# 1 Introduction

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## 1.1 General Introduction

Terrestrial ecosystems can be defined as functionally or structurally discrete units of the landscape. Primary and secondary produces are necessarily parts of terrestrial ecosystems as well as abiotic compounds, namely those that are involved in feedbacks to organisms and to the environment. The latter is the case for various soil components, like organic matter, exchangeable ions, some secondary minerals and the soil solution, which are all considered as part of the ecosystem. Furthermore, the atmospheric surface layer (Prandtl layer) which is influenced by the structure of the vegetation can be considered as part of the ecosystem. On the other hand, the primary soil minerals are considered as part of the environment of the ecosystem, since the mineral composition is mostly geogene and only to a minor extent affected by the organisms of the ecosystem at time scales relevant to ecosystem research. The element release by irreversible weathering of minerals is then seen as an external input (Ulrich 1992).

Tansley (1935), who introduced the term 'ecosystem' in 1935, views the ecosystem as "the basic unit of nature on the earth surface". The integration of abiotic and biotic compounds and their interaction through feedbacks differentiate the ecosystem from other levels of biological organization.

Forest ecosystems fulfil various functions that are important for humans: biomass production, habitat, immobilization of air pollutants, regulation of water and elemental cycling, erosion control and recreation. These functions are used by society to a different degree depending on local conditions and priorities. Besides the use of timber, in Germany, forest ecosystems have become more and more important for ground- and surface water as well as for recreation. While society benefits from forest ecosystems, their functioning has changed in the past and continues to change in the future due to alterations in environmental conditions and management practices. These changes may sometimes be seen as beneficial, as in the case of increasing growth rates of timber (Kauppi et al. 1992; Spieker et al. 1996; Mund et al.

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2002) or C-sequestration (Goodale et al. 2002), but sometimes they may also be detrimental to ecosystem functioning, as in the case of acidification and eutrophication (Fenn et al. 1998; Alewell et al. 2000a).

Ecosystem research is relatively young in comparison to other ecological disciplines. Milestone projects of forest ecosystem research started in the 1960s with the well-known Hubbard Brook catchment study in the United States (Likens et al. 1977) and the German Solling project (Ellenberg et al. 1986). In the Solling project, the detrimental effects of atmospheric pollution on forest ecosystems were first highlighted and the widespread decline of forest ecosystems forecasted (Ulrich et al. 1979). In fact, forest decline phenomena were recognized at the beginning of the 1980s in many regions of Europe and have initiated a large number of research projects in the following years on the functioning of forest ecosystems and the potential reasons for the decline. A synthesis of these is given in Schulze et al. (1989a), Ulrich (1989a) and in Kratz and Lohner (1997).

By the end of the 1980s, German forest ecosystem research was concentrated in 'ecosystem research centers', namely the Forest Ecosystems Research Center at the University of Göttingen, the Bayreuth Institute of Terrestrial Ecosystem Research (BITÖK) at the University of Bayreuth and the Höglwald-Project at the Ludwig Maximilian University in Munich, all working on more basic research questions related to environmental conditions affecting forest ecosystem functions and structures. Recently, forest ecosystem research has focused on more applied questions related to forest management. New coordinated projects were established in addition to the existing research centers at the University of Freiburg, the University of Dresden and at the Forest Research Institute in Eberswalde.

## 1.2. Goals and Approaches of BITÖK Research

The general task of ecosystem research, and also at the Bayreuth Institute of Terrestrial Ecosystem Research, is to investigate relationships between structure and function in ecosystems and their interactions with the environment and management practices (Fig. 1.1). The evaluation of ongoing changes, the prediction of their effects, mitigation measures as well as the development of criteria for the sustainable use of forest ecosystems should be based on understanding these relationships.

