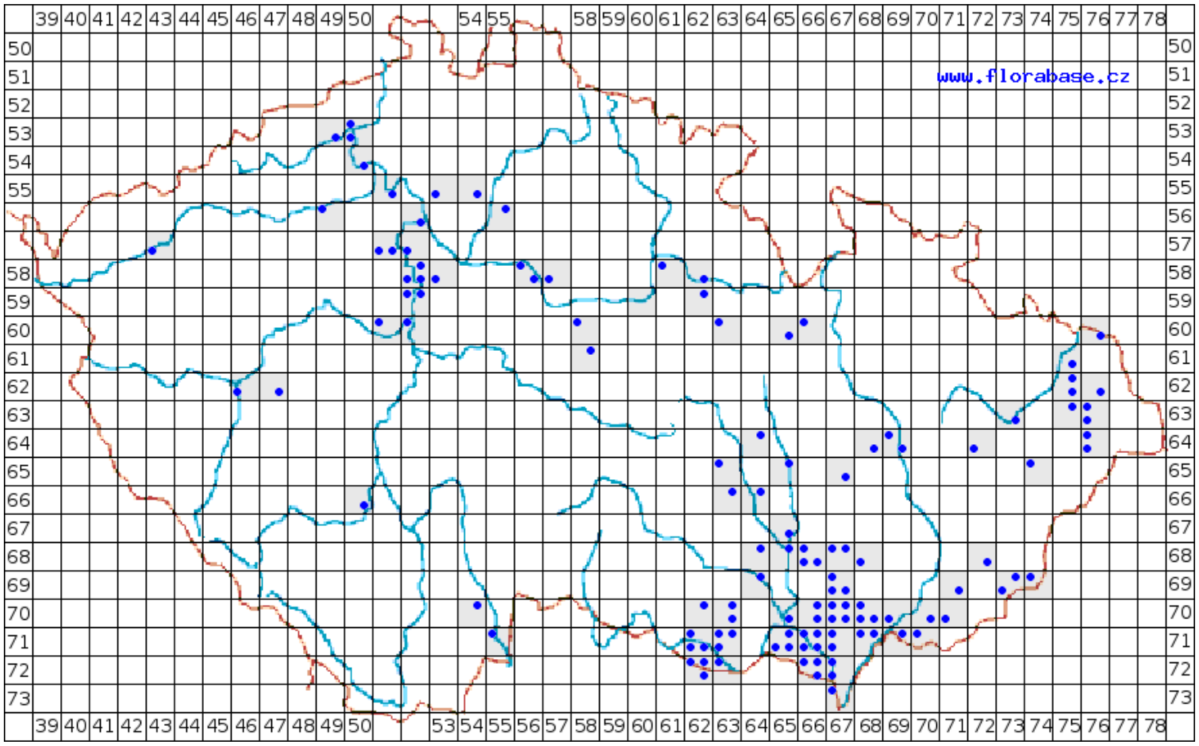
UNESCO protected World Heritage Lednice-Valtice Cultural Landscape. Lightning effect on an old oak tree (*Quercus robur*). Old oak, pine and spruce trees are more susceptible than trees which exhibit faster wetting of their bark, e.g. beach, maple, hornbeam trees.

UNESCO listed World Heritage and the protected national garden art heritage Château Průhonice in Prague. The park has been massively attacked by the bark beetle during the last three years. About 5000 trees had to be felled. The figure shows the extent of damage in the park.



Chateau Kravsko – protected garden cultural heritage. Box trees destroyed by the *Cydalima perspectalis* in synergy with climate effects (long term dry periods).

Example of the extent of an invasive species of the tree of heaven (*Ailanthus altissima*) in the Czech Republic.



Two monumental specimens of oak (Quercus pubescens) inside the Villa Ghigi Park in Bologna (STRENCH pilot site), subject to a progressive decline that led to their drying up. In the first case (upper picture) the plant dried up within a year without showing preliminary signs of deterioration and was cut down; in the second case (lower picture), the decay phase of the plant lasted for about ten years but, despite the analyses and treatments undertaken, the oak dried up in 2018. The main pathogens identified during the investigations and likely responsible of the decline of the two plants are: *Coniothryrium sp.* (fungi) and *Anisandrus dispar* (insect *Scolityd*).

