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Long-term ecosystem monitoring and research at LTER Zöbelboden – 20 year anniversary

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Abstract

The long-term monitoring and research site "LTER Zöbelboden" has been used for two decades to record trends in several hundreds of environmental parameters. The montane site of 90 hectares size in the Northern Limestone Alps has become the best examined karst forest ecosystem in Austria. Based on the measurements from Zöbelboden, the effects of air pollution and the consequences of climate change for ecosystems are analysed. Findings show that excessive nitrogen deposition disrupts the ecological balance of forest ecosystems leading to a loss in biodiversity and putting their protective function at risk. More frequent disturbances by windthrow and bark beetle infestation as a consequence of climate change are likely to reduce the carbon sink function of forest stands. Even though the deposition of lead and cadmium has decreased by 70 – 80 % due to emission abatement measures in the 1990s, heavy metal pollution in ecosystems is still an environmental problem today. As transport or leaching of heavy metals into deeper soil layers happens much more quickly than assumed, the high inputs from the 1980s may pollute the groundwater, water ecosystems and finally our drinking water after only a few decades. Half of the Austrian population is supplied with drinking water from karst areas. The results of karst-hydrological measurement and modelling at the Zöbelboden allow estimations of changes in water quality and water supply, thus enabling scientists and water suppliers to develop adaptation strategies. Long-term data collected at the Zöbelboden, in combination with research projects and models, provide an ideal basis for the interdisciplinary development of perspectives and solutions to a variety of environmental problems on national as well as on international level. LTER Zöbelboden is one of 35 sites in the national network "LTER-Austria" and therefore also part of "LTER-Europe", which involves more than 400 research sites, 100 institutions and thousands of research projects within 21 national networks.

Keywords

Forest, nitrogen deposition, heavy metals, carbon budget, biodiversity

Introduction

The Zöbelboden site in the "Reichraminger Hintergebirge" mountains is the core element of long-term ecological monitoring and research (LTEM/LTER) in Austria. This ideally equipped site has been used for two decades to record trends in several hundreds of environmental parameters (Figure 1). Based on these parameters, the Umweltbundesamt analyses the consequences of climate change and the effects of air pollutants on whole ecosystems. Within 20 years of continuous measurement and evaluation, and supported by substantial contributions from the Kalkalpen National Park and the Austrian Federal Forests, the site has become the best examined karst forest ecosystem in Austria. The Zöbelboden site is Austria's contribution to the Integrated Monitoring programme of the United Nations which is aimed at a better understanding of cause-and-effect relationships in ecosystems. It is part of a close-knit network of research projects and monitoring programmes. These include LTER-Europe, Global LTER, ALTER-Net, ESFRI/LifeWatch, EBONE, EXPEER und Life+ EnvEurope. Harmonised Europe-wide measuring methods and standards allow trans-boundary environmental monitoring, which provides the basis for effective air pollution policies and the development of adaptation measures to climate change (www.umweltbundesamt.at/oekosystem_monitoring).

Site description

LTER Zöbelboden has a size of 90 hectares and is situated in the northern part of the Kalkalpen National Park (Northern Limestone Alps), approximately 50 km south of Linz (N 47°50'30", E 14°26'30"; www.umweltbundesamt.at/im). The altitude ranges from 550 m to 956 m a.s.l. The main rock type is Norian dolomite (Hauptdolomit), which is partly overlain by limestone (Plattenkalk). Due to the dominating dolomite, the watershed is not as heavily karstified as limestone karst systems, but showing typical karst features, such as conduits and sink holes. These conduits and sink holes provide pathways for rapid water flow and quick response times to water input at the soil-bedrock interface. The long-term average annual temperature is 7.2 °C. The coldest monthly temperature at 900 m a.s.l. is -1 °C in January, the highest is 15.5 °C in August. Annual rainfall ranges from 1500 to 1800 mm. Monthly precipitation ranges from 75 mm (February) to 182 mm (July). Snowfall occurs between October and May with an average duration of snow cover of about 4 months.

