

WSL MAGAZINE

DIAGONAL

FOCUS

No sticking to the mean: Why we research extremes

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Dear reader

Our director Koni Steffen died in August in an accident while doing research in Greenland. This tragic loss has deeply affected all of us.

Shortly after Koni's death, a scientific paper with him as co-author was published entitled "Methods for predicting the likelihood of safe fieldwork conditions in harsh environments". About Greenland It says: "In this region extreme weather can even lead to loss of life." Yes, researching extreme events and extreme environments is associated with risks. Our researchers are aware of this, and we have safety and security plans to try to keep the risks as low as possible. But unfortunately there is no such thing as absolute safety.

Nevertheless, or perhaps precisely because of this, our research on extremes is important because it helps us to understand extreme events and thus to control them better. That is why we will continue to work on these topics. For example, we have launched an 'Extreme' research program, and founded, as of 2021, a centre for research for climate change, extreme events and natural hazards at our site in Davos.



Christoph Hegg
Acting Director of WSL



Extremes



LIVING WITH THE THREAT

Devastating landslides also occur in Switzerland. Thanks to research, monitoring and warning systems, people today are better protected. But there is still a residual risk.

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THINKING THE UNTHINKABLE

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Obituary: Prof. Konrad Steffen, Director of WSL

2 January 1952 to 8 August 2020



Photo: Reinhard Lässig, WSL

Koni, as his friends called him, was a citizen of the world: he felt at home with his family in his farmhouse in Hausen am Albis as well as on glaciers in Chile, in 'his' Swiss Camp in Greenland and in Antarctica. Snow and ice had been the interrelated themes at the centre of his research ever since his diploma thesis in Zurich, and afterwards in the USA, where he was a professor at the University of Colorado from 1991 to 2012.


In 2012, the Federal Council appointed Konrad Steffen Director of WSL. His ability to inspire people and his vast network enabled him to develop WSL further as an internationally recognised research institution. He strengthened the interfaces between 'forest', 'biodiversity', 'landscape', 'snow and ice' and 'natural hazards'. His focus was on understanding systems, especially with regard to the impact of human overuse of the natural environment as well as climate change.

Working in extreme environments shaped Koni. With his great charisma, he was very motivating and optimistic. His solutions were always pragmatic and guided by his deep humanity. This made him a respected director of research institutions and a convincing scientific expert at hearings in the US Congress and in international organisations. As camp leader in Greenland he was inspiring. But above all, Koni Steffen was a generous colleague, who never lost sight of the bigger picture in science and research, to which he remained committed.

In the summers of recent years, the surroundings of the Swiss Camp in Greenland have been transformed into a plain full of lakes where the melting ice forms torrential streams that plunge down into so-called 'moulins' and disappear into the depths of the ice sheet. While Konrad Steffen kept his guests fortified with espresso and chocolate in the camp, he would explain the scientific facts of climate change. Anyone who spent a few hours with him on the raised platform of the Swiss camp, understood, when they came away, what the melting taking place all around meant for Greenland and the whole world. Each visitor thus became an ambassador for protecting the climate.

Koni never returned from his last visit to this melting and disintegrating ice sheet. We mourn him as an outstanding researcher, an international ambassador for science, a visionary director, a generous colleague and a good friend.

Prof. Thomas Stocker, University of Bern

An aerial photograph of a mountainous region in winter. A village with several buildings is visible in the lower half of the image. A large, dark, and debris-covered path, likely an avalanche runout, descends from the upper center towards the village. The surrounding slopes are covered in snow, with some exposed rock or snow-free areas visible.

EXTREMES Extreme events are rare, but can have serious consequences for humans. Two WSL researchers discuss what ‘extreme’ actually means and why it is important to think the unthinkable.

Beyond our realm of experience

In the winter of 1999, extremely large avalanches occurred in many places in the Alps, causing considerable destruction and many fatalities. The avalanche in Galtür, Austria on 23.2.1999 killed 31 people.



Catastrophic avalanche events – tragic as they are – have ultimately led to greater safety. Thus, after 1999, the integrated avalanche protection system, i.e. the combination of structural with planning and organisational measures, was improved and expanded. SLF was involved in developing it further.

Galtür (A).

Photo: Stefan Margreth, SLF; text: cho

Extreme natural events occur regularly in Switzerland. Examples include the flood in 2005, where the cost of the resulting damage was around three thousand million Swiss francs, and the landslide on Pizzo Cengalo 2017, in which eight hikers died and debris flows destroyed parts of the village of Bondo (see also p. 10). The extremely dry summer of 2018, when trees' foliage became prematurely discoloured, is another example.

What do we consider to be an extreme event?

B: "Something is extreme when it is outside our own realm of experience. For example, a half-marathon is extreme for non-athletes, and a two-hundred-kilometre mountain run for an athlete. Even how natural events are perceived is subjective. If an affected person is faced with ruin because of a minor event, it is more extreme for them than if they have insurance to cover losses arising from a major disaster."

P: "What consequences the event has for people is very important. In economic terms, earthquakes and hurricanes are the worst because they affect large areas. Events in rich countries may destroy a lot of valuable infrastructure and thus also have great economic impact there."

And from a scientific perspective?

P: "Extremes are extraordinary. They are points on a curve – or events – that deviate greatly from the average."

B: "It also depends on the context. Something that is locally extreme is often normal on a larger scale."

For example, a torrent that fills cellars with mud is extreme for the local inhabitants because, on average, it only overflows its banks once every hundred years. However, since there are about two thousand torrents in Switzerland, when viewed on a national scale, such a once-in-a-century flood is statistically not unusual and occurs about twenty times a year. This statistical frequency is a key consideration in dealing with extreme events, especially when it comes to investing in protection measures. It helps in planning maximum additional protection for every franc spent. After all, if something happens somewhere, the spontaneous reaction is to introduce measures precisely there, which is not necessarily very efficient.

To estimate the extent of a once-in-a-century flood or once-every-three-hundred-year avalanche, however, good data and modelling are needed, i.e. computer models calibrated with past events. However, the more the events to be simulated go beyond what has been observed so far, the greater the uncertainty in the results. Some types of events can also cause the system to collapse, but this is difficult to predict with models. Metaphorically speaking, the light is then switched off instead of being dimmed further. What is often nevertheless unknown is where this point lies and what happens afterwards. For example, a single dry summer may lead to less tree growth. Several dry years in a row, however, may cause the trees to die (see also p. 18).

When experience is lacking

Sometimes WSL researchers also consider extremely rare events, i.e. events that are possible, but very unlikely. For example, major flooding of the Rhine or Aare, which statistically occurs only once in ten thousand years, could cause immense damage. Several nuclear power plants are located along these rivers. To be able to withstand such an event, as required by law, the operators need to know how much water would be threatening.



Michael Bründl is a geographer and head of the research group 'Avalanche Dynamics and Risk Management' and of the WSL research programme CCAMM.

Can you reliably estimate the effects of such an event if no one has ever experienced it?

B: "Yes. We can model the physical processes in the atmosphere and water with computers. This gives us an idea of possible scenarios even though they have never occurred before."

P: "Scenarios are important so that we can prepare ourselves. Thinking the previously unthought and unthinkable is the first step towards coping with such events."



Marco Pütz is an economic geographer and head of the 'Regional Economics and Development' research group at WSL.

Does it take a sudden event to speak of extremes?

P: "No, even a creeping process can assume a previously unknown dimension outside our realm of experience. For example, the loss of species diversity or the urban sprawl in the Central Plateau, which have both never been more pronounced than today, are also extreme."

B: "In many cases there is, I think, a connection with the weather. While the individual events need not be so extraordinary, an unfortunate combination is sometimes enough to cause extreme damage."

P: "Or when human action comes into play, such as in the Leuk forest fire in Canton Valais in 2003, which was started by an arsonist. In this case,




Extreme for those affected: heavy rainfall on 29 August 2020 triggered a debris flow, with mud and debris damaging houses.

the combination of a hot summer and human action was fatal. A whole hillside was devastated.”

B: “Our perceptions of what constitutes an extreme event are changing. Climate change means, for example, that long periods of drought and more intense heavy rainfall will become more frequent. What we still perceive as extreme in terms of weather and climate today may be normal in a few decades’ time.”


Research into today’s extremes therefore helps to find suitable ways of dealing with what in future may be normal. This is undoubtedly an important reason for science to consider such extraordinary events outside our realm of experience.

(bio)



As a rule, the stem circumference of a chestnut tree gives only a very imprecise indication of its age. For example, a tree with a stem eight metres in circumference could be anywhere between 300 and 700 years old.

This chestnut tree has an impressive circumference: 8.62 metres! It is one of the over 310 trees listed in the inventory of giant chestnut trees that the WSL geographer Patrik Krebs has compiled for Canton Ticino and the Misox valley (Canton Grisons). The inventory contains detailed descriptions and photos of all free-standing trees with a circumference of more than seven metres at breast height.



Each tree has its own story to tell. Until well into the 19th century, the locals collected chestnuts in autumn to use as a staple food in winter. WSL hopes the chestnut tree inventory will help to attract the interest of the local authorities and the general public in these giant trees and thus promote their protection.

A sweet chestnut in Lostallo (Canton Ticino).

When the mountainside thunders down to the valley. Devastating landslides also occur in Switzerland. Thanks to research, monitoring and warning systems, people are better protected today, although a residual risk still remains.

