

WSL MAGAZINE

DIAGONAL

FOCUS

Keeping the forest and people healthy

No. 1

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Taking landscape more into account, p. 24

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EDITORIAL

The forest is good for people, as several WSL studies have shown – especially during times such as these when the Corona pandemic is omnipresent. While human health is undoubtedly central, other organisms, indeed entire ecosystems, also frequently struggle with health problems. Several articles in this issue are on how trees and forests deal with well-known challenges such as the bark beetle, as well as with new diseases and the negative effects of climate change. We do not, however, leave out human health completely: currently unknown bacteria and fungi with antibiotic properties could be waiting to be discovered in permafrost – our experts on microorganisms in the soil are on their trail!

Their work, like that of all other researchers at WSL, should contribute to a better understanding of processes in nature – for the benefit of both people and the environment.



Christoph Hegg
Acting Director WSL



Health



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FOREST HEALTH Acid rain, bark beetles, drought damage: our forests are constantly facing new challenges – and so are WSL researchers.

The forest – a perpetual patient?

‘Forest dieback’ and ‘acid rain’ were topics of public concern. Here the district forester Hans Zehnder is pointing out the symptoms, presumably caused by sulphurous emissions, to a group of visitors.





At the beginning of the 1980s, foresters noticed progressive and pronounced defoliation in fir and spruce.

Concern about 'forest dieback' helped bring about the 1985 Clean Air Act, which specified measures such as catalytic converters for cars and desulphurised heating oil, as well as emission limits.

Möhlin in Canton Aargau, 7 May 1983.

PHOTO: KEYSTONE/SR

Location: somewhere in Canton Zurich. A long-haired reporter with a moustache and a woollen pullover is walking through the forest with a forester dressed in a suit and tie. "Look at this silver fir," says the forester. "It has hardly any needles left and very soon it will die off completely." The camera pans onto lanky fir trees, accompanied by dramatic music. The voice-over proclaims: "The forest is sick and suffering. The damage in Switzerland too is alarming." And asks: "What should we do?" The scene is from a 1983 Swiss television programme on 'forest dieback'.

Scientists at the time were initially at a loss about what was causing the defoliation of so many tree crowns – the main symptom of 'forest dieback'. Sulphurous emissions were thought to be entering the forests in the form of 'acid rain' and weakening the trees, which then made them susceptible to drought and pests. This cannot be proven beyond doubt because no comparable data from the past is available.

To remedy this lack of information, WSL's Sanasilva (Latin for 'healthy forest') Inventory was started in 1984. Since then, annual checks of the condition of the forest have been carried out at around 50 forest sites across Switzerland. The researchers decided to monitor defoliation, i.e. needle or leaf loss, as a symptom of disease because it is easy to assess. The threshold for classifying a tree as damaged was set at 25 percent defoliation.

The question of what constitutes a healthy tree or a healthy forest has preoccupied WSL researchers since the Institute was founded in 1885. At that time, people were already worried about the forest, especially in the mountains, where forests had been

plundered and overexploited. In 1876, after terrible floods, Switzerland passed a forest law that was revolutionary at the time and instigated the idea of sustainable forest use. WSL's predecessor, the 'Central Station for Experimental Forestry', was founded with the mission: "To create a secure basis for all aspects of forest management."

The researchers quickly began setting up permanent observation plots across Switzerland, where they measured the growth, composition and condition of the forest. This information was then used for planning timber harvesting. They also confirmed relationships between the forest and avalanches, landslides and floods. At that time, a forest was considered 'healthy' if it provided people with sufficient wood and protected them from natural hazards. But when air pollution began to take its toll in the 1980s, it became apparent that too little was known about the forest to explain why the trees were becoming unhealthy. That is why the Long-term Forest Ecosystem Research (LWF) was launched shortly after Sanasilva. Since 1994, researchers at WSL have been using a whole battery of measuring instruments to record environmental conditions and air pollutants on around twenty test plots throughout Switzerland to see how the trees there react to them.

The long-term data collected soon showed that, while the forest had been damaged, its existence was not directly threatened – in other words, the forests were not dying. In the 1980s, however, no reference values for assessing the condition of the forest were available, and both scientists and the public had the impression that an immense number of trees had weakened or even died.

Dead trees support new life

Perceptions of forest health have changed considerably since the 1980s. "While the focus was on 'forest dieback', people only looked at the trees," says Andreas Rigling, a forest engineer and member of the WSL Directorate. "Today we also take into account soil organisms, and indeed the entire ecosystem." Dead trees are part of this. When they fall, they make room for young growth, as well as for animal and plant species that require light, such as orchids or the woodcock. In addition, every third forest organism is thought to depend on deadwood, including wood-decomposing fungi, deadwood beetles and woodpeckers. Since 2005, the National Forest Inventory, which WSL conducts, has recorded the amount of deadwood as an important component of the forest ecosystem.

It is therefore normal, and even desirable, for some of the trees in a forest to be dead. Nevertheless, defining what constitutes a healthy forest is not easy because it depends very much on what people want a forest to provide. A forest could be considered healthy as long as it supplies enough wood or sufficient protection against avalanches, or even as long as people enjoy relaxing in it. Depending on the region, forests in Switzerland may have to fulfil several of their important functions at the same time: providing protection against natural hazards, supplying timber, and/or serving as a place for recreation, a habitat for flora and fauna, a sink for greenhouse gases, and a filter for water and air. Forests must, therefore, be multifunctional, but with the functions weighted differently.

For more information on the Sanasilva Inventory and Long-term Forest Ecosystem Research LWF, see:
www.wsl.ch/sanasilva-en
www.wsl.ch/lwf-en

Forest policy and management experts are constantly asking themselves questions like: What needs to be done where? And how much money is available? Clearly something should be done to tackle environmental toxins or introduced diseases. “But opinions differ even on how to deal with our native bark beetles,” says Eckehard Brockerhoff, a forest insect specialist and head of the ‘Forest Health and Biotic Interactions’ Research Unit. How much bark beetle damage can and should be tolerated? WSL provides diagnoses and computer models to help foresters contain beetle infestations when the services forests provide are at risk (see page 16).


Forthcoming crises

Bark beetles are not the only problem the forest has to contend with. Forest pollution with nitrogen and ozone from agriculture and combustion processes is still critical in many places even though air pollution control measures have greatly reduced pollutant inputs. “We succeeded in getting rid of acid rain, but high nitrogen inputs continue to make sensitive soils too acidic,” says Peter Brang, a forest engineer and expert on forests and climate change at WSL. Moreover, we are to some extent powerless against the many invasive plants and pests introduced through international trade – despite improved border controls. In 2014, a high-security laboratory was set up at WSL to diagnose and study such new arrivals and search for natural ways to combat them (see page 8).