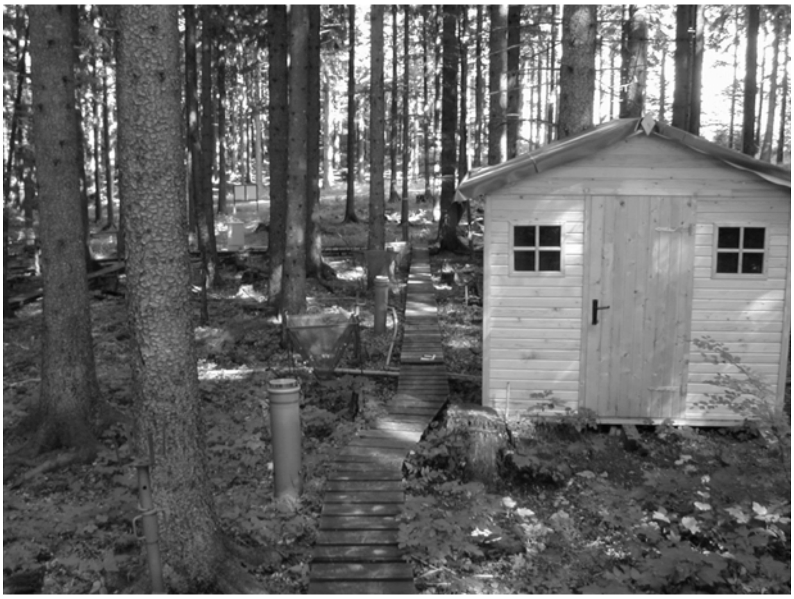

Figure 1: Forest ecosystem processes and element cycling are continuously measured at three intensive plots (Foto: Umweltbundesamt)

The watershed can be divided into two distinct sites: A very steep (30 – 70°) slope from 550 – 850 m a.s.l. and an almost flat plateau (850 - 956 m a.s.l.) on the top of the mountain. The areal coverage of each site is 50 % of the watershed. At each site, intensive plots have been selected for comprehensive measurements of hydro-chemical variables. Intensive plot I (IP I) is located on the plateau where Chromic Cambisols and Hydromorphic Stagnosols are found. Intensive plot II (IP II) is located on the slope and dominated by Lithic and Rendzic Leptosols. The mean slopes are 14° at IP I and 36° at IP II. IP I is dominated by a Norway spruce (*Picea abies*) following plantation after a clear cut around the year 1910, whereas a mixed mountain forest with beech (*Fagus sylvatica*) as the dominant species, Norway spruce (*Picea abies*), maple (*Acer pseudoplatanus*), and ash (*Fraxinus excelsior*) covers IP II. After wind and bark beetle damage at IP I a third intensive plot (IP III) has been established in the year 2008 representing the plateau ecosystem. IP I is still used for studying the effects of disturbance on these ecosystems.

Selected Results

Excessive nitrogen disrupts the ecological balance of forests

The natural ecosystems of today are exposed to nitrogen levels which are 5 - 10 times higher than in preindustrial times. The causes of these elevated nitrogen levels lie in the use of fossil energy sources, animal husbandry and the fertilisation of agricultural land. At the LTER site Zöbelboden, total nitrogen deposition in the forest amounts to about 30 - 40 kg/ha/year. As a rule, forest ecosystems tend to be more exposed to air pollutants than other land use forms. At the LTER site for example, the site-specific limit value for eutrophication, measured on the basis of open field deposition according to the Critical Loads of the UNECE, is complied with – whereas the same limit value is considerably exceeded in the forest. Forests respond to excessive amounts of nitrogen in different ways: While the spruce stand at the Zöbelboden site deposits large amounts of nitrate in the groundwater in some years, efficient nitrogen fixation is achieved in the mixed beech forests (Jost et.al 2011). Nitrate losses are a certain sign of excessive inputs of nitrogen in forest ecosystems. Apart from disruptions of the nutrient cycle, there is also a negative impact on biodiversity. Loss of lichen, moss and vascular plant diversity will occur in the long term. In addition the protective function of the forest will be impaired (Zechmeister et al. 2007, Hülber et al. 2008, Dirnböck & Mirtl 2009, Diwold et al. 2010, Pröll et al. 2011). Epiphytic lichens growing on trees are a particularly good indicator of nitrogen effects (Figure 2). While the lichens have been recovering slowly when the acid rain has subsided in the 1990s and 2000s, many species are lost today as a result of nutrient accumulation. At the Zöbelboden site, epiphytic lichen diversity declined dramatically since 2005. This was caused by an exceedance of limit values for nitrogen inputs for many years. Excessive nitrogen levels putting the protective function of ecosystems at risk are a Europe-wide issue. Based on measurements at monitoring sites the UNECE working groups prepare the principles and methods of emission reduction policies.