Living with such a threat is part of everyday life for the inhabitants of Brienz/Brinzauls (Canton Grisons). Their village is built on a geological slip zone that moves downslope by over a metre every year. Houses develop cracks, streets become impassable, and holes open up in pastures. Moreover, above the village up to 22 million cubic metres of rock are in motion on the mountain. Again and again heavy boulders weighing many tons crash down the slope and roll onto the cantonal road. Until now, the damage has been slight, thanks in part to a warning system that automatically closes the road in case of danger. For some years, however, the slope movements have been accelerating, and in some places they are now as much as four to six metres a year.

Where rock is in motion, huge landslides can occur, changing whole landscapes. The most devastating landslide in Switzerland in recent times occurred in Goldau (Canton Schwyz) in 1806. Up to 40 million cubic metres of rock slid down from Rossberg, burying several villages and triggering a tidal wave in Lake Lauerz. 457 people died. One reason there were so many deaths is that only a few of the inhabitants had tried to find shelter. People had known for a long time that the mountain was unstable. On the day of the catastrophe, boulders kept coming down, there were crashing sounds in the forest and clouds



The landslide on Pizzo Cengalo on 23 August 2017 and the subsequent debris flows led to huge deposits of rock debris accumulating in Val Bondasca.

of dust formed. But such signs were apparently all too familiar. Hardly anyone thought that a catastrophe was about to happen.

Today things are different: well-known landslide sites like the one in Brienz are under permanent observation. The canton and the municipality have commissioned engineering firms to continuously monitor slope movements using laser scans, GPS and radar measurements. Should these movements accelerate critically, an alarm can be triggered and the village evacuated. “Precursors of a large rockfall event are usually noticeable over a period of several weeks,” says Andrin Caviezel, who researches rockfall processes at the WSL Institute for Snow and Avalanche Research SLF. He passes Brienz every day on his way to work: “What is happening there is frightening, but from a scientific perspective it is also fascinating.”

Data helps to calculate extreme events

He and other SLF researchers are carrying out measurements in Brienz and using data, for example from laser scans, for different types of analysis. For instance, temporal comparisons help them to visualize deformations in the slope. They are also investigating how much water is produced during snowmelt, as water strongly influences slope movements. The analyses help them understand the processes taking place on the mountain better and improve the geological model. The researchers are also collecting data for the RAMMS (Rapid Mass Movement) simulation programme, which can be used to calculate various scenarios for an imminent landslide. The data they collect helps to improve the programme and enables quicker and more accurate estimates of future extreme events.

SLF researchers also used such simulations after the landslide on Pizzo Cengalo, where three million cubic metres of rock broke off in August 2017.

For up-to-date info on the Brienz landslide, see: <https://bit.ly/brienzerrutsch> (German)



Sliding slope above Brienz. The SLF researcher Yves Bühler prepares a drone to take aerial photographs.

Photo: Andrin Caviezel, SLF

Eight hikers died in the Bondasca Valley. The landslide triggered a debris flow. Mud and debris flooded the village of Bondo, which, thanks to a warning system, was evacuated in time. It is not entirely clear how the debris flow started. One possible explanation is that the falling rock masses pressed water out of an older rock avalanche deposit, creating a mudflow that swept down to Bondo.

What would happen if ...?

Such an event could be repeated: one to two million cubic metres of rock are still in motion on Pizzo Cengalo. Although the volume of rock is smaller than that which failed in 2017, what would happen if the rock fell not in summer but in winter? Would the snow-melt water trigger an even more devastating debris flow? Might the debris even dam the Mera River and form a lake, which could flood the town of Chiavenna downstream if the dam failed? “It is important to think through such ‘worst case’ scenarios,” says SLF’s director, Jürg Schweizer, who was part of a group of experts commissioned by the canton to analyse the events and the impact of potential developments following the landslide in August 2017.

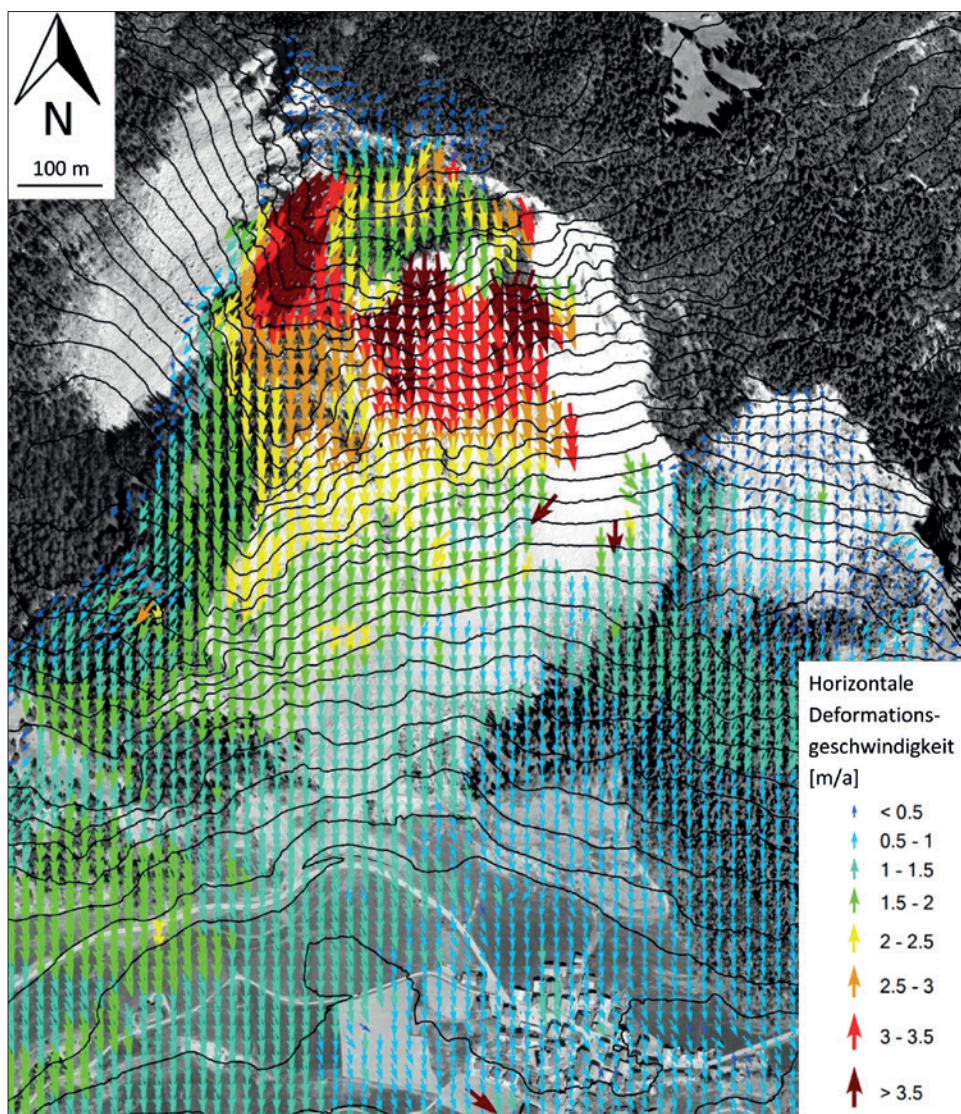
To assess such consequences, the RAMMS group first developed a new module in the RAMMS simulation programme. It can be used to model interconnected events – in this case the combination of a landslide, avalanche and debris flow. They used it to calculate scenarios for a landslide in winter by varying, among other things, the volume of rock that fails, the temperature and the water content of the snow cover.

The results indicate that it is unlikely, even in winter, that a mixture of snow, rock and water could reach Bondo or the river Mera since the volume of rock would probably be smaller. The only way this could happen would be if heavy rainfall in spring further wetted the snow cover. The Alpine summer hamlets (*Maiensässe*) of Lumbardui and Lera above the village in the Bondasca Valley are, on the other hand, at great risk. Based on the simulation results, the canton has assigned the Maiensässe to a red danger zone. In addition, radar is now being used to continuously monitor Pizzo Cengalo until new protective structures in Bondo have been built.

As a result of climate change, interconnected events such as the landslide and the subsequent debris flows in Bondo could, in future, occur more frequently. This is because extreme precipitation is increasing, melting glaciers are forming new lakes, and mountainsides are becoming unstable due to glaciers melting and permafrost thawing. In the interdisciplinary WSL research programme CCAMM (Climate Change Impacts on Alpine Mass Movements), scientists are currently investigating how natural hazards in the Alps are changing. The programme should provide a basis for developing new protection strategies, and will be the focus of the new research centre that WSL and the Canton of Grisons are founding with the support of ETH Zurich.

Meanwhile, the authorities in Brienz continue to monitor the situation closely. After intense rainfall, the slope movements may accelerate, as in June 2020, when once again, several boulders rolled down close to the cantonal road. This will continue to be an everyday occurrence in future. According to the engineering firms’ calculations, rockfalls of up to 100,000 cubic metres –

For more information on the Cengalo landslide, see the Forum für Wissen 2019 contribution (only in German): www.wsl.ch/cengalo



For more information about the CCAMM research programme, see: ccamm.slf.ch

So-called vector fields can be calculated from airborne laser scans of Brienz's sliding slopes. The arrows show the direction and speed of the slope movements (annual average displacements recorded in the scans between 15 June 2018 and 6 December 2019).

equivalent to the size of about 100 houses – will become very probable, but it is unlikely that the entire 22 million cubic metres of rock in motion above Brienz will break off in one fell swoop. Drillings are currently being carried out on the mountain to determine the geological stratification and hydrology more precisely. This should help to further narrow down potential landslide scenarios. Although absolute certainty is not possible, such measurements and calculations will help to provide the best possible protection for the local population.