The research at BITÖK is concentrating on forested catchments in the heterogeneous landscape of NE Bavaria, Germany (Chap. 2), but the activities go far beyond the studies at these sites. The approaches used to address the various questions include measurements of fluxes and structural properties in intensive sites, both at the plot and catchment scale, assessments of gradients and patterns at different scales, experiments in the field to test hypotheses at

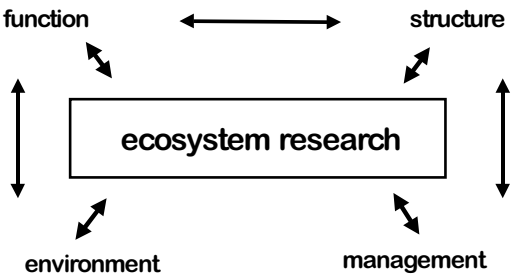



**Fig. 1.1.** General tasks of ecosystem research

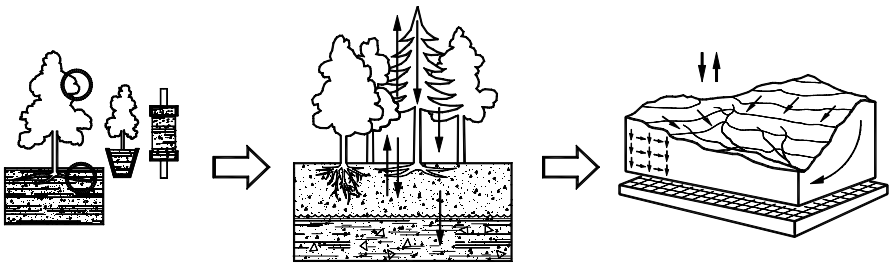


**Fig. 1.2.** Ecosystem research at different scales

the ecosystem scale, experiments in the laboratory to gain detailed process understanding, model application at different scales and regionalization using empirical indicators of ecosystem functioning (Fig. 1.2).

## 1.3. Scope of the Synthesis and Problems Addressed

This volume is a synthesis of up to 15 years of biogeochemical research at the two major study sites of BITÖK, the forested Lehstenbach and the Steinkreuz catchments in NE Bavaria.

These catchments were chosen because they each represent typical landscape units of NE Bavaria: The Lehstenbach catchment stands for higher-elevation sites on poor magmatic and metamorphic rocks, often covered by Norway spruce stands. These stands are highly affected by the deposition of air pollutants (Schulze et al. 1989a). The Steinkreuz catchment represents lower-elevation sites on acidic sedimentary rocks often covered by deciduous species, mainly European beech and sessile oak. These sites generally are supposed to be less affected by air pollutant deposition.

As will be shown in Chapter 3, the environmental conditions of forest ecosystems in Germany have changed in the last decades. Thus, special

emphasis will be given to the effects of these changes, especially to the response of water- and $CO_2$ exchange and to the cycling of mineral elements and dissolved organic matter. Furthermore, specific structure–function relations and management effects are addressed.

The **acidification of soils and waters** has been a subject of ecosystem research for more than two decades. Depletion of nutrient cations from forest soils and the release of potentially toxic Al-ions from soil minerals as a result of acidic deposition were often seen as a major cause of forest decline in areas subjected to acidic deposition (Ulrich 1989a, 1989b; Cronan and Grigal 1995; Matzner and Murach 1995; Shortle et al. 2000). There is a general consensus that acidic deposition, namely the deposition of sulfuric acid, is the cause of surface and groundwater acidification in central and northern Europe as well as in North America (Sullivan 2000). Today, under conditions of decreasing $SO_4$ and $H^+$ depositions in Europe and North America, the question of the recovery of acidified soils and waters is under debate (Stoddard et al. 1999; Alewell et al. 2000b). The time needed for recovery and the processes involved seem to differ in various regions mainly in relation to soil conditions (Jenkins et al. 2001), with soil S pools and N behaviour as the main driving variables.