The impact of storms and bark beetle on forests which are CO2 sinks

Disturbances such as windthrow and bark beetle infestation are part of the natural development and dynamics of forest ecosystems. As a consequence of global climate change, however, the negative effects from such disturbances are accumulating and leading to an increasing damage frequency worldwide. How disturbances from small-scale windthrow events and bark beetle infestation affect the carbon balance of a montane forest has been investigated at the LTER site Zöbelboden. A disturbed old-growth forest stand was compared with an adjoining undisturbed forest. The carbon balances show that both forest stands are carbon sinks. However, the carbon budget for the disturbed forest is almost balanced. If the disturbance intensifies, which can be assumed, the forest stand will become a carbon source. This is due to the decreasing carbon sequestration of the forest stand, combined with an increased decomposition of organic soil matter caused by higher soil temperatures. The results show that more frequent small-scale disturbances from windthrow and/or bark beetle infestation in the investigated area are likely to reduce the carbon sink function of the forest. The further development of the carbon balance depends on many factors and is the subject of a variety of research projects.

Figure 2: Finger cup lichen (*Cladonia digitata*) at Zöbelboden (Foto Roman Türk).

Heavy metal deposition on the decrease since the 1980s

The Industrial Revolution and especially the economic boom after World War 2 resulted in a dramatic rise in heavy metal emissions in Europe. Thus, heavy metals were increasingly deposited via (long-range) transport even in remote ecosystems such as the LTER site Zöbelboden. The higher the concentrations, the higher became the potential threat to fauna, flora and to ground and drinking water. Against this background, the Protocol on Heavy Metals to the 1979 Convention on Long-range Transboundary Air Pollution (CLRTAP) was adopted in Aarhus (Denmark) in 1998. One of its most important aims is the reduction of the three heavy metals lead, cadmium and mercury below their levels in 1990. This target has been successfully achieved in the case of lead and cadmium due to emission abatement measures such as eliminating lead from gasoline. Checking the effectiveness of such measures is one of the tasks of the international cooperation project „Integrated Monitoring" of the UNECE. The data measured at Zöbelboden show that the amounts of heavy metals from long-range transport ending up in Austrian forests are much smaller today than only a few years ago (Figure 3). Loads of particularly harmful heavy metals (cadmium, lead) remain far below the applicable guidance and limit values and are much lower than the values measured in forest ecosystems in the 1980s. Lead and cadmium concentrations have decreased by 70 - 80 % (Umweltbundesamt 2009). At the same time, it has been shown that cadmium and lead pollution in ecosystems is still an environmental problem today. Transport or leaching of heavy metals into deeper soil layers happens much more quickly than initially assumed. Up to now, experts had expected heavy metals to remain bound up in the soil for a period of 100 up to 200 years. Data collected at the Zöbelboden site have proved this hypothesis wrong. They provide information about reaction times in different soil types (Kobler et al. 2010). Thus, the high heavy metal inputs from the 1980s may be leached into the groundwater, pollute water ecosystems and finally our drinking water after only a few decades.

Figure 3: At LTER Zöbelboden, airborne heavy metals are monitored in the course of the Austrian Ambient Air Quality Act (Foto: Umweltbundesamt).