(cho)



The German Tamarisk (*Myricaria germanica*, in front) can survive even when covered by metres of sand and gravel.

Photo: Sabine Fink, WSL

HABITATS **Uncomfortable places to live preferred.** Whether buried in gravel, frozen to the core, or constantly windblown, some living organisms can colonise the most extreme habitats. How do they cope – and why is this interesting for research?

Sabine Fink keeps an eye out for her study objects while standing in fishing boots by the Moesa river, which is gushing noisily through the Misox Valley in the Grisons. She checks her location on a map. She puts on a life jacket, stomps into the water and starts searching along the riverbank. “The current is okay until the water is knee-deep. Then it gets tricky.” On the map, a blue triangle marks the spot where a German Tamarisk (*Myricaria germanica*) used to grow.

But during the flood of the century in October 2019, the Moesa’s riverbed shifted, sweeping the plant along with it. “The water used to be shallow here, but now it has become the main channel,” says Sabine. The German Tamarisk is typically found on gravel banks, which are characteristic features of ‘untamed’ rivers. “Since the construction of watercourses, gravel banks have become rare, and the German Tamarisk has disappeared in many places – especially on the Swiss Central Plateau.”

In the ‘Hydraulic Engineering and Ecology’ research programme, the biologist is investigating, together with hydraulic engineers from ETH Zurich and fish specialists from EAWAG, how sediment transport and water discharge function; how hydropower production affects them and what river revitalization measures can achieve. Their findings help to indicate how well the Moesa is functioning as a habitat. Sabine measures the location and size of the tamarisk and collects a few leaf samples for genetic analysis. “Their genetic diversity and the information we collect on the habitat show how suitable the site is for the survival of the German Tamarisk.”

Where life becomes too hard for others

Those animals, plants and fungi that can cope with extreme conditions usually pursue two of three ecological strategies. Pioneer species are quickly on the scene in the new spaces created through floods, avalanches or fires. There they grow and multiply rapidly before other species can gain a foothold. In contrast, stress-tolerant organisms do not rely on speed, but on longevity and toughness. The species associated with each strategy can endure very adverse conditions in which others cannot survive: icy cold, drought or lack of nutrients. What they also have in common is that, in less extreme locations, they are both at a disadvantage against species that pursue the third survival strategy, namely competing strongly for space, light and nutrients.

Pioneers often create conditions that make other life possible. WSL microbiologist Beat Frey is studying microorganisms that thrive on the debris of melting glaciers and even in the ice itself. There they defy extreme UV radiation and temperature fluctuations of up to 40 degrees. At the foot of the Damma Gla-

cier in Canton Uri, WSL researchers have recorded no fewer than 1000 species of bacteria and 200 species of fungi. “They turn apparently dead stone desert into soil,” says Beat.

Stress-tolerant species, in contrast, colonise extreme locations and persist in these habitats in the long-term. In 2011, botanists found a flowering purple mountain saxifrage (*Saxifraga oppositifolia*) on the Dom mountain (4545 m above sea level), whose age they estimated at 30 years. “For specialised species, the conditions may not be so inhospitable,” says Christian Rixen from the SLF Group ‘Mountain Ecosystems’, who researches flora on mountain summits. Snow acts like a protective blanket in winter. The cushion or rosette growth of the plants stores warmth close to the roots. While the saxifrage can survive being frozen through completely at night, several other plant species store anti-freeze.

The survival artists are interesting for research for several reasons. For example, the influence of climate change is particularly evident at extreme locations. “In the high mountains changes in vegetation are mostly due to climate change,” says Christian. At extreme locations, moreover, the number of species threatened with extinction is often above average. With global warming, summit dwellers, for example, are being displaced by competitors from lower altitudes. Very nutrient-poor habitats such as bogs and their highly adapted inhabitants have also become rare.

The German Tamarisk is typical of gravel bank and floodplain landscapes, which have become rare in Switzerland, but which other threatened species also depend on. It is a true pioneer, but it also shows signs of stress tolerance. The seedlings survive on recently exposed and dried out gravel banks where other young plants have already died. The adult plant tolerates ‘wet feet’ and can even sprout again if buried up to one metre deep. New shoots sprout directly from buried plant parts. The long network of roots not only anchors the plant itself, but also the river banks. In France, tamarisks are planted on artificial embankments to stabilise them.

Moving boundaries

Which conditions are extreme depends on the life form. For a tall-growing plant, such as a tree, the timberline at an altitude of 1800 to 2000 metres is where it becomes critical. “Its upright growth makes it difficult for it to make optimal use of the soil heat and exposes it to wind and snow,” says Peter Bebi, head of the SLF Group ‘Mountain Ecosystems’. Trees need a growing period of at least three months with a mean temperature of about 6 °C. Single trees can survive in sheltered places at altitudes of up to 3000 metres, but are usually very old and small.

“As a result of climate change, we expect the timberline to shift upwards in many areas and northwards in the Arctic,” says Peter. A higher timberline also has repercussions for the climate, in particular because forests radiate less heat back into space than snow. Biodiversity could also change since plants above the timberline receive, for example, much more light but have to withstand greater temperature extremes. Moreover, animals find less cover there. That is why Peter and his team are researching the factors that influence tree growth at high altitudes.



Sabine Fink demonstrates a survival strategy of willows on sandy and gravel banks: extremely long roots, which have here been exposed by erosion.

Extreme habitats are not only fascinating. They also deserve special attention and protection. The research into how well the inconspicuous German Tamarisk can spread along the Moesa provides some indications of this threatened shrub's prospective future. But it also shows how near-natural – or not – the entire river system is. This is why WSL researchers will continue to explore wild waters like the Moesa in fishing boots and life jackets. *(bki)*

DROUGHT **Forest under stress.** How does a summer without rain affect the forest? Since the 2018 drought, a WSL research initiative has been addressing such questions – and considering the future of the European beech on the Central Plateau.

Information platform
for early detection of
drought in Switzerland:
drought.ch

The summer of 2018 will be remembered for being very hot. There was very little rain, riverbeds dried out, and fires outdoors were banned. The cities experienced several tropical nights in a row when temperatures did not drop below 20° C at night. “Already at the beginning of July 2018 we could see that, based on the forecasts, a prolonged drought was likely,” says the hydrologist Manfred Stähli, head of the Research Unit ‘Mountain Hydrology and Mass Movements’. The data indicating this came from the Information Platform drought.ch, which the WSL operates and manages together with other partners. The platform shows how dry it currently is and whether droughts can be expected on the basis of several parameters, such as precipitation, lake runoff, soil moisture and water stored in the snow.

The beginning of July was also when the leaves of the first trees in the Schaffhausen region began to change colour. A group of researchers therefore seized the opportunity and launched the WSL research initiative ‘Drought 2018’ in August. “We wanted to find out as much as possible about how this extreme drought directly affects the forest, whether it can recover or whether lasting



In 2019, the beech forests in the Ajoie (Canton Jura) still showed signs of the damage caused by the drought in the previous year.

Photo: Valentin Queloz, WSL



Too little water: The water level of Lac de Joux (Canton Jura) reached a low point in October 2018.

damage will occur,” says Andi Rigling, head of the Research Unit ‘Forest Dynamics’ and joint head of the research initiative.

Early end of season for some beech trees

Switzerland has experienced longer periods of drought on several occasions, for example in the 1920s and 1940s, and most recently in 2003 and 2015. What was new this time, however, was that, in addition to conifers, broadleaf trees across large areas also showed signs of drought stress, especially beech trees. Until now, this tree species was considered to be quite robust, and in the previous hot summers only a few trees in Switzerland developed discoloured leaves so early.

However, in 2018, entire groups of beech trees shed their leaves up to three months too early, first in north-eastern parts of Switzerland and later in north-western parts up to the Jura. “This ‘early autumn’ helped the trees to protect themselves so they did not lose too much water through evaporation,” explains Andi. This meant, however, the trees were then no longer able to carry out photosynthesis and stopped growing early.

The situation was no better for spruce and silver fir. In addition to the actual damage caused by the lack of water, the weakened trees also suffered from a very high bark-beetle infestation. By the end of 2018, this beetle (*Ips typographus*) had infested twice as much spruce wood as in the previous year, and thousands of trees had to be removed from the forests.

Spells of hot dry weather change the forest

In some regions of Switzerland, the summer half of 2018 was the driest since measurements first began. Such an extreme event occurs statistically only every forty to fifty years. This dry period ended with heavy winter precipitation, but signs of the drought were still visible in the forest. About 20 percent of the

For more information on WSL's research initiative 'Drought 2018', see: www.wsl.ch/drought2018

beech trees that had experienced early discolouration of their foliage in 2018 showed signs of subsequent damage one year later, such as cracks on the stem or dead parts of the crown. Nevertheless, only two percent of the trees in the study have died completely since 2018. “Tree death on a large scale can therefore be ruled out,” says Andi. But that could change quickly. “Whether the forest can cope with an extreme event like that in 2018 depends largely on how dry the subsequent years are because the stress the trees suffer from drought accumulates with each event.” They thus become less able to withstand further droughts and more susceptible to disturbances or disease.