And then we have climate change. It is progressing so fast that the natural adaptive capacity of forest ecosystems cannot keep up. This became evident during the dry summer of 2018 when numerous trees died due to lack of water. “We have to do everything we can to ensure forests remain stable in the future,” says Andreas Rigling. Forests with a varied structure and diverse tree species are better at withstanding pests, storms and other disturbances and can recover from them more quickly. To promote such forests, a near-natural management system is needed that can steer forest development in the right direction in the future. “At the same time, we must first make sure that diverse young stands can fully mature,” says Peter Brang. This is an issue because the currently large populations of red deer and roe deer are fond of eating the saplings of future climate-tolerant tree species such as oak and silver fir.

With all these issues, WSL staff can once again provide advice and support. Economists calculate what it costs to maintain the services a forest provides and how to compensate forest owners for maintaining them. Forest scientists are identifying tree species that can cope with the future climate in a new large-scale project, where the team is led by Peter Brang and Kathrin Streit. The project involves planting over 50,000 trees across Switzerland and monitoring how they develop over the next thirty years.

One thing the outcry in the 1980s about ‘forest dieback’ did show is that rapid action is possible. At the time, politicians and the general public were so concerned about the health of the trees that clean air regulations were introduced at record speed, and desulphurised heating oil, flue-gas filters and catalytic converters in cars became the norm. The coming crises will also require targeted action, which should be based on sound scientific findings. This is why WSL will continue its research on forest health. *(bki)*



In the 'Healthy Alps' project, WSL and the University of Natural Resources and Life Sciences Vienna investigated the connection between biodiversity and people's well-being and health. 22 volunteers spent an extended period of time in different alpine meadows.



The participants reported that they could reduce their stress levels better in the managed meadow with fewer species than in the meadow that was no longer managed.



The participants' cognitive performance after staying in the more species-rich meadow that was no longer managed was better than after staying in a managed meadow.



Both species-rich and less species-rich alpine meadows seem to have had a positive influence on the participants' health and well-being. Thus, higher diversity does not always mean a greater positive influence.

PLANT PROTECTION **Investigating a new pathogen.** Tree pests – beetles, fungi and bacteria – are on the increase in Switzerland. Researchers at the WSL Plant Protection Laboratory identify new pathogens and, if necessary, try to find ways to combat them. One recent example is how they tackled a newly discovered species of fungus.

The orange spots on the bark of this arm-thick hornbeam branch are actually quite pretty, but for the tree in the Jura near Delémont, they are not a good sign. The pustules come from a fungus that makes the tree sick. Ludwig Beenken, a forest pathologist working for Swiss Forest Protection at WSL in Birmensdorf, puts the infected branch back on the laboratory table and picks up another tree sample: a piece of bark from the alluvial forest near Brugg. It also has orange pustules on it, as does part of a tree stem from the Lägern in Aargau and a branch from a forest near Neuchâtel. The name of the pathogen is *Cryphonectria carpinicola*. ‘*Carpini*’ is the Latin name for the hornbeam, and ‘*cola*’ means ‘grows on’. Until recently, little was known about this fungus because researchers have only just discovered it and described it as a new species.

Chance find near a cemetery

Hundreds of different tree pests exist, with fungi among the most dangerous. Very aggressive fungi can cause trees to die completely within a few months. The new culprit, *C. carpinicola*, was first detected in Switzerland by Valentin Queloz, head of Swiss Forest Protection, in January 2018. He found it by chance while on the trail of another tree disease near a cemetery in Basel. He photographed the fungus and took a sample. “We then started our detective work in the Plant Protection Laboratory at WSL,” Valentin recalls. They wanted to know whether the fungus had already been identified. Had it been found in Switzerland before? And how aggressive is it?

To answer these questions, Ludwig Beenken first looked at the morphology of the fungus under the microscope, i.e. at its tissue structure of filaments and spores. This information is enough for experts to already recognise most of the known wood fungi – and also to see whether they are looking at something previously unknown. The researchers also cultivated the fungus in the laboratory. To do this, Ludwig uses tweezers to pick out a tiny piece from one of the fungal pustules, which he then places on a nutrient medium in a Petri dish.

Where does the new fungus come from?

In her laboratory one floor below, Carolina Cornejo takes the lid off one of the dozens of Petri dishes stacked on the lab benches, each with such a fungal culture. The culture medium in the dish is covered with an orange-yellow growth. “*Cryphonectria carpinicola*,” says Carolina. The biologist is responsible for isolating and examining the genetic material of bacterial or fungal pathogens,

For further information on WSL's Plant Protection Laboratory, see: www.wsl.ch/plantprotectionlab



Looking into the genes: Carolina Cornejo, a WSL researcher, analyses the isolated fungal DNA in the diagnostics laboratory.

which enables her to reliably identify organisms. Carolina can also create a genetic family tree by comparing genes of similar fungi.

In the case of *C. carpinicola*, its branches indicate that the fungus is related to *Cryphonectria parasitica*, an aggressive cousin that was introduced from Asia in the 1940s. It causes the dangerous chestnut blight that has affected native chestnut trees. However, *C. carpinicola* is even more closely related to a group of fungi that have been resident in Europe for thousands of years and split off from the Asian parasitica branch at an early stage. From this, Carolina has been able to glean crucial information: *C. carpinicola* was probably not introduced into Europe recently, but has been here for a long time and is only now becoming active.

Infecting trees in a controlled way

But how dangerous is the fungus for the trees? “It is difficult to assess this only on the basis of observations of infected trees in nature,” says Daniel Rigling, head of the Phytopathology Group at WSL. Why trees become diseased is often due to a combination of pathogens – sometimes several at the same time – with environmental factors, such as drought. To clarify the effects of *C. carpin-*

icola, the researchers therefore carried out infection experiments in the Plant Protection Laboratory, some with young trees, which they monitored in the secure greenhouse, and others with sections of tree stems. To infect them, the researchers drill small holes in the wood into which they put, with a spatula, a bit of the fungal culture.

Daniel opens the door of the climate chamber where the infection experiments are taking place. In the rows of plastic boxes, hundreds of tree-stem samples, each about a finger-width wide and 20 centimetres long, are being infected. Daniel takes out one of the pieces and points out the black spots a centimetre long that have formed beside the borehole. “These are lesions, i.e. injuries caused by the fungus.” It seems that, even though the young trees may develop such *C. carpinicola* lesions, they can still keep the fungus at bay and do not die – which is good news.

Drought makes trees more susceptible

Further *C. carpinicola* findings have provided a clue as to why the fungus has now become active after remaining undetected for so long. Valentin Brühwiler, a master’s student at WSL, investigated Swiss hornbeam forests to see where the fungus does and does not occur. He found that *C. carpinicola* only breaks out on drought-affected hornbeams. “The long dry periods in recent summers have weakened the trees and made them susceptible,” explains Valentin Queloz. This has enabled the fungus, which the trees were previously able to keep in check, to suddenly spread.