The small beech wood (*Fagus sylvatica*) in the Villa Ghigi park in Bologna, was planted in the late nineteenth century. In recent times, its conditions are very critical: several trees have dried up and crashed to the ground. The beech, a mesophilic species that grows in the mountain range of the Apennines, no longer finds the environmental conditions suitable for its growth at the lowest altitudes near the plain. The main pathogens identified during the investigations and likely responsible of the decline of the plants are: *Kretzschmaria deusta* (fungi) and *Bionectria ochroleuca* (plant pathogen).

Two majestic exotic trees planted at the end of the nineteenth century in the Villa Ghigi park in Bologna that have reached senescence and have extensive drying of the foliage: a specimen of *Calocedrus decurrens* on the left, and one of *Thuja plicata* on the right.

The typical damage caused by wild boars (*Sus scrofa*) in the meadows adjacent to the buildings of Villa Ghigi Park (upper pictures) and Villa Aldini Park (lower picture) in the town of Bologna. The turf is explored and broken by animals in search of bulbs and tubers they feed on.

The more and more frequent and intense rains concentrated in a short time cause significant damage in the network of paths and in the regulation of surface water in parks and gardens. Some examples in the Park of Villa Ghigi in Bologna: one of the secondary entrances (upper picture) and two sections of the path network (lower pictures).

Two examples of snowfall in the Villa Ghigi park in Bologna with different effects on the vegetation cover, in relation to the period of the event. In the upper picture, the plentiful snowfall of February 2012, in the heart of winter, which caused limited damage. In the lower picture, the weak “off-season” snowfall in mid-November 2017 which instead heavily damaged many deciduous plants with nipping and crashing of trees.

Ruins in redeveloped hamlets – loss of functional, landscape and historic context may cause gradual loss of CH due to a lack of management and vandalism. Examples of fortified structures' ruins in the Province of Novara (Italy).

The relationship between defensive buildings (or what remains of them) and their territory is at present exposed to the risk of being lost. The anthropic transformation of the territory, often a consequence of uncontrolled speculative plans, led to the desertion of large parts of it. Almost unrecognizable ruins of fortresses located in deserted areas with abandoned historical tracks, covered by spontaneous vegetation, are at risk of collapse. Traces of a defensive system documenting the ancient organization of territory will be definitely lost without systematic plans to secure them and to renovate the surrounding net.

The fortified structures identified and selected on the territory of the province of Novara for the pilot project are: Castles of Arona, Biandrate and Lesa; the Ricetto of Casalvolone and Recetto; Tower and ruins of the Castles of Gozzano and Prato Sesia; City-wall and urban doors in Oleggio; the Castrum Domini in Pombia.

These are historical heritage that have lost their original function but that, unlike some cases that are integrated into the surrounding housing or simply have been transformed by acquiring new functions, can now be ascribed to the category of the ruins, given the complete state of abandonment.

Sordinesca Tower (ruins) in Rocca Borromea Park, Arona (NO) - Source: Bartolozzi, C. and Novelli, F., Resti e ruderi di strutture fortificate in provincia di Novara: studi per una strategia di conservazione e valorizzazione, p. 115.

Castle of Lesa (NO), fortified wall - source: Bartolozzi, C. and Novelli, F., Resti e ruderi di strutture fortificate in provincia di Novara: studi per una strategia di conservazione e valorizzazione, p. 115.

Ruins in abandoned hamlets. As an example the Ekenštajn castle is presented. The ruins lay on the top of the narrow hill, in ca 300 m distance above the Šalek castle ruins, above the Velenje town in Slovenija. The castle has most probably developed gradually as a military fort from the middle of the 13th century on. It was abandoned in in the 17th century and the seat of the estate was transferred to the former agricultural center of the estate (on the hill below the old castle), converting it into in the Gorica mansion, still preserved. In the middle of the 19th century, the castle ruins were considered an important landscape-mark: some portions of the ruins were even faked in wooden planks «because of the romantic beauty». After the World War, the ruins were deliberately demolished for a longer period by the prisoners of war, led by a commander, riding the white horse. The stone was used as a building material, as after the war it was very difficult to obtain any material at all. In the 2nd half of the 20th century the ruins were completely covered with forest, which erased them from the landscape. No potential of the place is exploited, the ruins are unprotected and endangered, because of the intentional destabilization of large portions of walls (vandalism) visiting the site is potentially dangerous. The access is sloppy, the paths are slippery, no fences are installed. It is clearly a degraded cultural area.