Climate change threatens to make the extreme conditions of the summers of 2003, 2015 and most recently 2018 the norm in future. Moreover, the dry years are also likely to become increasingly hotter. “These ‘hotter droughts’, i.e. the very hot dry periods, are what will decide how our forests develop in the future,” says Andi. According to modelling in the ‘Forest and Climate Change’ research programme of WSL and the Federal Office for the Environment, beech trees on Switzerland’s Central Plateau may also find it increasingly difficult to obtain sufficient water. In coming decades, this tree species may thus well come under pressure on the Central Plateau and shift its distribution area to lower and more humid sites as well as towards the Pre-Alps and the Alps (see p. 23). “The summer of 2018 has shown us not only that beech has already reached its limits in some places, but also that our models for the future are probably correct,” says Andi.

The experiences gained in summer 2018 will help WSL researchers to adapt their scenarios for future forest development. Water management must also be geared towards summers that are warmer and drier. The federal government is currently working on a nationwide early warning system for drought, similar to that already in place for forest fires or floods, for example. This should help to identify regional water deficits as early as possible and to adapt water management in the affected catchment areas accordingly. The aim will be to ensure that sufficient water is available for both the local population and agriculture despite the lack of rain, and that the level of the groundwater does not fall too much. This should also indirectly benefit the forest. *(lbo)*

A woman with blonde hair tied back, wearing a teal jacket, stands in a field of tall, dry grass. In the background, a body of water reflects the light, creating a shimmering effect. The woman is smiling slightly and looking towards the camera.

Käthi Liechti, Birmensdorf

“I have always loved coming to Türlensee. It has something to offer in every season – flowers in spring, a cool-down in the water in summer, a stroll in the autumn wind, and if you’re lucky with the weather, you can walk across the ice in winter.”

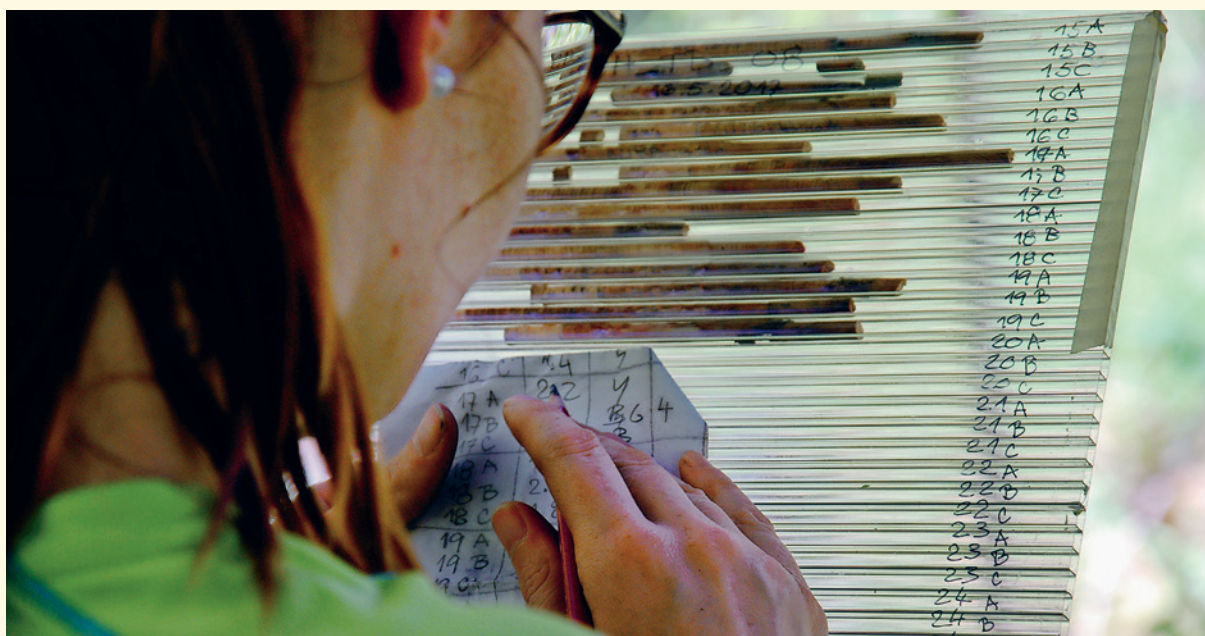
FLOOD-WARNING FOR ZÜRICH

Käthi Liechti works in the Hydrological Forecasts Group. She is jointly responsible for the operation of the Sihl flood forecasting system, which WSL operates for the Canton of Zurich. Since this year, she has also been in charge of the Swiss flood

and landslide damage database, which WSL has maintained since 1972. “I get a break from the office measuring climate gases and carbon fluxes in the forest near Davos at the ICOS measuring station. My work is so varied – I really enjoy it.” (bki)

FOREST Which genes make trees fit for climate change?

Annual rings provide a key



The annual rings visible in the wood cores reveal not only a great deal about past climates, but also, in combination with genetic data, how individual trees react to climate change on the basis of their genetic material.

Every tree is an individual, shaped by its environment and its genes – just like us humans. Trees differ in how they cope with environmental changes and extremes: one spruce survives a dry period better than another, and a European beech recovers more slowly from a late frost than its neighbour. What role do different genes play here? This is what Patrick Fonti and Christian Rellstab are interested in.

Trees document their own life and growth in their annual rings. This is a stroke of luck for the two researchers as Patrick, an expert on annual rings, explains: “If you statistically ‘filter out’ the average influence of the climate from the course of growth, the annual rings still differ from tree to tree. They reveal not only which individuals are able to deal with challenges such as drought or late frost, but also how well they

do so, based on their genetic make-up.” The researchers are studying seven different species with a total of 3577 trees whose annual rings and genome have both been characterised. Christian, a biologist, is now using a great deal of computer power to search for correlations between the growth features in the annual rings and genetic patterns.

Currently their work can be considered basic research. But if Patrick and Christian succeed in finding which genes and gene networks play an important role in how tree species adapt to climate change, this could be relevant for forest management. For example, seeds from trees with suitable genetic material could be used specifically for regeneration. *(bio)*

The data set comes from the EU Horizon2020 project GenTree, www.gentree-h2020.eu

FOREST Trees on the move: Some species do not get to new sites quickly enough

If, for example, the local climate becomes drier due to global warming, some tree species will disappear from their current habitats, while others that are better adapted will thrive there. They may not, however, be already present on site, in which case they will first have to get there. As trees only spread through their seeds, this can take a long time. “The question is whether trees can keep up with climate change,” says the ecologist, Heike Lischke, from WSL.

To find out, she and her team used the computer model ‘TreeMig’ to simulate the migration of various tree species. They used various climate change scenarios, and included information on the trees’ seed dispersal, survivability, growth and how long it took them to develop, as well as competition from other tree species. The result: depending on the species, the annual migration speed is between 10 and 1000 metres. “In some cases this is significantly slower than the climate shift, especially in the boreal zone,” which includes large parts of Scandinavia, North America, Alaska and Russia. According to the simulations, from the end of the century onwards some species will have a migration lag that could last several thousand years.

In Switzerland, the lag should be less pronounced because changes in the climate on the slopes of the Alps occur within shorter distances and the trees do not have to move so far. The species likely to be most affected here are those that mainly distribute their seeds over short distances, such as beech or Swiss stone pine. Other species, such as larch, on the

other hand, should have an easier time because their seeds disperse further and they can thus get to higher altitudes before their slower competitors.

If tree migration lags behind climate change, this may impair forests’ ability to perform certain functions, such as protection. The model can be used to calculate which species, such



In Switzerland today, the downy oak grows mainly in Canton Valais and along the southern foot of the Jura. With global warming, it is likely to spread in the future to new areas.

as the drought-loving downy oak, will probably be too slow and might therefore need support in the form of targeted planting along their migration routes. *(cho)*

www.wsl.ch/treemig

Greater mouse-eared bats like closed forests

Forests with large old trees, a closed canopy, not many shrubs on the ground and open spaces for flying are ideal for the Greater mouse-eared bat, one of the largest bat species in Switzerland. Katja Rauchenstein explored which of these structural elements are crucial for the bats in her master's thesis at WSL. The species is classified as 'vulnerable' on the Red List. At dusk the bats fly from their daytime quarters in residential areas into the forest to hunt.

Such forest structures can be identified with laser measurements from the air and mapped using a computer model. Katja compared this model with her recordings of the bats' flight activities at night in the forests around 18 bat colonies. In the parts of the forests the model classified as presumably 'suitable', the bats were indeed more active than in the 'less suitable' and 'unsuitable' areas'.

"I was surprised that it was not the herb layer that determined how many bats hunt there, but whether the crown cover was closed," says Katja.

These findings can now be used to refine the model and predict which forests the Greater mouse-eared bats hunt in. The forests can then be provided with targeted protection. The model should also make it easier to forecast the flight paths along which the bats enter the forest. For Martin Obrist, the biologist at WSL who supervised the master's thesis, Katja's results therefore help to fill in the puzzle in a larger project aimed at protecting the flight corridors of bats. *(lbo)*

www.wsl.ch/bats



Greater mouse-eared bats like hunting in this beech forest near Beggingen (Canton Schaffhausen).

Photo: Katja Rauchenstein

BIODIVERSITY Competition from below: For the mountain hare, the air at higher altitudes is becoming thin



On the trail of the mountain hare: Maik Rehnus collecting hare droppings hidden in the tall grass.