C. carpinicola is not an isolated case: “In recent years, we’ve noticed that more and more new pathogens are being detected,” says Valentin Queloz. Many of them have been introduced. Global trade has led to them spreading rapidly across oceans and continents, for example in transported soil, ornamental



This bark sample is completely covered with the typical orange *C. carpinicola* pustules. Under the microscope, the fine structure of the fungus becomes visible.

plants, pallets or wooden packaging. “An aggressive pathogen can cause a great deal of damage,” says Carolina Cornejo, “which is why identifying and monitoring newly appearing organisms is so important.”

Intersection between research and practice

The researchers maintain good relationships with many foresters, tree-nursery employees and interested private individuals, who are a great help. In many cases, they report infestations before the researchers know about them. They send in information about the infestation on a form, often together with a photo and a sample. Swiss Forest Protection received over four hundred such reports in 2020.

The data from forest observations, infection trials and genetic studies is amalgamated in WSL's Plant Protection Laboratory and used to help researchers assess how to deal with a pathogen. It is now clear that trees infested with *Cryphonectria carpinicola* do not need to be felled. Nor is it necessary to set up traps to filter fungal spores from the air to monitor the pathogen. But the forestry services have been informed about the new fungus and asked to report infested trees. WSL researchers will also continue to search for the pathogen in the forests. “The fungus attacks trees suffering drought stress, which means it is likely to spread further with global warming,” says Daniel. “We want to keep an eye on how this develops.”

(*sru*)

For information
on the work of Swiss
Forest Protection,
see:
waldschutz.wsl.ch

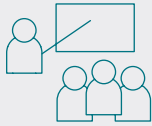


A spatula tip of fungal culture, taken from the Petri dish, is enough to infect the wood. Such infection experiments show how badly a pathogen affects a tree.

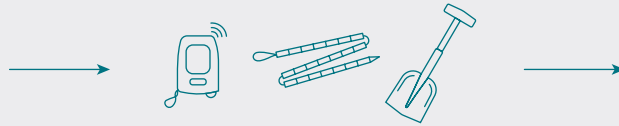
Avalanche danger means lives are at risk

AVALANCHE PREVENTION

What you can do to avoid avalanche accidents is: make sure you have info about the avalanche danger and weather; plan your tour carefully; carry the right equipment and attend an avalanche course.



Attend an avalanche course



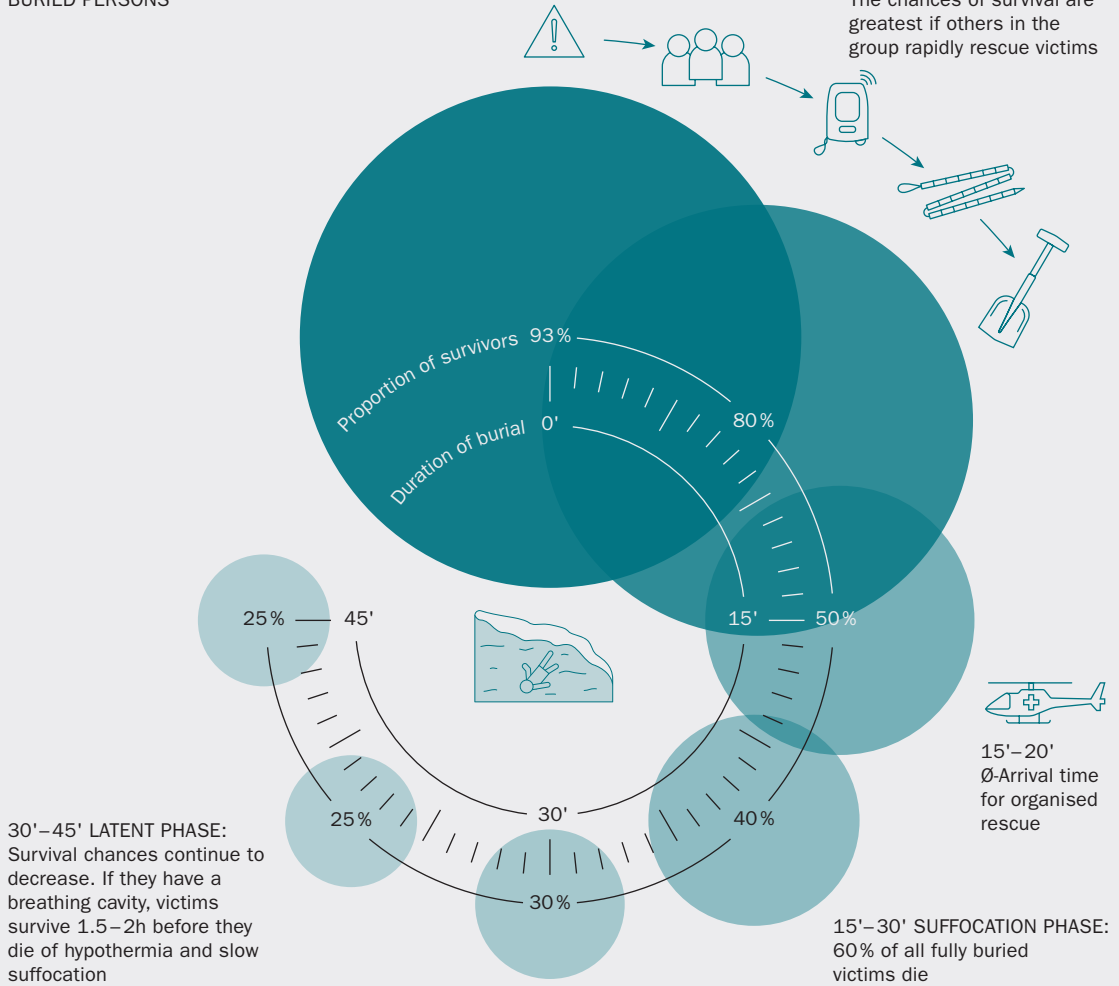
Carry an avalanche transceiver, probe and shovel (emergency equipment) with you



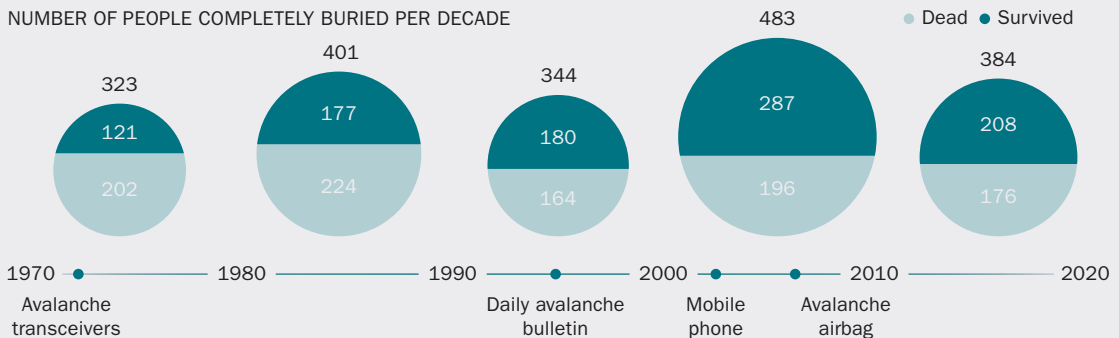
Consult the avalanche bulletin before each tour

SURVIVAL PROBABILITY OF COMPLETELY BURIED PERSONS

RESCUING CAMERADES
The chances of survival are greatest if others in the group rapidly rescue victims



NUMBER OF PEOPLE COMPLETELY BURIED PER DECADE



ONE-TWO “Parents should foster a love of nature in their children.” Outdoor exercise – cycling, jogging or working in the garden – is good for our health. But is this true for everyone all the time? Nicole Bauer, an environmental psychologist at WSL, and Hans-Peter Hutter, a doctor in environmental and preventive medicine, discuss how our relationship with ‘nature’ shapes us.