Ekenštajn castle ruins – source: http://kraji.eu/slovenija/grad_ekenstajn/slo

Inappropriate intervention for commercial exploitation may cause an unacceptable degradation of CH values. The castle in Bobolice located in southern Poland in the province of Silesia is such an example. In the years 1998-2011, the legally protected ruins of the castle, were rebuilt by a private owner and intended for the hotel. Before the “reconstruction”, archaeological and security works were carried out. Apart from the nineteenth-century images of the castle in ruins, there were no messages, plans or sketches of the castle. The castle was built on the basis of preserved ruins and a project developed by architects in cooperation with historians and archaeologists. The rebuilt castle was to correspond to the form of a castle from the 16th century. As a result, the object was completely transformed into a full cubature form and the historical value of the ruin was lost. “Reconstruction” was criticized by the conservation community. The object is still listed as a historical ruin in the register of monuments.

Bobolice Castle, historical ruin before refurbishment.

Source: httpsupload.wikimedia.orgwikipediacommonsffaBobolice%28js%29_1.jpg

Castle in Bobolice after refurbishment ("reconstruction").

Source:
https://pl.wikipedia.org/wiki/Zamek_w_Bobolicach#/media/File:20140619_Zamek_Bobolice_3877.jpg

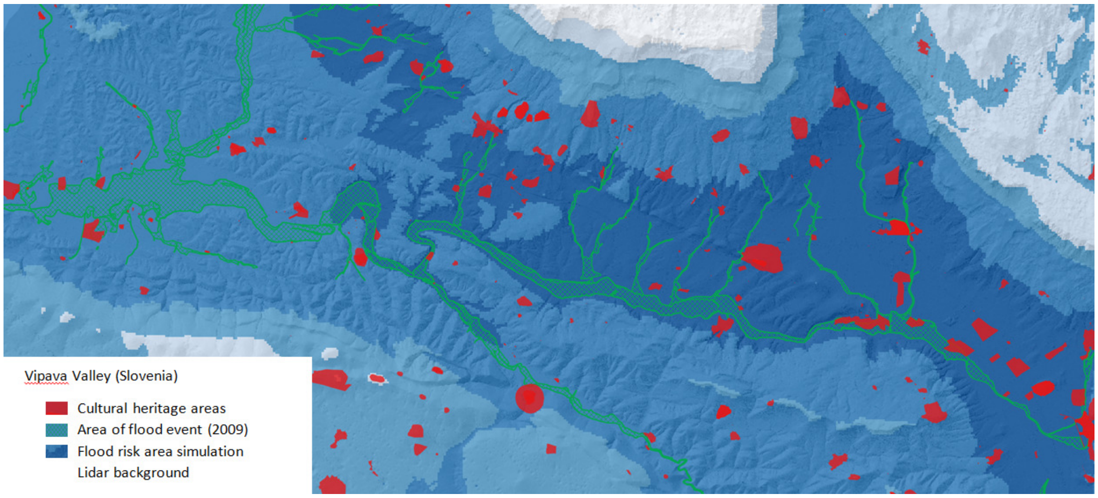
Balaton, HU. An eroded high cliff made of loess near Fonyód. The slow landslide between 2015–2017 was a danger (among others) to the lookout tower beyond the cliff (a cultural heritage site).

Balaton, HU. Reed fire at Balatonboglár (2017), on a Natura 2000 nature protection area (2017).

Balaton, HU. Reed fire in the so called "Little Balaton" area, on a Natura 2000 nature protection area (2020).