How do you study an animal that you rarely see and that gets stressed when humans are present? You look at what it leaves behind and use genetic methods to study it. This is possible because faeces, or rather the DNA in them, contain information about the individual that produced them.

Since 2014, WSL researchers have therefore been systematically collecting mountain hare droppings (faeces) from an area in the Swiss National Park to find out more about the habitat and population structure of these shy animals. For her master's thesis at WSL, Laura Schenker evaluated the DNA of the mountain hare droppings that had been collected up to 2018. She was able to show that an average of 6.4 animals occurred per square kilometre, which is almost twice as much as previously estimat-

ed. In springtime, more males came to the study area each year, where they went in search of females. By autumn these males had disappeared again.

Unwanted kinship

What the young researcher also found was that, in 2016, a European hare had left its droppings at 2300 metres above sea level – the first evidence of this related hare species occurring at this altitude in the National Park. “With climate change, the European hare has been able to spread to higher altitudes and thus compete for the habitat of the mountain hare,” says Laura. Although climate change is also pushing the mountain hare upwards, this is reducing its habitat, as the area available at higher altitudes is smaller. But this is not all that is happening: if

male European hares mate with female mountain hares, hybrid animals will be created, which will also be able to reproduce with European hares. “With each generation, the proportion of the mountain hare’s genetic material will thus decrease further.”

The WSL biologists Felix Guggerli and Kurt Bollmann, who supervised the master’s thesis, are therefore continuing the long-term study on the elusive mountain hare in the Na-

tional Park. They also recommend monitoring the species nationally. “The species will be classified as ‘near threatened’ in the revised national Red List. As an Alpine country we have an international responsibility for this species, whose habitat is constantly shrinking with climate change,” says Kurt. (lbo)

BIODIVERSITY

Stubble fields as a refuge



The field hornwort (*Anthoceros agrestis*) occurs almost exclusively in fields of cereal stubble.

Like many other plants in fields, hornworts enrich the biodiversity of cultivated land. But both species found in northern Switzerland, the yellow and black hornwort, are threatened. Their gradual decline in the 20th century was followed by a veritable collapse from 2005 onwards, according to a new report on the field moss flora the WSL biologist Ariel Bergamini wrote together with other researchers for the Federal Office for the Environment (FOEN). For the report they evaluated the data from their hornwort monitoring, which they started almost thirty years ago.

The main reasons for this sharp decline are Switzerland’s soil protection requirements for agriculture, which have been in force since 2005, as well as climate change. Since 2005, farmers have been required to plough and replant cereal fields as quickly as possible to prevent erosion and nitrogen leaching. What is good for the soil is bad for the hornworts, which have lost their most important habitat, namely cereal stubble fields, which used to be left standing until late autumn. In addition, drier summers have meant the plants sometimes fail to develop because their growth depends on moisture.

To halt the decline of hornworts and other field mosses, the researchers recommend a number of measures. According to Ariel: “The most promising would be to leave some fields as stubble again in alternation with other fields.” (bki)

A man with short dark hair and a slight smile, wearing a brown and olive green jacket over a dark shirt, stands in a greenhouse. He is leaning on a table filled with numerous small, clear plastic pots containing soil and small plants. The background shows the structural elements of the greenhouse, including metal frames and translucent panels.

Gabor Reiss, Birmensdorf

“I spend a lot of time in WSL’s greenhouses. There I can really do what I am good at and work productively. We look after researchers’ experiments and raise rare tree species.”

PLANTS FOR RESEARCH

Gabor Reiss is head of the Experimental Garden at WSL in Birmensdorf. The trained nurseryman provides seeds and plant material for scientific experiments and advises the researchers when they have questions about tending plants, for ex-

ample about fertilisation. Together with his team, he also sees to the near-natural design of the site at WSL. “My job is very varied, I work with the plants both in the office and outside. That’s something I really appreciate.” (lbo)

LANDSCAPE 'Fiat Nox': Nature reserves need buffer zones for light



Fog can intensify light pollution up to 18 times because water droplets scatter light.

Darkness has become rare in densely populated Switzerland, and hardly any places are left that are not illuminated at night by artificial light. Nocturnal light disrupts the day-night rhythm of humans, animals and plants. It is therefore surprising that comparatively little is known about how light pollution can be measured locally and how relevant the different forms it takes are.

Ecological studies on the subject usually use nocturnal satellite images. "Such images say, however, rather little about the local lighting conditions because they provide only momentary snapshots," says Léo Constantin, who did his master's thesis on the topic at WSL. More relevant would be to find out more about what light animals are actually ex-

posed to – for example in nature reserves with endangered species.

Clouds increase light pollution

Léo therefore set up twenty light loggers in the Katzenssee nature reserve near Zurich, which is one of the brightest in the canton at night. These recorded the level of brightness every minute for three days. To locate the light sources spatially, he also took photos not only when the skies were clear but also when it was foggy or cloud-covered. For this he used a fish-eye camera, which has a rounded lens that captures almost the entire sky.

He found that light sources near Katzenssee, such as Zurich Affoltern or the airport, cause a strong 'sky-glow', i.e. a dome of light visible from

far away. This is particularly evident in fog or clouds because water droplets scatter light strongly. Some nights with fog were brighter than those with a full moon.

Intermittent light sources on buildings or the headlights of cars also put a heavy localised strain on Katzenssee. “Such light effects could be significantly reduced by targeted planting of shrubs or trees,” says Léo’s supervisor, Janine Bolliger, an ecologist at WSL.

Léo’s study is the first to provide clear indications of the distance with-

in which light emissions should be reduced in nature reserves. The size of the light buffer zone depends on the situation: if larger residential areas are located nearby, it should be at least one kilometre wide because of the ‘skyglow’, but in the case of intermittent light sources, such as floodlights or single lamps, about 500 metres. *(bki)*

www.wsl.ch/master_constantin

LANDSCAPE How far is it worth transporting biomass for energy production?

To promote the energy transition in Switzerland, more sustainably available wood could be used for heating and more farmyard manure for bio-gas production. But these raw materials often have to be transported over long distances to their destination. This consumes energy in the form of fuel, increases CO₂ emissions and costs money.

Taking these aspects into account, researchers from the Sustainable Forestry Group at WSL investigated the distances it would be worthwhile transporting biomass. They interviewed experts to identify the main transport routes for logs, wood chips, liquid manure and dung, as well as the machinery used for loading, unloading and transport. This enabled them to calculate the distances for which the energy consumption for the transport would exceed the energy contained in the raw materials.

The result: in terms of energy consumption, transport over hun-

dreds of kilometres can be worthwhile. The resulting CO₂ emissions are relatively insignificant if the amount of fossil CO₂ saved by using biomass is considered. Currently, transport distances from the source to the consumer are between five and ten kilometres for farmyard manure and between one and 30 kilometres for logs and wood chips.

It is the costs more than the energy consumption that limit how far it makes sense to transport biomass, but even here there is still room for manoeuvre. Under optimal conditions, it is worthwhile transporting liquid manure up to 80 kilometres, logs up to 110 kilometres and wood chips up to 480 kilometres. *(cho)*

www.wsl.ch/biomass-transport

NATURAL HAZARDS How is climate change affecting debris flows in the Illgraben catchment?

Debris flows are extreme events. They occur after prolonged or heavy rainfall, intensive snowmelt or an earthquake. With three to eight debris flows a year, the Illgraben catchment in Valais is one of the most active debris-flow channels in the Alps. WSL has been carrying out measure-



Debris-flow test site near Susten (VS). The Illgraben catchment is one of the most active debris-flow channels in the Alps.

ments there for over twenty years, with the new debris-flow force plate, the largest in the world, playing a central role. Sensors measure the forces of the mixture of water and debris acting on the ground. The flow rate, water content, density and flow velocity of the bulk material are also analysed with additional radar and laser measuring devices, as well as acceleration sensors and video cameras.

Most debris flows in the catchment occur in July after heavy thunderstorms. However, the decisive factor is not only how heavy the rainfall is, but also how much water the soil already contains. The debris flows

carrying the most material, for example, have so far been those in May, when additional water is available from the snowmelt. But how, in future, will the shorter winters and drier summers forecast affect debris flows?

In the research programme ‘Climate Change Impacts on Alpine Mass Movements’ (CCAMM), WSL researchers are investigating how climate change affects mass movements in the mountains. In a CCAMM sub-project, Jacob Hirschberg, a doctoral student at WSL, is studying the influence of climate change on debris flows in the Illgraben. “We assume that, while in future it will rain on fewer days during the summer months, the precipitation will be heavier,” says Jacob. The analyses to date also show that debris flows in the Illgraben could occur increasingly frequently in spring and autumn, when it is likely to rain more than today. However, fewer frost days could lead to a reduction in the number of debris flows as less rock will become weathered. In an extreme climate scenario, debris flows towards the end of the century would only occur in spring, as in summer all mobilisable debris would already have been transported down into the valley.

At higher altitudes, however, the thawing permafrost could lead to more loose rock. “As a result, debris flows are likely to become more frequent and larger there,” says Jacob. (sni)

ccamm.slf.ch

NATURAL HAZARDS The forest as insurance against avalanches and rockfall

The forest protects countless houses in the mountains against avalanches and rockfall. A team led by economist Roland Olschewski aims to find out, as part of the National Research Programme 'Sustainable Economy', whether this protective capacity can be increased, and what this would cost. Moreover, would the public be willing to pay the price?