Outdoor exercise in a natural environment is good for us humans. But which is more important – the exercise or spending time outside in ‘nature’?

NB: Both are important, but have slightly different effects. We have found in different studies that, even without being outside in nature, the test subjects felt better after just doing some physical exercise on a treadmill. But other indicators of well-being, such as how calm or awake the test persons felt, only improved when they combined exercising outside with experiencing the natural world.

Where does this effect come from?

NB: Nature fascinates us humans in a special way. It captures our attention without us having to make an effort. This is very beneficial and makes it easier for us to find some distance from the stress of everyday life. Moreover, the expansiveness we see in nature makes us feel less constricted than in built-up areas. Another important factor is how diverse the landscape is. Hobby gardeners seem, we found, to recuperate better in species-rich gardens than in gardens with fewer species.

HPH: The different quality of environmental factors in natural

and in urban areas also affects us. The air in natural environments contains fewer harmful particles such as soot from combustion processes. And most people react positively to pleasant sensory impressions in nature – the light, colours, smells and sounds, which increases the positive effect that exercise has on our health.

How universal is this effect? Does everyone benefit from exercising in nature?

NB: Basically, yes. However, in one study we found an exception. We analysed to what extent the test persons’ stress levels depended on how often they spent time in nature. Frequent outdoor activities were clearly associated with a lower stress response. Only for people who were under a great deal of time pressure did spending time in nature have a counterproductive effect – because they experienced it as an additional stress factor. Fitting an obligation such as “I have to go jogging for an hour every other day” into an already stressful daily routine is hardly likely to reduce stress.

HPH: In preventive medicine we recommend incorporating exercise into everyday activities to alleviate this self-imposed pressure. By sim-



Hans-Peter Hutter is a specialist in hygiene with a focus on environmental and preventive medicine. He is deputy head of the Department of Environmental Hygiene and Environmental Medicine at the Medical University of Vienna.



Nicole Bauer is an environmental psychologist at WSL in Birmensdorf, and conducts research on the influence of natural environments on health.

ply using the stairs instead of taking the escalator or going short distances by bike instead of by car, we can all easily get some exercise in a way that fits into our everyday lives.

But how much everyone should exercise for the sake of their health is subject to guidelines.

HPH: Yes, these recommendations are supported by research. Even exercising for half an hour a day reduces the risk of dying prematurely by around twenty percent. Practically no medicine reduces the risk of illness as much and as sustainably as regular exercise – and this applies to cardiovascular diseases, as well as diabetes and cancer. This is one of the reasons why parents should encourage their children from an early age to enjoy active exercise, especially outside in nature. Research has shown very clearly that children’s experiences during their first few years of life have a strong influence on their later preferences and behaviour, including their enjoyment of movement.

In what way?

NB: Take, for example, my little nephew. He lives in a housing estate where the detached houses have gardens with low-maintenance lawns and stone beds. Once, when he was two years old, I took him to explore the woods. He was amazed and a bit scared, looking around with wide eyes. He didn’t know what a forest was.

HPH: I’m concerned when I see so many small children wearing sandals to cross the grass in open-

air swimming pools. They no longer walk barefoot to go from their towels to the pool because the grass is prickly or they fear insects.

Is this a problem?

HPH: It’s a gross misconception that this absolutely harmless experience of nature could be bad for them. But will someone who has never walked barefoot across a lawn dare to go into the forest alone when they are older?

NB: For many children today, the natural world is something frightening and even disgusting, especially in Anglo-Saxon countries, as research has shown. This means they have few opportunities to experience self-efficacy, which would help them cope with difficult situations later. If they continue to fear nature on into adulthood, they will not be able to experience its beneficial and stress-reducing effects later in life.

Has the Covid 19 pandemic possibly improved this situation? Apparently people spent more time outside in nature during the lockdowns.

HPH: Several international studies suggest that the lockdowns actually led to more negative behaviour, such as more alcohol consumption, unhealthy nutrition and physical inactivity. It is therefore likely to be a fallacy that lots of people have discovered the natural world for themselves as a result of the pandemic. The severity of the lockdowns, however, varied greatly from country to country. During the first lockdown in Austria, for exam-

“Even exercising for half an hour a day reduces the risk of dying prematurely by around twenty percent.”



Pleasant sensory experiences in natural environments increase the positive effect that exercise has on our health.

ple, people were only allowed to walk at most around the block.

NB: We have studied this in Switzerland. It turns out that during the lockdown in spring 2020 people were divided into one of two extremes. Before the lockdown, most people went to the forest occasionally, while very few were there either very often or hardly at all. During the lockdown, however, this frequency pattern shifted: many people hardly went into the forest any more, while many others did so much more frequently than before.

In Switzerland, some natural recreation areas attracted huge crowds of visitors.

NB: Yes, precisely because many urban parks or promenades were closed, the pressure to use urban forests, for example, increased.

HPH: And people increasingly went by car to see lakes or mountains. This generated more traffic, more air pollution and more noise – which are all things that significantly diminish the recuperative value of nature. It's better to use public transport or go by bike to explore the countryside – not only for the sake of the natural environment but also for the sake of us humans. *(sru)*

FOREST INSECTS **The spruce bark beetle is accelerating the transformation of Swiss forests.** Bark beetles have been killing more spruce trees than almost ever before. Human activities are partly responsible for this. Foresters are trying to make the forest more resilient by promoting more robust mixed forests in gaps in the forest.

Bark beetles play an important role in a healthy forest. By boring under the bark of dying trees, they perform important functions for the forest ecosystem such as enabling wood-decomposing fungi to establish on the trees. They also serve as food for other insects and birds. However, if a large number of trees are weakened, the beetles can proliferate rapidly.

Currently the situation is particularly bad. Many forests are full of withered conifers and cleared areas. After the drought of 2018, bark beetles multiplied en masse – in particular the spruce bark beetle (*Ips typographus*). It killed thousands of spruce trees in 2019 alone – the equivalent of over 50,000 truckloads. This is the second highest figure ever recorded.