In order to address this subject, we present long-term trends on atmospheric deposition of acidifying substances, on soil solution and runoff chemistry and on element budgets. We will investigate the role of soil S, deposited Ca, Mg and N for the recovery process. The role of riparian zones and of $NO_3$ and $SO_4$ reduction for the water quality in runoff will be addressed, as well as the dynamics of dissolved organic matter (DOM) and its relevance for the acidity and Al concentration of the runoff.

Central European forests have been subjected to high deposition rates of nitrogen for several decades. The **fate of deposited N and N-saturation** of the ecosystems are major questions presently addressed in ecosystem sciences. While the actual rates of N deposition in forests cannot be exactly quantified and the processes involved in the deposition of N are today not fully understood, the rates for central European forests are estimated at a range of 20–45 kg $ha^{-1}$ $year^{-1}$ (Harrison et al. 2000; de Vries et al. 2002). These rates by far exceed the N demand for the timber accumulation in a growing forest. Since the high rates of deposition have lasted for several decades, substantial amounts of N (several hundreds of kilograms per hectare) were accumulated in the ecosystems, transported to ground- and surface waters in the form of nitrate or emitted to the atmosphere as nitrose gases (Papen and Butterbach-Bahl 1999). The fate of deposited N is related to the C turnover (Schulze 2000) and a major N sink seems to be the soil.

The long-term shifts in ecosystem functioning as a consequence of N deposition are often summarized under the term 'N-saturation'. According to Aber

et al. (1989), N saturation is indicated if the storing capacity of the ecosystem is exhausted and nitrate losses with seepage and runoff exceed the natural background losses.

Considering the fate of deposited N and the time needed to reach N saturation, the soil N pool and soil N turnover are of major importance since the N pool of soils by far (often ten times) exceeds the N pool of the vegetation. The mechanisms of N accumulation in forest soils, their kinetics and limitations are yet unresolved and predictions of the N cycle in response to changing deposition and environmental conditions are thus very uncertain.

Here, we present results on the long-term development of nitrate concentrations and fluxes in soil solution and runoff in highly N-polluted forest ecosystems. Actual rates of N deposition and the role of fog deposition will be estimated. We will contribute to the fate of N by estimating the N accumulation in the forest floor during litter decomposition and we will address the role of dissolved organic N for the N turnover in the ecosystem. The effect of high leaf N concentrations on gas-exchange will be elucidated. The phyllosphere organisms and their influence on temporal and spatial patterns of throughfall N fluxes will be part of the synthesis as well as the hydrological conditions related to nitrate in runoff.

Knowledge on climatic controls of **water-vapor exchange between vegetation and atmosphere** is important to predict evapotranspiration, a significant component of the catchment water balance. The relevant controlling variables are available energy, saturation vapor pressure deficit of the air, the aerodynamic ($g_a$) and canopy conductance ($g_c$, average stomatal conductance) of the vegetation (Monteith 1965). Within these parameters, the estimation of $g_c$ is most difficult because it represents the highly sensitive reaction of approximately $10^{11}$ stomata per tree (Larcher 2001) to their highly variable micrometeorological situation. This makes $g_c$ dependent on plant internal structural and physiological variations and micrometeorological changes, as well as plant external variations in genetic properties and vegetation structure. The latter dependencies may be retrieved in spatially integrating measures of vegetation structure, e.g., the temporal and spatial variability of plant age, size, height, stand density and leaf area index (LAI) (Shuttleworth 1989; Oliver 1997). Thus, knowledge on vegetation controls must still be based on empirical estimates of $g_c$ derived and up-scaled from different levels of integration (leaf, tree, forest canopy), and the investigation of effects of vegetation change on the water balance has been confined to studies at the catchment scale (Bosch and Hewlett 1982). Structural dynamics of vegetation may be strongly influenced by human activities, e.g. increased N input or forest management practices. Therefore, predicting and valuing potential effects of environmental change requires understanding and quantification of dependencies between vegetation structure itself and atmospheric exchange processes. Up to now, plant parameters in land surface–atmosphere exchange models are

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