Using fictitious but realistic scenarios, the researchers therefore asked the inhabitants of seven mountain municipalities what the forest's protective function is worth to them. For example, would they be prepared to pay something for the additional forest maintenance to ensure further protection if the danger zone rating for their house was reduced from red to blue? Roland was pleased to find many would be prepared to spend money on making the protection forest even more effective. The research team is also investigating whether this money could be used for additional maintenance.

An operational business model is the aim

As a next step, Roland and his colleagues want to develop a practical business model – a kind of insurance policy – that adapts existing regulations to take into account the new findings. This requires not only cooperation with the insurance industry and the public sector, but also – and above all – economic expertise. For example, an insurance policy will not work if the pool of service providers or premium payers is too small, i.e. if only a few property or forest owners participate. Nor should these cir-



When placed correctly, even dead trees can provide protection against rockfall, as computer models and experiments, such as here in Schiers (Canton Grisons), have shown. But would the public be willing to pay something for the additional costs of such forest maintenance?

cles overlap too much. For example, it will not work if the municipality owns both the protection forest and the endangered building.

But will this willingness to contribute identified in the survey also be there when a premium bill for insuring the protection forest drops through the letterbox? "People's willingness to pay does not necessarily mean they as individuals will be prepared to pay individually. Payments can also be made through the public sector," Roland explains. *(bio)*

www.nfp73.ch

SNOW AND ICE Heavy attack from above! When snow and ice on roofs become a danger



The folding sliding-shutters on the tall Meret Oppenheim building close automatically if there is a storm or snowfall.



The incline of the roof of the Elbe Philharmonic Hall is as much as 50° in some places. Using the right materials prevents snow falling off the roof.

A large icicle hangs from the edge of a roof over a busy pavement. It does not bear thinking about what would happen if several kilos of ice fell on passers-by. “To prevent sliding snow or falling ice from causing accidents or damage, a snow expert should be consulted as early as possible in the planning of a building,” says Stefan Margreth, head of the ‘Avalanche

Protection Measures’ group at SLF. He advises architects on how to minimise risks and prevent accidents involving snow and ice.

In most cases, Stefan first assesses whether there could be a problem with a building by checking the snow situation and the building geometry. How many days does it snow at the site where the building is being constructed? What snow depths can be expected? He then evaluates the various proposals made by the architects regarding materials and building design and selects the best solution. Often small adjustments to the building are sufficient, for example narrower window ledges where less snow can accumulate, or a heated gutter.

In recent years, Stefan has provided expertise for various building projects, including for spectacular buildings such as the Elbe Philharmonic Hall in Hamburg by Herzog

and de Meuron. In 2008 he was asked by the renowned Basel architects to assess the danger of roof avalanches and ice forming on the roof edge of the approximately 110-metre high building. The roof looks like a mountain landscape with inclines of up to 50°. “The surface and shape determine whether snow will stay on the roof or slip off,” says Stefan. A rough surface prevents snow from slipping off. For the roof of the Elbe Philharmonie Concert Hall, round aluminium panels with a perforated pattern were chosen. There are gaps between the individual panes so that the snow cover interlocks and does not slip.

Not an exact science

For expensive projects, architectural firms often produce a 1:1 scale model of a critical building element. But to really understand the problems that snow and ice could cause, you would have to observe the model over several winters. Nobody has that much time. “Intuition is therefore important – and keeping your eyes open when walking through winter landscapes. I can often transfer what I have observed on avalanche barriers covered with snow to comparable situations on buildings,” says Stefan.

In 2014, the architects Herzog and de Meuron gave SLF another contract. This time it was for the building façade of the tall Meret Oppenheim building in Basel, which is 81 metres high and located directly by the busy southern entrance to the main railway station. A characteristic feature of the building is its adjustable metal façade, with folding sliding-shutters, which can be opened and closed individually. But what happens when it snows? If the shut-

ters are open, snow could accumulate on them and fall off when they are closed. Stefan discussed different materials and construction methods for the shutters with the architects. They decided to use a controlled closing mechanism where, in the case of heavy snowfall or a storm, all shutters will close automatically.

Stefan was also involved in planning the ‘Circle’ at Zurich Airport, which is currently the largest and most expensive private construction project in Switzerland. The building has a closed, boomerang-shaped façade, which slants considerably over the three motorway lanes leading to the airport. Stefan Margreth advised the architects on the façade and the edge of the roof. “My recommendation is not to have many window ledges. It would be very unfortunate if snow fell from the building onto the road.” The building is planned to open towards the end of 2020. *(sni)*

www.slf.ch/structural-avalanche-protection



Carolyn Willibald, Davos

“If you’re going to live in the countryside, then you might as well do it properly. This old farmhouse near Davos is ideal. Having lots of snow and winter sports opportunities right on the doorstep is as much part of the long winter as chopping wood.”

FASCINATION FOR SNOW

As someone who enjoys ski touring, Carolyn Willibald has long been interested in understanding the processes in snow better. In her dissertation, the physicist is investigating the mechanics and micro-structure of snow. To simplify the complexities in-

volved, she has developed a form of model snow using ice pellets to find out how well the particles bond and how they react to stress. Such questions are relevant for understanding avalanches and other phenomena involving snow better. (sni)



Health is valuable - this applies not only to us humans, but also to the forest. A healthy forest is in equilibrium and can fulfil many important functions. It provides protection against avalanches and rockfall, ensures the groundwater is clean and provides a safe habitat for many animals and plants. WSL researchers are investigating how to protect forests against disease and help them adapt to climate change. At the same time, they are also studying how the landscape and natural areas have a positive effect on people's well-being, reducing stress and thus improving mental health. *(cho)*

Diagonal can be ordered free of charge: www.wsl.ch/diagonal

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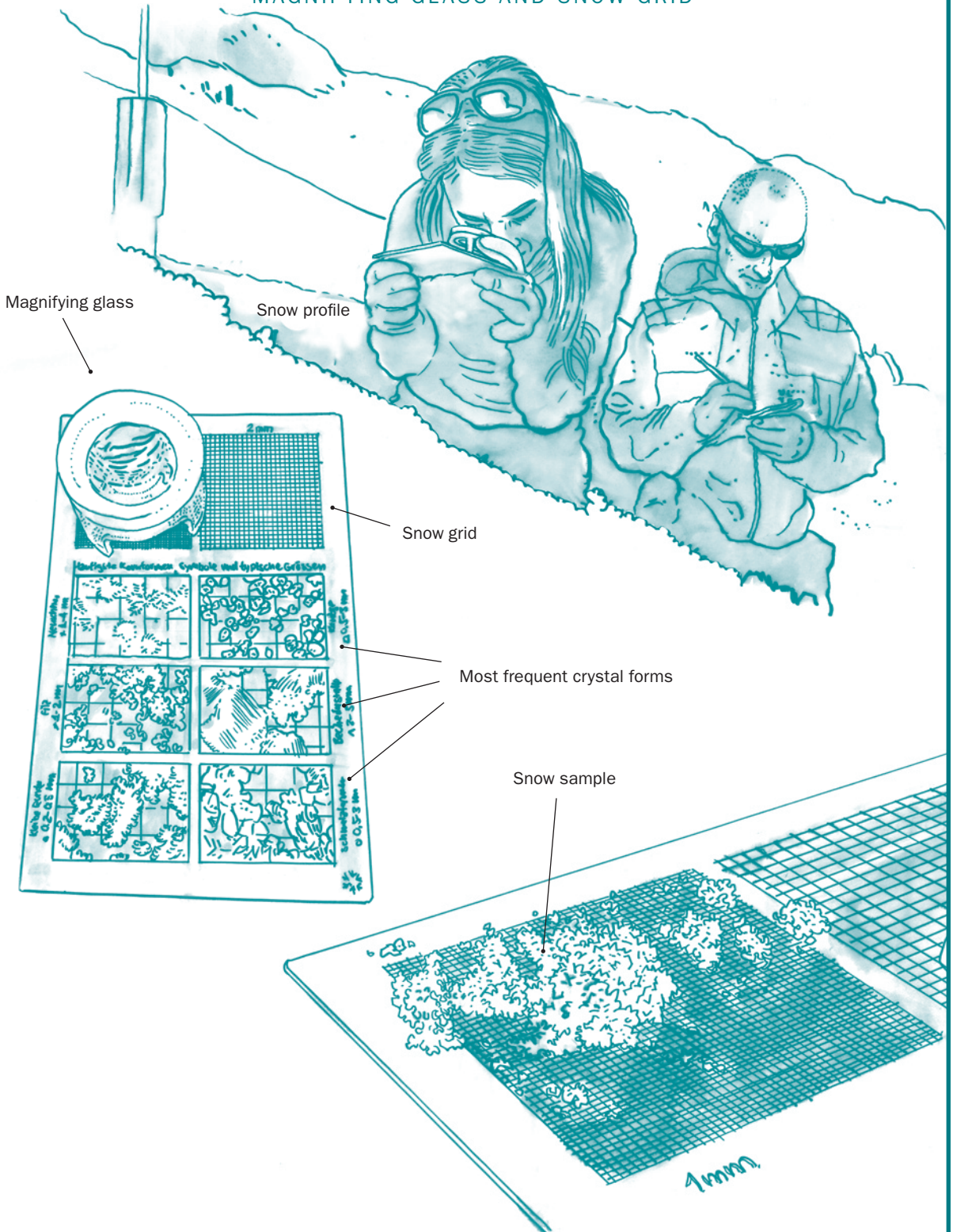
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PEOPLE



The Diagonal editorial team, from left to right, top row: Sara Niedermann, Birgit Ottmer, Beate Kittl; bottom row: Claudia Hoffmann, Sandra Gurzeler, Lisa Bose

MAGNIFYING GLASS AND SNOW GRID



Tried and tested things hardly ever change: snow researchers still work with magnifying glasses and snow grids to examine snow crystals even today – just as they did eighty years ago. They take samples from the different layers of a snow profile and place them on the grid. Cells of different sizes in the grid serve as a reference for determining the size of the crystals. Once the shape and size of the snow crystals are known, conclusions can be drawn about the properties of the snow layer.