It has been a bitter blow for Switzerland's forest industry, where spruce is the most important crop tree species. The problem is, however, quasi homemade. In the Middle Ages, instead of cultivating the deciduous trees originally native to the Central Plateau, people began planting fast-growing spruce trees, which thrive well at higher and cooler altitudes. But with climate change, it is becoming too hot and dry for them, and the spruce bark beetle has flourished.

Recently, spruce trees have even had difficulties in their traditional habitats in the mountains. The warmer climate means the beetles can, in some ar-

For further information on bark beetles, see: www.wsl.ch/bark-beetle



The spruce bark beetle is the most frequent bark beetle species in Switzerland.



The effects of the dry year 2018 are still being felt: spruce infested with bark beetles in the Jura in July 2020.

eas, produce a second generation of offspring each year. “Some forests have been losing their protective function,” says Martin Bader from the Swiss Forest Protection Centre (WSS). Increasing populations of red deer and roe deer are further aggravating this situation. Their browsing destroys the young trees that would make the forests more resilient.

The Swiss Forest Protection Centre helps the forest services, local authorities and private owners diagnose beetle infestations, and advises them on appropriate measures to take. Since pesticides are banned in Swiss forests, potential breeding sites for the beetles must be minimised, Martin says. Infested trees should be felled and removed or debarked. To enable foresters to plan how to control the beetles better, WSL has developed a computer model to estimate the spruce bark beetle’s development. It shows the regional status of the beetle’s development. WSL researchers are using other computer models to try to forecast the likely impact of the beetles under climate change.

The number of spruces at low altitudes will, in future, diminish, but they will probably not die out completely. Bark beetles have natural enemies, such as chalcid and braconid wasps, which are currently reproducing and decimating the beetles. According to Martin: “In one or two years – depending on the weather – the situation could ease.”

Promoting more robust mixed forests in gaps in the forest is thus important, explains Martin, to ensure trees can withstand both voracious insects and climate change better. Instead of growing spruce for timber production, it should be replaced by more drought-resistant conifers such as Scots pine or Douglas fir (see page 21). “The bark beetle is driving the transformation of the forest.” *(bki)*

Computer simulation
of bark beetle
development in
Switzerland:
www.borkenkaefer.ch

Millions of unknown microorganisms occur in the permanently frozen ground. Some of them could produce new active substances that are urgently needed. Researchers at WSL are on their trail.

An increasing number of antibiotics are losing their effectiveness because bacteria are becoming resistant to them. As a result, some infectious diseases can no longer be treated. According to the World Health Organisation (WHO), around 25,000 people die every year in Europe alone due to resistant hospital germs. That is why scientists all over the world are searching for new antibiotics.

The biologist Beat Frey at WSL is one of them. His speciality is the microbial world in permafrost, i.e. in permanently frozen soil, which is precisely where he wants to find new active substances. “The biodiversity in permafrost is enormous,” says Beat. If you analyse the microbes found in a clump of frozen debris, you will find their genetic material is very diverse and about forty per cent of it cannot be assigned to any known species. It could be that, among the unknown organisms, however, there are quite a few that produce active new substances, including novel antibiotics. These presumably help the bacteria and fungi eliminate their competitors in the battle for scarce resources. They could be of great use in medicine. Beat is convinced: “there is a treasure trove slumbering in the permafrost.”

The first promising candidates

He and the doctoral student, Joel Rüthi, would like to unearth this treasure. The two have already isolated 1500 bacterial strains from permafrost samples, most of which come from the Swiss Alps. Joel has already tested two hundred isolates of so-called actinobacteria in the laboratory to see how well they can produce antimicrobial substances. In collaboration with the Zurich University of Applied Sciences (ZHAW) in Wädenswil, he found a promising candidate that was effective against *Staphylococcus aureus*, which is a typical hospital germ.

This seems like a success, but it should be treated with caution: “It may well be that it is not a new antibiotic, but one that is already known,” says Beat. For these often reoccur in nature. The genetic analyses currently being carried out at the ZHAW should clarify whether the researchers have found a previously unknown substance. And Joel and Beat will continue their search for other antibiotic producers that may still be lying dormant in the permafrost.

(cho)

A woman with brown hair tied back, wearing a yellow and black striped short-sleeved shirt and dark blue pants with yellow and black stripes at the bottom, is running through a lush green forest. She is smiling and looking to her right, holding a small white map or piece of paper in her left hand. The background is a dense forest with many trees and green foliage, slightly blurred to suggest motion.

Karin von Känel, Birmensdorf

“I have been doing orienteering for six years. I like the way it challenges you mentally and involves being outside in ‘nature’ in all weathers. When orienteering, children, amateurs and professionals start out together. The team spirit is great, even though it’s an individual sport.”

TRACKING CHEMICAL ELEMENTS

Karin von Känel is a chemist who works in the Central Laboratory at WSL in Birmensdorf. She analyses water, plant and soil samples that WSL researchers collect in the field. For example, she identifies nutrients like phosphorus, sodium or potassium in

soil water, as well as heavy metals. She also trains apprentices to become chemical laboratory assistants. This involves planning the young people’s assignments and acting as the contact person should they, for example, have problems at school. (bki)

FOREST “The way we have managed our forests up until now has left them vulnerable”



This oak is hundreds of years old and an obstacle for timber production. For biodiversity, however, the gnarled tree is a blessing.

It might seem that commercial forestry is incompatible with forest biodiversity. After all, what’s most efficient for timber production is a monoculture of fast-growing trees. In contrast, high biodiversity requires varied tree species, old trees and deadwood. In a recent book, Frank Krumm, a forest scientist at WSL, and 156 colleagues from 19 European countries show how the two seemingly incompatible interests can nevertheless be united under one canopy.



Frank Krumm is a research scientist in the Mountain Ecosystems Research Group.

Frank Krumm, you call upon forest owners and foresters to do more for biodiversity in the forest. But why should they?

FK: First of all, we have a moral responsibility to preserve existing

species. Secondly, more biodiversity also benefits forest owners because species diversity increases the forest’s ability to cope with change, such as global warming effects like long periods of drought. However, the way forests have been managed up to now has left many of them vulnerable. In recent years, for example, bark beetle damage has increased in Europe, and in Switzerland, the forests have also suffered from record droughts. For timber producers, this has led to massive losses.

What can we do to change this?

FK: We have to start thinking more holistically. Up until now, forestry and species conservation have

usually been kept spatially separated. In one forest you find economically favourable but vulnerable monocultures grown for timber production, while in another, the forest has been turned into a forest reserve for species protection. A better alternative would be to carry out both functions in the same forest.

That sounds like a huge change.