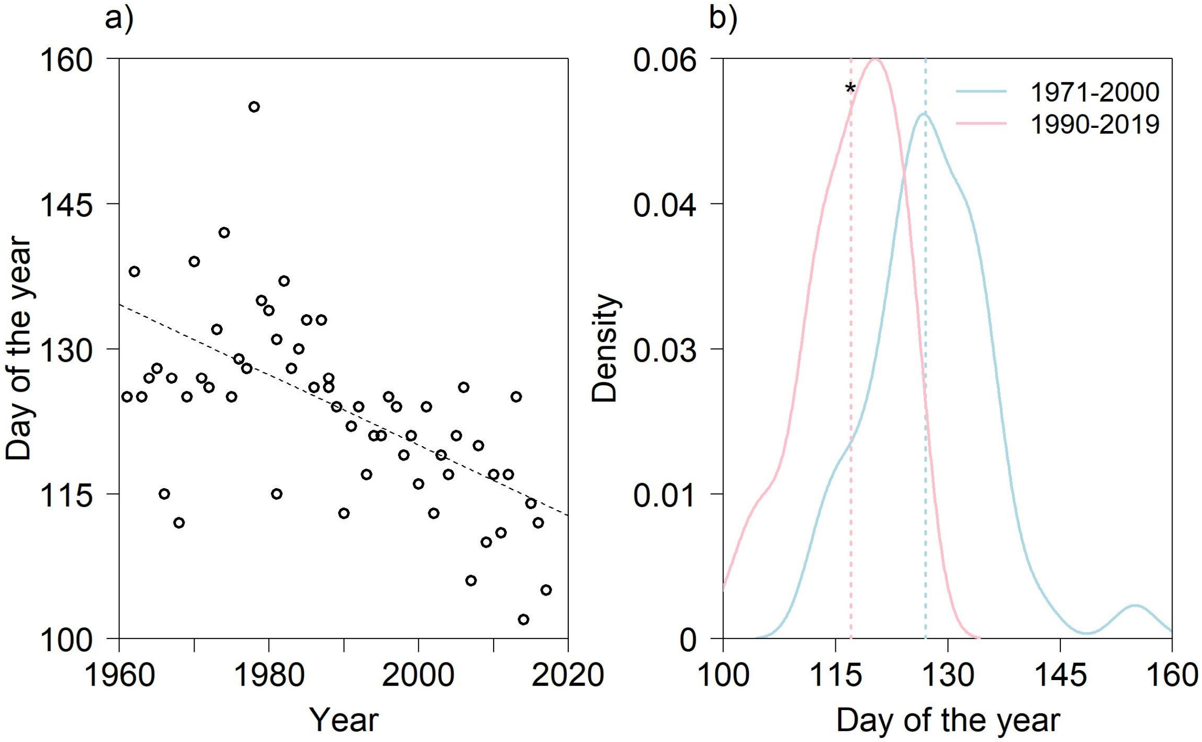
Vipava valley, SLO. Flash flood

Vipava valley, SLO. Flash flood.



Vipava valley, SLO. Flash flood.

Late frost events diminished the harvest of cherries by about 60% to 80% in 2020. Meadow orchards and fruit tree plantations are part of the cultural landscape of the District of Forchheim.



Data source: Deutscher Wetterdienst

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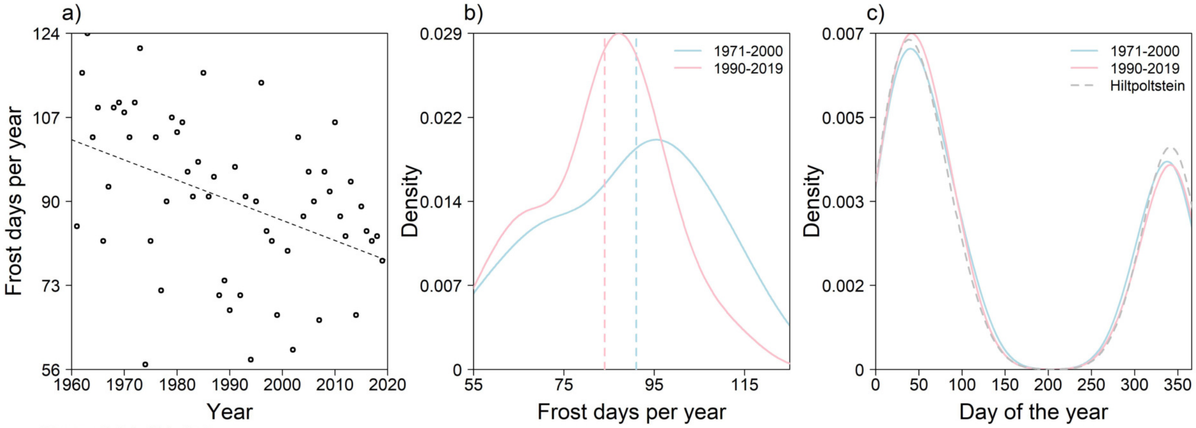
Graph indicating earlier beginning of flowering of apple trees in the District of Forchheim.



Data source: Deutscher Wetterdienst

Graph showing that frost events tend to become less frequent but frost events not occurring earlier.