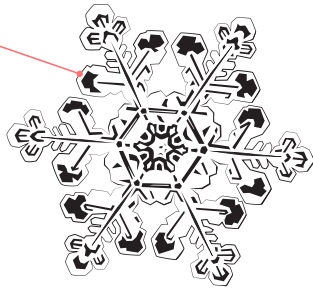
Video at:
www.wsl.ch/object



EXTREM VIELE

10 Trillionen

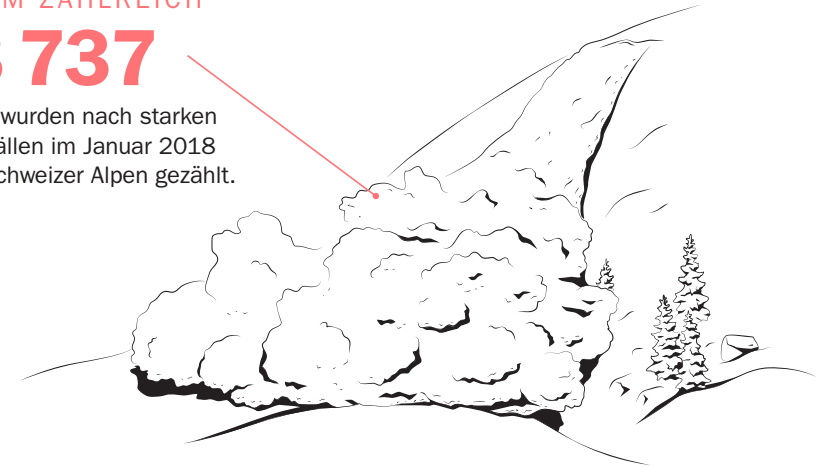
Ungefähr 10^{19} Wassermoleküle enthält ein Schneekristall mit einem Durchmesser von 1 Millimeter.



EXTREM ZAHLREICH

18 737

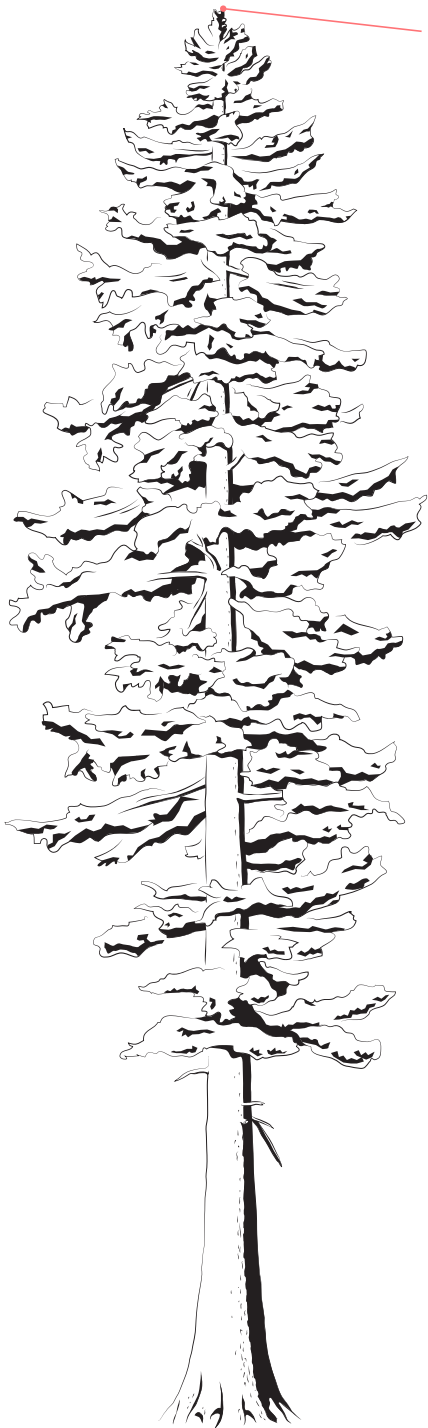
Lawinen wurden nach starken Schneefällen im Januar 2018 in den Schweizer Alpen gezählt.



EXTREM HOCH

58 m

Der höchste Baum der Schweiz, eine Weisstanne, steht in Oberlangenegg (BE).



EXTREM SELTEN

3

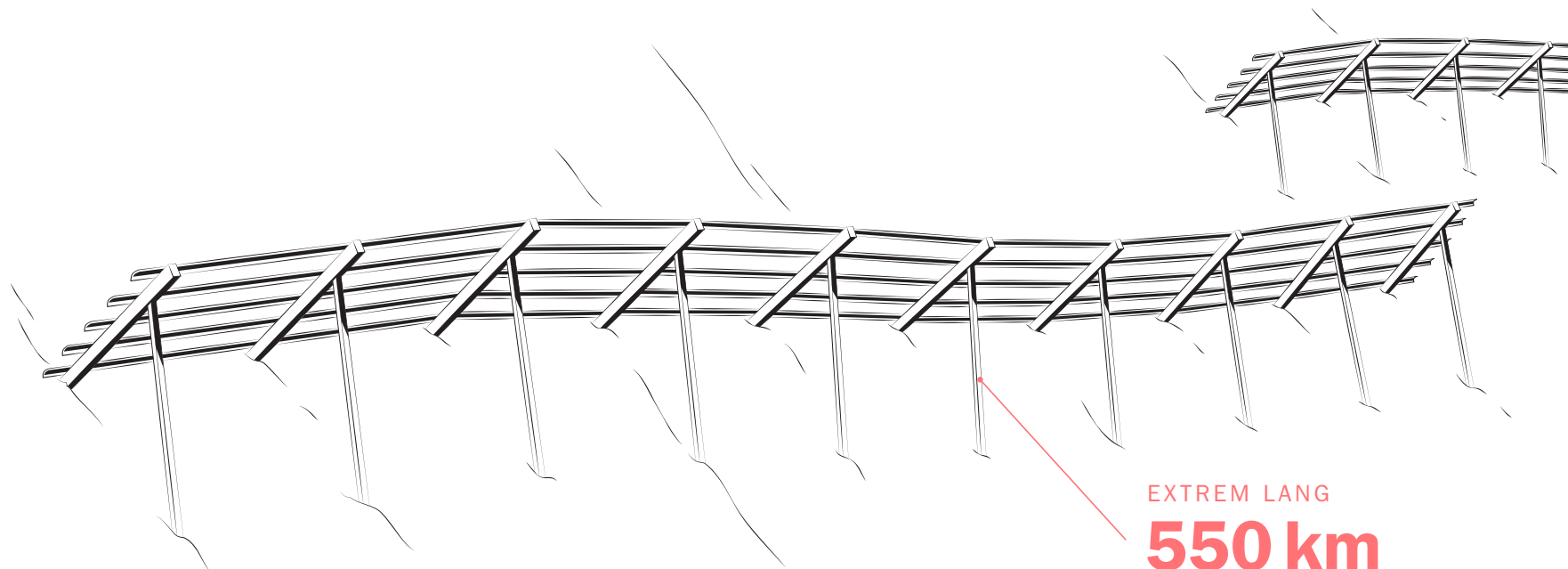
Die Flechte «Schwarzfrüchtiger Kugelträger» hat man in den letzten 50 Jahren in der Schweiz nur an 3 Orten gefunden.



EXTREM LANG

550 km

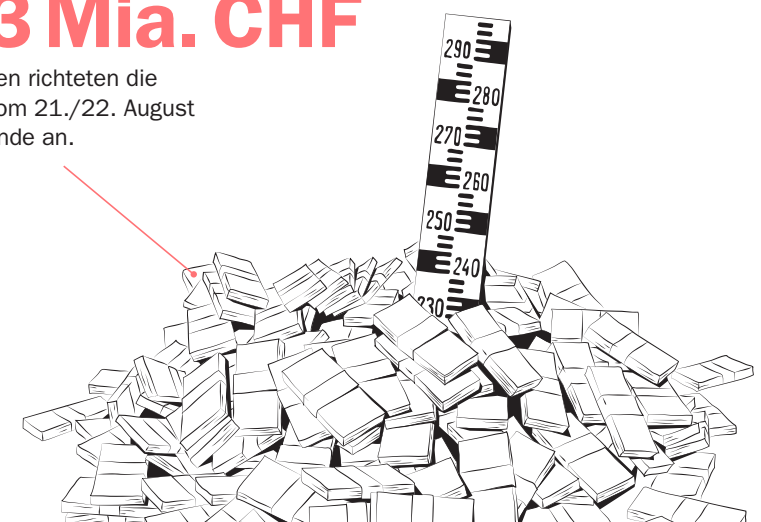
beträgt in etwa die Gesamtlänge der Lawinverbauungen in der Schweiz.