FK: Not necessarily, because even simple measures can have a big effect. For example, if forest owners just opt to cultivate two or three tree species instead of having monocultures, they can already make a difference. This approach is also economically advantageous for them. Suppose, for example, one tree species succumbs to a pest, the other species can compensate for the loss. And biodiversity increases because different animal and plant species depend on different tree species. We also recommend leaving more deadwood in the forest because the different decomposition processes it undergoes are vital for many microorganisms, fungi, insects and birds. Keeping old, hol-

lowed-out trees, which provide a habitat for many tiny creatures, is equally important. Having just a few such old trees 100 metres apart from each other already promotes biodiversity.

In your book, you also describe existing projects that combine wood production with biodiversity.

FK: Yes, one example is the special forest reserve in the municipality of Amden in Canton St. Gallen. The forest there was designed to provide an ideal habitat for the endangered capercaillie. This involved, for example, thinning out some areas and keeping large trees suitable for perching and roosting. As a result, the capercaillie population has made a good recovery. The municipality still, however, sells timber, and has accepted that it now sells less than if the forest were primarily geared to timber production. (sru)

<https://forbiodiv.wsl.ch/en/the-book>

FOREST The Douglas fir: a controversial tree for the future

Foresters love them. The Douglas fir (*Pseudotsuga menziesii*) is a coniferous tree species from North America that grows quickly and provides valuable wood. In Switzerland, it has been cultivated since 1850 and today accounts for 0.3 % of the wood stock.

As a robust and efficient conifer, it is considered a possible alternative to spruce on the Central Plateau in the light of climate change. Spruce is

a very important source of timber, but is threatened by storms, drought and beetle infestations (see also page 16). The Douglas fir, on the other hand, tolerates drought well and tends to be less severely attacked by native bark beetles.

“Many forestry enterprises are now planting groups of Douglas fir in the gaps created through sanitary felling of beetle-infested timber,” says



In its native habitat on the Pacific coast of North America, the Douglas fir grows over a hundred metres high. In Switzerland, the largest specimen is 63 metres tall.

Thomas Wohlgemuth, a forest ecologist at WSL. But conservation experts are alarmed: they worry that the exotic species could spread uncontrollably and displace native plants and animals.

Young Douglas firs have a hard time

Tom and his team have checked whether these concerns are justified. They looked for young trees in 39 old stands of Douglas fir. In 34 of them, less than five percent of the young growth was Douglas fir. The trees require a lot of light when young, and

foresters have to actively remove competing trees. Only on three dry, barren sites in Ticino and Valais did the researchers find dense young growth of Douglas fir.

In intact forests on the Central Plateau, the Douglas fir cannot spread by itself. It can thrive in dry locations, and can also be easily cut down. But is it a threat to biodiversity? Tom surveyed the literature and found 34 studies on the topic. It seems fewer insects and spiders live in Douglas fir crowns than on native beech, oak and spruce. They therefore attract fewer insectivorous bird species. Moreover, fewer species of fungi were found in the soil under Douglas firs. Nevertheless: “As long as Douglas firs only occur as individual trees or in small groups, they pose little threat to the overall biodiversity in the forest.”

Tom thinks Douglas firs are acceptable in suitable locations on the Central Plateau so long as they are in mixed stands and do not grow on a large area. He recommends biodiversity monitoring on larger plantations. “Douglas firs alone will not compensate for the loss of spruce. Cultivating it is just one of several strategies to make forests and forestry fit for climate change.” *(rkü)*

Lukas Dürr, Davos

“Grüschler Älpli is a magical place with lush alpine meadows and gnarled old trees. The rugged rocks of the Rätikon provide a sharp contrast and for me a place to go climbing – a great passion of mine.”



PREDICTING AVALANCHE DANGER

Lukas Dürr is an avalanche forecaster at SLF and a mountain guide. He enjoys – in both professions – having to deal with natural hazards and with people. As an avalanche forecaster, he wants to produce avalanche forecasts that are as accurate as

possible so that all those who go off-piste have a good basis for planning their tours. “Being an avalanche forecaster is a dream job for me. I like the variety: producing forecasts, leading training courses and supervising our observers.” (sni)

LANDSCAPE European city-planning should pay more attention to findings from research



An oasis in the city: parks like the Parco delle Cave in Milan (above) ideally form the backbone for planning urban regions.

For thousands of years, we humans have shaped landscapes to suit our purposes. We have built roads and settlements, cleared forests, drained marshland and altered watercourses. “Landscapes became complex mosaics a long time ago,” says Anna Hersperger, a landscape researcher and member of the WSL directorate. The pieces in these landscape mosaics fulfil very different functions for us humans. Natural areas, for example, can provide places for recreation, improve a city’s quality of life and, at the same time, promote biodiversity. “This interplay between landscape and people is particularly important in the development of urban regions,”

says Anna. Together with her team, she investigated the extent to which such a holistic view is taken into account in the planning of urban regions.

Transformed cities: from industrial to service economies

The researchers analysed in their study the spatial planning documents for 18 European urban regions, ranging from Helsinki in the North to London, Berlin, Milan and finally Lisbon in the South. As Anna explains, “Many of these urban regions are undergoing a transition from the industrial age to modern service

economies.” In Milan or Turin, for example, the huge sites of the former car industry have become obsolete and require sensitive redevelopment. Each city faces different challenges. Analysing their spatial planning documents should clarify the importance of landscape as a holistic concept in the planning of these urban regions. The team also wanted to find out whether relevant findings from research have been incorporated into planning.

Many of the documents they analysed do, the researchers found, incorporate findings from research. For example, they take into account the way particular changes in the landscape can affect biodiversity or the recreational value of a natural area. But their analysis also revealed shortcomings. For example, only half of the strategic plans consider multiple perspectives with all the different services a landscape provides, such as those supporting recreation and the local population’s health, ecological functions, such as biodiversity, or aesthetic aspects. The other plans deal with only one or two of these aspects.

In practice, however, the documents should help professional planners to coordinate how best to take into account different functions. For example, what kind of places for recreation do the residents in a new development area need locally in order to feel comfortable? How will new roads disrupt wildlife habitats? “This is why such a holistic view should already be integrated in the planning documents,” says Anna.

The analysis also shows that, although most plans do take the landscape into account, it only plays a subordinate role. It is often only mentioned in the concrete measures. Anna thinks: “More attention would

be paid to landscape if it were already central to the overall planning goals.” This would make it easier, for example, to ensure the main transport axes are clustered because: “It is difficult to design a diverse landscape if it is crisscrossed with traffic routes.”

People have to get involved

Finally, the analysis showed that, in most urban regions, governance processes could be improved. Anna refers to the “integrative power of the landscape”, and says: “It would make sense to make the interaction of landscapes and people more central in planning.” All the actors who are shaping landscapes, such as farmers, landowners, and organisations that promote biodiversity or recreation, should be included throughout the planning process. Shaping the landscape in a targeted way today requires political decisions and committed local people, Anna says. “This means you have to keep offering people opportunities to get involved.”

