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MONITORING THE SWISS FOREST: BUILDING A RESEARCH PLATFORM

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1. BACKGROUND

During the late 1970s and the beginning of the 1980s, several cases of forest decline were reported in several areas of Europe. Air pollution was largely incriminated originally, which triggered the setting up in 1985 of the *International Co-operative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests* (ICP Forests), under the *Convention on Long-range Transboundary Air Pollution* (CLRTAP) of the UN/ECE. ICP Forests provides the Executive Body of CLRTAP with scientific knowledge of the effects of air pollution and other environmental factors on forests. The data gathered within the framework of this programme and other parallel programmes assessing the effects of air pollution on other receptors (ICP Vegetation, Waters, Materials) contribute to the development of legally binding protocols on international air pollution abatement policies (EC-UN/ECE, 2001). Switzerland is one of the 36 European countries participating in the ICP Forests programme. To fulfill national and international commitments in the domain of protection of forests, two programmes were set up in Switzerland. 1) The forest health inventory (Sanasilva), which assesses tree crown condition every year over a systematic grid, was implemented for the first time in 1985. 2) The *Swiss Long-term Forest Ecosystem Research* LWF was established in 1994, with the aim of gaining a better knowledge of how natural and anthropogenic stresses affect forests in the long term (Cherubini and Innes, 2000). LWF will also help to develop alternative indicators of forest health that have greater value than crown defoliation and to better understand cause-effect relationships in forest ecosystems. Both programmes are based at the Swiss Federal Institute WSL at Birmensdorf.

2. FOREST HEALTH INVENTORY SANASILVA

The forest health inventory Sanasilva has been carried out in its current form every year since 1985. Its objective is to monitor the health of the Swiss forest using crown and tree parameters as indicators of forest condition. Sanasilva fulfills the requirements of the so-called Level I assessment of ICP Forests, which aims at monitoring the spatial and temporal variation of forest condition over a systematic grid (16 x 16 km) throughout Europe. The size of the systematic sample grid in Switzerland has been changed twice since 1985. From 1985 until 1992 approximately 8,000 trees were assessed on nearly 700 plots over a 4x4 km grid. In 1993, 1994 and 1997 approximately 4,000 trees were assessed over a 8x8 km subgrid. In 1995, 1996, 1998, 2000 and 2001 approximately 1000 trees over a 16x16 km subgrid were assessed.

In 2000, for the first time since 1995, crown defoliation clearly increased in Switzerland (Figure 1). Three out of 10 assessed trees exhibited more than 25% defoliation. Several potential natural and anthropogenic factors could be involved. Part of the increase can be ascribed to the storm Lothar (December 1999), but the storms alone cannot be held responsible for the increase in crown defoliation: the increase in regions not affected by the storms (4.9%) was almost as high as the increase in affected regions (5.1%). In France and Baden-Württemberg, where Lothar and Martin also caused considerable damage, crown defoliation did not increase; in Bavaria and Austria however, which were less affected by the storms, defoliation increased. The long dry period in spring 2000 or natural tree ageing could also have contributed to the deterioration of the crown condition (Dobbertin and Brang, 2001).

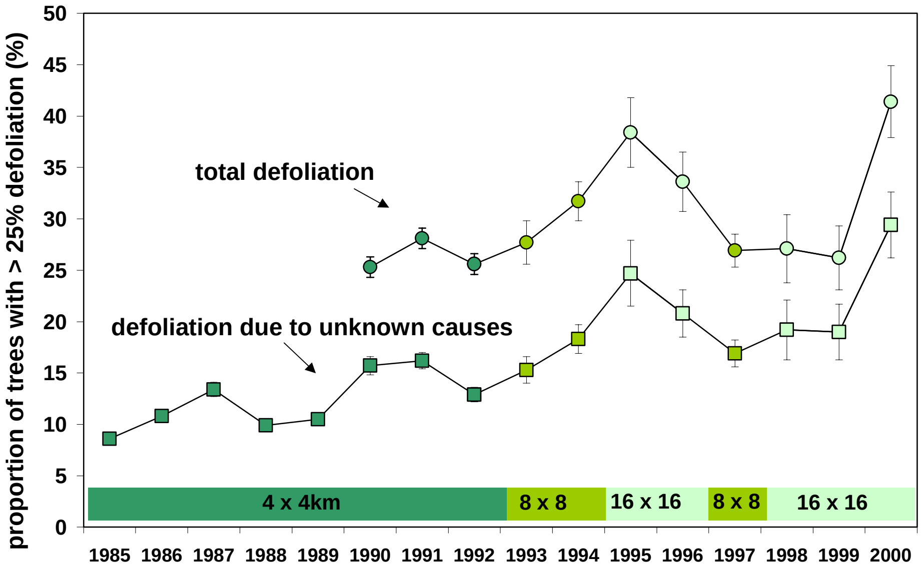

Figure 1. Evolution of the proportion of trees with a more than 25% defoliation in Switzerland from 1985 to 2000; the error bar represents the standard error (Dobbertin and Brang, 2001)

The Sanasilva data only allow speculations about the causes of crown decline and show the need for further investigations involving a more detailed assessment of the ecosystem components. The multi-disciplinary, long-term studies undertaken within the framework of the Long-term Forest Ecosystem Research LWF will help in establishing cause-effect relationships between assessed indicators of the forest ecosystems and potential natural or anthropogenic stress factors.