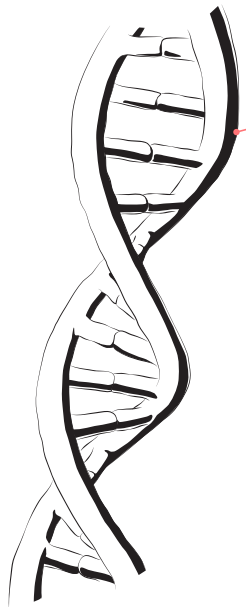


EXTREM TEUER

Ca. 3 Mia. CHF

Diesen Schaden richteten die Hochwasser vom 21./22. August 2005 hierzulande an.





EXTREM WENIG

1

Um Tiere an einem Ort nachzuweisen, würde die genetische Information aus einer einzigen Zelle ausreichen.

EXTREM SCHÄDLICH

102 277 m³

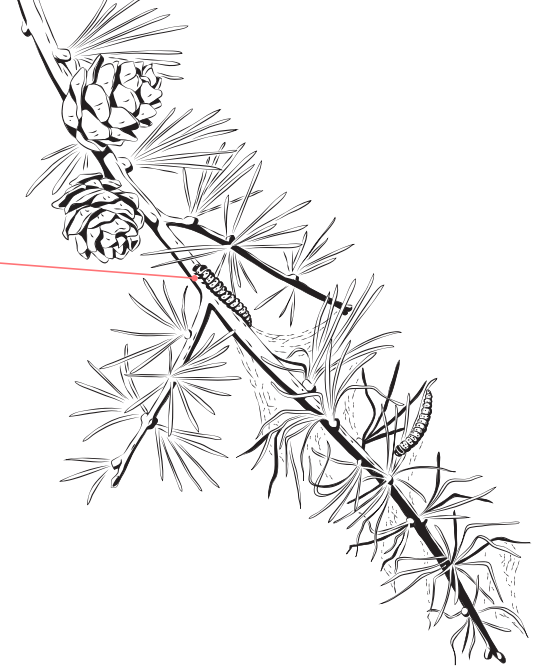
So viel Holz musste 2019 wegen des Eschentriebsterbens zwangsgenutzt werden.



EXTREM REGELMÄSSIG

Alle 9 Jahre

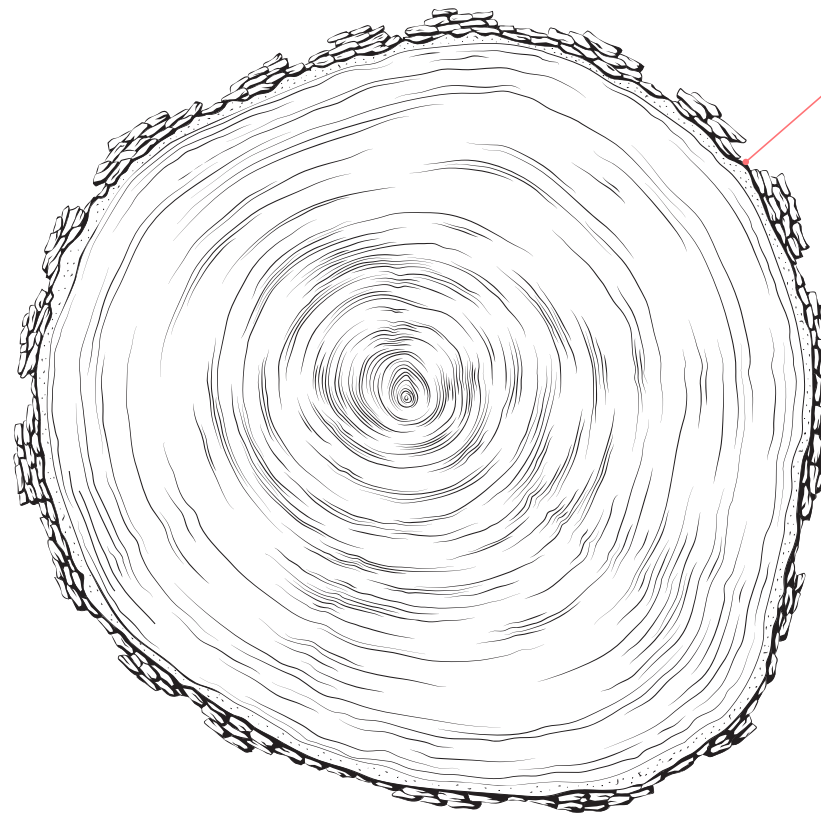
findet die Massenvermehrung des Lärchenwicklers statt, dessen Raupen ganze Lärchenbestände kahl fressen.



EXTREM BESTÄNDIG

1888

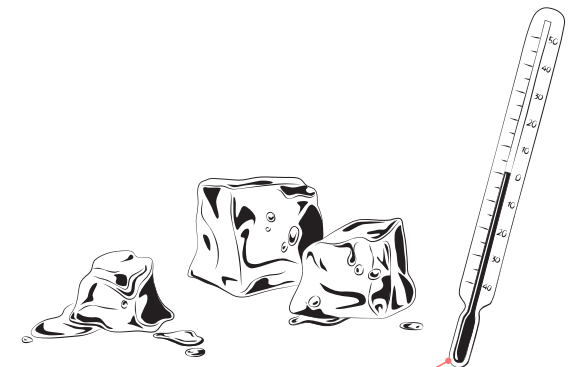
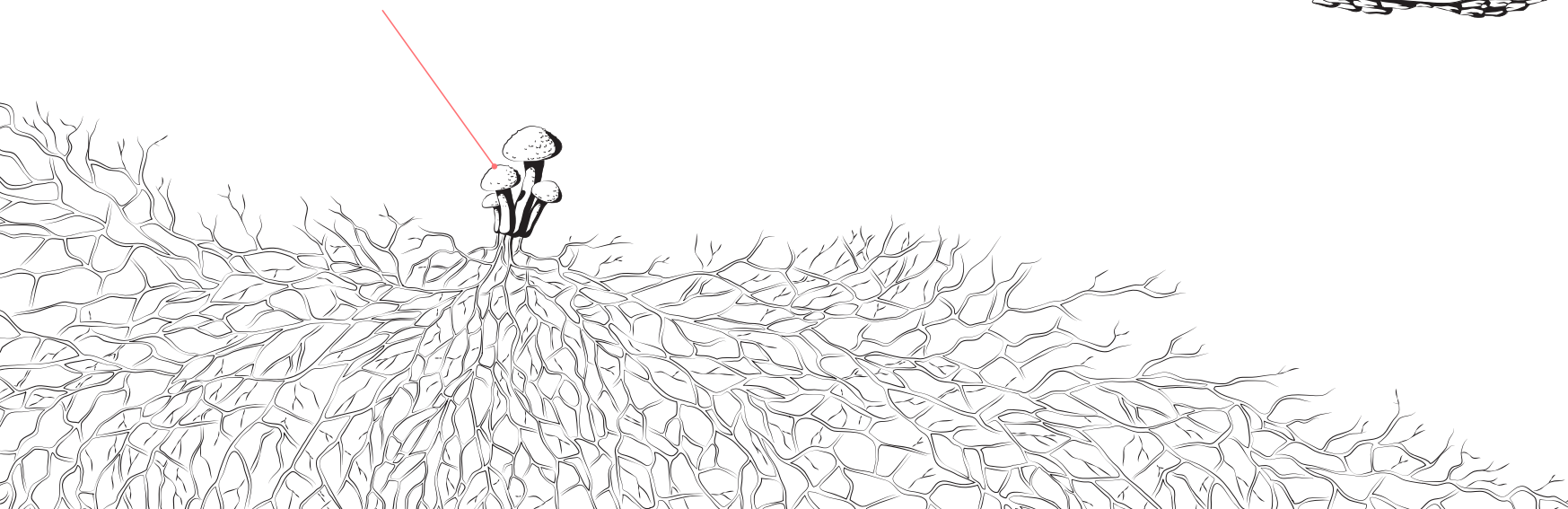
wurden die ersten Versuchsflächen eingerichtet, um den Ertrag des Schweizer Waldes zu erforschen. Sie sind noch heute in Betrieb.



EXTREM GROSS

37 ha

Der grösste Pilz der Schweiz, ein Hallimasch, wurde im Schweizerischen Nationalpark entdeckt, sein unterirdisches Geflecht erstreckt sich über eine Fläche von 50 Fussballfeldern.



EXTREM WARM

1,6 °C

Der bisherige Temperaturrekord am höchsten Punkt Grönlands, beim Summit Camp auf 3216 m ü. M., wurde am 2. August 2019 gemessen.

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RESEARCH FOR PEOPLE AND THE ENVIRONMENT

The Swiss Federal Institute for Forest, Snow and Landscape Research WSL conducts research into changes in the terrestrial environment, as well as into the use and protection of natural spaces and cultural landscapes. It monitors the condition and development of the forests, landscapes, biodiversity, natural hazards, and snow and ice, and develops sustainable solutions for problems that are relevant to society – together with its partners from science and society. WSL plays a leading international role in these research areas, providing the basis for sustainable environmental policy in Switzerland. WSL employs more than 500 people in Birmensdorf, Cadenazzo, Lausanne, Sion and Davos (WSL Institute for Snow and Avalanche Research SLF). It is a Swiss federal research centre and part of the ETH Domain. You can find WSL's annual report online at: www.wsl.ch/annualreport.