(sru)

LANDSCAPE Science on foot: Eight hikes to WSL research sites in Valais

Valais is the sunniest region in Switzerland and, with its high mountains, a Mecca not just for tourists but also for environmental research. “Why not combine the two?” thought Thomas Wohlgemuth, an ecologist at WSL. Together with Christine Huovinen from WSL’s Communications Unit, he has produced a hiking guide entitled: “Hiking where others do research”. It contains eight hikes that take you to different sites in central and upper Valais where WSL has been doing research for, in some cases, over thirty years.

One important topic for both research and tourism is dealing with natural hazards such as avalanches, debris flows or rockfalls. The hikes take you to many places where equipment is installed for experiments to investigate these hazards. Valais is a dry region, and thus also ideal for seeing early warning signs of changes arising from global warming. This is

why WSL researchers are studying dehydrated pines and the impact of forest fires.

The book, and the practical web app that accompanies it, include some surprising detours, for example to a protection forest with a traditional ‘bisse’ or ‘Suone’ (open ditch) irrigation system. Among the suggested routes are tourist classics, such as the Aletsch Glacier and the Lötschental. Some less well-trodden paths are equally appealing, for example to the Vallée de la Sionne, where the SLF is carrying out extensive avalanche tests.

The hiking book is an entertaining answer to the frequently asked question “What do you researchers at WSL actually do?” It should not be missing on the bookshelf of any fan of hiking, environmental science or Valais. *(bki)*

The book is available in German and French from Haupt Verlag, hiking.wsl.ch



The Bhutan Bridge leads over the Illgraben, known for its numerous debris flows. WSL researchers have been monitoring and investigating these for years.

Photo: Christoph Graf, WSL

BIODIVERSITY Long wings, small bodies: Land use determines insect characteristics

Intensive or extensive? How people manage the land determines not only which species can occur in a habitat, but also their characteristics. This, Felix Neff, a doctoral student at WSL, was able to show on the basis of his studies of cicadas, bugs and grasshoppers in grasslands that are used with varying intensity.

The insects were caught between 2008 and 2016 in the nets of researchers who were recording data as part of the large-scale project 'Biodiversity Exploratories' of the German Research Foundation DFG. Felix measured various physical characteristics of insects belonging to species determined by experts. Those species occurring in intensively used areas had longer wings and smaller bodies than those from extensively used sites. "These features make the insects more mobile. If the grass is cut frequently, they can escape more easily to surrounding areas," says Felix, "whereas larger species are more likely to be killed." Land-use intensity thus acts like a filter, favouring certain physical traits in insects and discouraging others.

This can also have an influence on ecosystem processes. "If only small insects are present in a meadow, they may eat less than large ones, and the biomass production of the meadow would then be correspondingly higher," says Felix. Whether insect feeding rates are actually lower in intensively used areas is something he is investigating in another study. (lbo)



The Rufous grasshopper (*Gomphocerippus rufus*) prefers tall grass and therefore tends to occur in extensively used areas.

www.wsl.ch/funcnet-en

BIODIVERSITY Plastic waste in the soil alters the communities of bacteria and fungi



Collecting soil samples in Greenland: countless bacteria live in cold soils, including those that colonise plastic waste.

Plastic accumulates not only in oceans and rivers, but also in the soil. Researchers at Empa, the Swiss Federal Laboratories for Materials Science and Technology, have calculated that about forty times more plastic in Switzerland ends up in soil than in water. Little is known about how this affects soil organisms, especially those in alpine and arctic soils, which react particularly sensitively to environmental changes.

That's why the WSL biologist Beat Frey and PhD student Joel Rüthi have been investigating the effects of plastic on bacteria and fungi in cold soils. The microorganisms play an important role in soil health and fertility because they, among other things, break down organic material and

provide nutrients for plants. "Our assumption was that plastic changes the species composition in the soil," says Beat. Such an effect is known to occur in the ocean, where the bacterial communities that settle on floating plastic particles differ from those in the surrounding seawater.

Joel conducted a laboratory experiment with Alpine soil samples from a mountain near Pontresina in the Grisons and Arctic soil samples from northern Greenland. He placed the samples in containers and buried small pieces of plastic – two types of biodegradable plastic and non-degradable polyethylene – in them. The 'Alpine' containers were then kept at 15 degrees Celsius for two months, while the 'Arctic' samples were stored for four months to simulate Arctic summer conditions. Afterwards Joel dug out the plastic pieces again and analysed the DNA of the microorganisms that had grown on their surfaces.

The results showed that the fungi and bacteria on the plastic differed in composition from those in the soil that had not come into contact with the plastic. Moreover, on the plastic, the bacteria in particular were less diverse. "Our study is the first to demonstrate such effects in soils from cold regions," says Beat. The phenomenon has, however, up until now received little research attention and no clear conclusions can be drawn about its effects on the ecosystem.

Hunger for bioplastics

The changes in the bacterial communities found on the biodegradable plastics were significantly greater

than those on the non-degradable polyethylene. The reason for this is clear: for certain species of bacteria, biodegradable plastic is like being served food on a plate. For them the plastic is food, which they decompose. The researchers found several known 'plastic eaters', but also some new species. The decomposition process in cold soils seems, however, to be very slow. In the experiment, hardly any differences could be seen after two months, and only after four months did the first signs of decomposition appear. "It may take years

for the material to completely disappear," says Beat. "That's why even supposedly environmentally friendly, biodegradable plastic should not be released without some form of control into the environment." (cho)

BIODIVERSITY The mires in Rothenthurm are becoming drier

Despite conservation efforts, many Swiss mires are developing in an undesirable way: they are becoming drier. Some of them are becoming overgrown with vegetation, and too many nutrients are accumulating in them, especially in raised bogs. Canton Schwyz wanted to know whether this is also happening to the Rothenthurm mires, especially those in Schwyz. The plan to establish a military training area there was what triggered the Rothenthurm Initiative, and led to the protection of mires of national importance being written into Swiss law in 1987. On behalf of the canton, a WSL team led by the biologist Meinrad Küchler carried out a survey of the mires in Rothenthurm thirteen years after the previous assessment.

The results are sobering: the mires there are developing in the same way as in other places in Switzerland. The sites are not getting enough water, and some rare species such as the sedge *Carex heleonastes*



The area with protected mires in Rothenthurm is still largely intact, but the quality of the habitats is steadily declining.

have disappeared. "The current rehabilitation projects are essential and must be continued," says Meinrad. This means filling in more drainage ditches and regularly removing bushes. "This is the only way to preserve this special habitat." (lbo)

High insect diversity in Zurich thanks to a mosaic of habitats

Cities provide diverse habitats with a mix of built-up and open areas and a variety of green spaces. They are also warmer and drier than the surrounding countryside. A team led by the WSL biologists Marco Moretti and David Frey wanted to find out how these living conditions affect the species composition of insects in the city, especially ground beetles and wild bees, and what characteristics they have.