Hydro-geochemical monitoring and research

In Austria 50 % of the population is supplied with drinking water from the karst areas of the Northern and Southern Limestone Alps. Pollutant inputs and climate change disturb the functionality of the ecosystems in these catchments. Extensive karst-hydrological measurement and modelling activities at the Zöbelboden allow estimations of how the water supply for the population will change and how the water suppliers can adapt to the new conditions (Figure 4; HUMER & KRALIK 2008, HARTMANN et al. 2011). In tracer experiments was shown how precipitation seeps into deeper-lying systems and reaches the surrounding watercourses through the springs. It was also shown how the water moves at different speeds through the rock fissure system. While the tracer substance could be detected within a day at some of the springs, traces of the same substance were still found at another spot four years after the experiment. Age detection with CFCs, tritium and helium has shown mean residence times of 20 years or more at some of the springs in the area (KRALIK et al. 2009). Special sampling and analytical methods reveal how pollutants pass through the mountain massif during heavy rainfall events. Based on the analysis of data collected at the Zöbelboden a hydrological prediction model shall allow a scientifically sound assessment of changes in environmental conditions. Coupling long-term assessment and model development makes it possible to place the findings in a larger context. One example is the EU ORIENTGATE project, which investigates how climate change affects nitrate leaching. Measurements at the Zöbelboden have shown that during the snow melting period and during thundery summer showers increased levels of nitrate are found in the spring water. Researchers intend to find out whether increased nitrate concentrations will occur more often in future and how water suppliers can prepare themselves for this situation. Here not only climate change plays an important role but also forest management, since excessive timber harvesting and soil damage lead to additional nitrate loss. The long-term data collected at the Zöbelboden, in combination with individual research-oriented projects and models, provide an ideal basis for the interdisciplinary development of perspectives and solutions to a variety of environmental problems.

Figure 4: At LTER Zöbelboden, long-term physical and chemical runoff data is collected at measurement weirs (Foto: Umweltbundesamt).

The future: LTER Zöbelboden as part of the European Long-term Ecosystem Research Network

Since 2012 LTER has been part of the International Programmes of the Austrian Academy of Sciences. This ensures that the results from the Zöbelboden site are linked to other research projects and strategies, bringing Austria one decisive step closer to the early detection of environmental problems, the precautionary principle and sustainable development. Since the 1970s sites of long-term ecosystem research have mostly been defined in terms of their natural characteristics (e.g. catchments of small water bodies). They were limited in size (10 – 1000 hectares) and, preferably, they were semi-natural areas with protection status. At the beginning of the 21st century intensive discussions started about the future orientation of existing and planned LTER networks. Sustainable preservation of essential ecosystem services against a background of global change had been the central political goal formulated prior to the discussions. In Austria, the available LTER infrastructure was consolidated, too. The national network "LTER-Austria" involves 35 LTER sites including the Zöbelboden (http://www.lter-austria.at). With their group („Trägerverbund") of highly instrumented forest sites, the University of Natural Resources and Life Sciences, the Federal Research Centre for Forests and the Environment Agency Austria demonstrate their commitment to cooperation and to the maintenance of their LTER sites. LTER Austria is part of LTER Europe, which combines more than 400 research sites, 100 institutions and thousands of research projects within 21 national networks, covering the full range of European ecosystems from the Arctic and alpine sites to Mediterranean ecosystems (http://www.lter-europe.net). By aligning these sites with European standards it becomes possible to identify long-term ecological changes on different scales – from local to continental – and to interpret them. To meet the requirements of modern ecosystem research the ecosystem concept was broadened by integrating social, economic as well as demoscopic aspects and aspects of historical use. LTSER symbolises traditional ecosystem research with the added human factor. LTSER platforms are selected regions with sophisticated research networks combining several scientific disciplines and working in close interaction with local communities, regional developers and decision makers. In Austria, two LTSER platforms are being implemented: „Tyrolean Alps" in the Ötztaler and Stubaier Alps and „Eisenwurzen" in the Northern Limestone Alps (http://www.plattform-eisenwurzen.at). The Zöbelboden and other classic LTER sites represent important ecosystem types of the Eisenwurzen area. With the integrative LTSER approach it is possible to deal with issues from the region in an interdisciplinary manner and to provide results relevant to society and facilitating decision-making in favor of sustainable development at local, regional and national level.

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