The researchers therefore collected insects on various green spaces in the city of Zurich and determined their species. They also consulted data from earlier WSL surveys. One of the things they were able to show is how surprisingly diverse the species are, as each green space has its own insect community. For example, you are more likely to find smaller wild bee species with shorter tongues in gardens than on flat roofs and in parks. “The plants people se-

lect determine what food is available and thus which insect species occur where,” says David. They also discovered differences among the ground beetles. The species they found in sun-exposed allotment gardens are better adapted to drought than those that occurred in private gardens.

Their results show how important urban green spaces are for biodiversity. However, more demanding species such as large ground beetles or cuckoo bees have difficulty becoming established in cities because the habitats there are often too small or isolated, and may change very quickly. More efforts are therefore needed, says David, to stop further biodiversity loss through urbanisation. *(lbo)*



With the right choice of plants, even rather rare species of wild bee may be attracted to visit private gardens and allotments, like this carpenter bee harvesting nectar from a vetch.

NATURAL HAZARDS Potential ice avalanches: expertise helps authorities decide what to do



The Planpincieux glacier in the Mont Blanc massif: large masses of ice are threatening to break off.

The Planpincieux Glacier is located on the Italian side of Mont Blanc. A huge mass of ice is threatening to fall from this glacier into Val Ferret (in the Aosta region) – a worrying situation for the local population and guests in the valley. The glacier made negative headlines in August 2020 when it was thought that 500,000 m³ of ice were about to break off. Fortunately, the situation calmed down after a few cooler days.

But the danger has not been averted. The road leading into the valley is, in particular, cause for concern, not least because the valley lives from tourism. “There is great pressure on the authorities to keep the access road open,” says Stefan Margreth, head of the Avalanche Protection Measures Group at SLF. His expertise should help the Italian authorities responsible with their decisions. Using the SLF software RAMMS, he simulates scenarios with

different break-off volumes to determine the necessary safety measures. He also calculates how far avalanches could advance into the valley in winter if masses of ice were to fall on an unstable layer of snow. In a worst-case scenario, parts of the village of Planpincieux could be buried. Stefan believes, however, that this is unlikely to happen because not only would the avalanche danger have to be very high, but also the break-off volume would have to be at a maximum. Smaller ice avalanches are nevertheless still possible at any time. Since 2019, the glacier has therefore been monitored by radar and an alarm system has been installed. *(sni)*

SNOW AND ICE Research in the Arctic: accurate climate forecasts require precise snow data



Amy Macfarlane, a researcher at SLF, took part in the recent MOSAiC expedition. Here she is wading through a meltwater pond to take a new device, the so-called 'NIRbox', to a snow profile.

In autumn 2020, the largest Arctic expedition ever came to an end. Its name, MOSAiC, stands for 'Multi-disciplinary drifting Observatory for the Study of Arctic Climate'. For over a year, researchers let themselves drift on board the icebreaker 'Polarstern', frozen in the ice, towards the North Pole. Scientists from various research fields used highly sophisticated instruments to study, for the first time, the interaction between the Arctic Ocean, the atmosphere and the ice over the course of the year.

The Arctic plays a key role in climate warming. What happens to it has an impact on the whole planet. "When the sea ice melts, it has an impact on the global climate – and also on the whole food web in the Arctic Ocean, ranging from the algae to the

polar bears," says Martin Schneebeli. He is head of the Snow and Permafrost Research Unit at SLF and took part, together with four WSL colleagues, in the MOSAiC expedition. It may seem surprising at first glance that Swiss researchers were also among the participants from twenty nations. Martin explains: "We were not only in demand as researchers, we were also able to supply the best snow instruments, including the micro-computer tomograph." This instrument was used by the so-called 'ice team', to which Martin also belonged, to analyse snow samples three-dimensionally.

Snow is a big unknown in the climate puzzle. Until now, it was not clear exactly how much snow falls in the Arctic and what physical and

chemical processes take place in the Arctic snow cover. Snow is a material that is always relatively close to its melting point. This means transformation processes, i.e. changes in microstructure also known as ‘snow metamorphosis’, are constantly taking place. The researchers were able to study these processes for the first time in Arctic snow samples using a computer tomograph. “The snow cover has never before been measured so precisely and over the entire annual cycle,” says Martin. “We found the changes in the snowpack are more dynamic than previously thought.”

The quantity and structure of the snow are decisive

The physical properties of snow – such as how much light it reflects or how much heat it transports – depend on the structures of the snow crystals. For example, large snow crystals reflect less sunlight than smaller ones. Moreover, whether and how much snow is lying on the ice influences whether the ice grows and when it begins to melt. When the sun shines more intensively and longer in spring, the snow cover protects the sea ice. If the snow eventually melts, ponds of melt water form on the ice. Their dark water surfaces absorb a lot of solar energy and warm up, which further accelerates the melting of the ice.

Amy Macfarlane, a doctoral student at SLF, also spent six months on the expedition and was able to experience these melting processes firsthand during the Arctic summer. She also succeeded in studying one special type of snow – summer snow – in the computer tomograph. This does not fall from the sky, but is formed from sea ice through trans-

formation processes. “We have studied snow in all its stages and hope to gain new insights from this,” says Amy.

The very extensive measurements taken during the course of a whole year are now available. The resulting data is being fed into the climate models and should make them more accurate, which was the main goal of the MOSAiC expedition. The data is being evaluated at top speed, but will keep the teams busy for a while yet. *(sni)*

www.slf.ch/blog-mosaic-en



The research vessel ‘Polarstern’. The expedition’s goal: to explore the Arctic over the course of a year.

Fabian Bernhard, Birmensdorf

“The Platzspitz park is one of my favourite places in Zurich because it is so full of contrasts and history. Here ‘nature’ meets the city, the wild Sihl river joins the leisurely Limmat and the past mixes with the present.”



FORESTS UNDER DROUGHT STRESS

In his doctoral thesis, the environmental engineer Fabian Bernhard is investigating how drought affects forests. He is using, to this end, a computer model to map water processes in the soil in order to be able to predict the soil water available

at different locations and different soil types. In the field, he takes samples from soils and trees and tracks the path of the water with the help of stable isotopes. “I like being able to combine basic and applied research.” (lbo)



In the next Diagonal we will take you on an expedition: whether in Africa, Siberia or Spitzbergen, WSL scientists frequently undertake major research trips. They collect data in remote areas to answer global questions, for example about snow distribution in the Arctic and about past climates, using information recorded in old wood. But there is also a lot to discover in Switzerland – on mini-expeditions to bogs and mountain peaks.

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

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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

THE RADIOMETER

Electronics

Antenna holder

Power supply

Scaffolding

Horn antenna



Satellites measure soil moisture on the Earth in order to better understand the global water cycle and to increase the reliability of weather forecasts. Radiometers, which were developed at WSL, among other places, are used for comparative recordings on the ground. They have been installed, for example, in Davos Laret (CH) and on the Tibetan plateau. The measurements of the microwave radiation provide the basis for calculating how much water is present in soils, vegetation and snow.

Video at:
www.wsl.ch/object



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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.