3. LONG-TERM FOREST ECOSYSTEM RESEARCH LWF

The Swiss Long-term Forest Ecosystem Research LWF was established in 1994 under the Forest Observations Programme (now called Forest Monitoring in Switzerland) (Innes, 1995; Cherubini, 1995; Kräuchi, 1996a and 1996b; Kräuchi, 1998; Cherubini and Innes, 2000; Kräuchi and Cherubini, 2000; http://www.wsl.ch/forest/risks/riskshome-en.ehtml). It is one of four programmes designed to provide basic information about forest dynamics in Switzerland, primarily in relation to the sustainable management of the forest resource. It is a joint programme between the Swiss Federal Institute WSL and the Swiss Agency for the Environment, Forests and Landscape (SAEFL). LWF is the main Swiss contribution to what is termed level II assessment of ICP Forests, set up in 1994 to contribute to a better understanding of the relationships between the condition of forest ecosystems and anthropogenic and natural stress factors through intensive monitoring on selected permanent observation plots in Europe. LWF data thus represent an important addition to international policy-making in relation to pollution control.

4. AIMS

In agreement with the objectives of ICP-Forests, level II, the mission of LWF is to improve our understanding of how natural and anthropogenic stresses affect forests in the long term, and assess which risks for humans are involved. LWF focuses on gaining a more profound knowledge of the cause-effect relationships in the forest ecosystem and the underlying processes. The aims of LWF are:

to assess external anthropogenic and natural stresses (e.g. atmospheric deposition, climate)
to assess changes of relevant forest ecosystem components
to evaluate the influence of external stresses on forest ecosystems
to develop indicators of forest health
to analyse the risks under different stress scenarios
to provide input data for forest ecosytem models
to provide a sound basis for sustainable environmental policies, insofar as forests are concerned
to contribute to the assesment of the effectiveness and impacts of the national air pollution abatement policies (e.g. reductions in the release of sulphur dioxide over the last twenty years)

5. SITE SELECTION

To achieve these aims, 17 permanent plots have been selected throughout Switzerland (Figure 2, Table 1) using various criteria (Cherubini and Innes, 2000), including:

the areas should be homogeneous with respect to their ground conditions and stand structure (local relief, vegetation)
should belong to a forest community type that is important in Switzerland
should be located in a region sensitive to environmental change
should, if possible, already have been the subject of past or ongoing environmental studies.

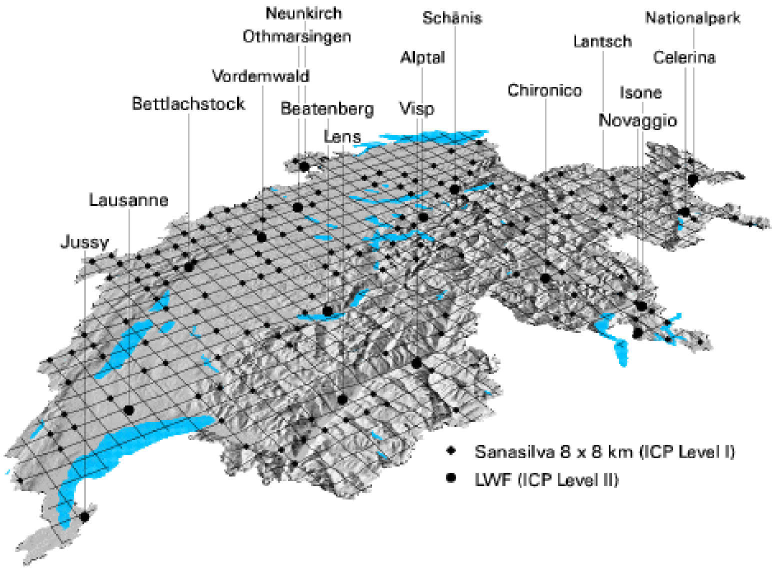

Figure 2. Location of the LWF sites (red dots) and of the Sanasilva 8 x 8 km grid (green dots) (map: A. Baltensweiler)

6. PLOT DESIGN

Each LWF plot (3 plots excepted) is 2 ha in area. It consists of a core area surrounded by a buffer zone in which sampling with destructive methods is performed. In each plot, a 43 m x 43m subplot is dedicated to intensive monitoring of a number of components.

Table 1. Site characteristics of the 17 LWF plots

site	altitude a.s.l. (m)	Aspect	mean slope (%)	main tree species	species mixture	development stage	silvicultural system	soil type (FAO, 1988) (Lorenz Walthert, pers. comm)	woodland association (Ellenberg and Klötzli, 1972)
Bettlachstock	1149	S	66	*Fagus sylvatica*	mixed broad-leaved	middle-aged timber tree	forest reserve	Rendzic Leptosole	*13h: Cardamino-Fagetum tilietosum*
Neunkirch	582	N	58	*Fagus sylvatica*	broad-leaved	old timber tree	forest reserve	Rendzic Leptosole	*13: Cardamino-Fagetum tilietosum*
Jussy	501	flat	3	*Quercus robur*	broad-leaved	young timber tree	unmanaged / group selection	Eutric Gleysole	*35: Galio silvatici-Carpinetum*
Lausanne	807	NE	7	*Fagus sylvatica*	broad-leaved	old timber tree	group-selection	Dystric Cambisole	*8: Milio-Fagetum*
Othmarsingen	484	S	27	*Fagus sylvatica*	broad-leaved	old timber tree	group-selection	Haplic Acrisole	*7: Galio odorati-Fagetum typicum*
Vordemwald	480	NW	14	*Abies alba*	mixed coniferous	old timber tree	group-selection	Dystric Planosole	*46: Bazzanio-Abietetum*
Alptal	1160	NW	23	*Picea abies*	coniferous	young timber tree	selection	Mollic Gleysole	*49: Equiseto-Abietetum*
Beatenberg	1511	SW	33	*Picea abies*	coniferous	middle-aged timber tree	selection	Podzole	*57: Sphagno-Piceetum calamagrostietosum villosae*
Schänis	733	W	60	*Fagus sylvatica*	broad-leaved	old timber tree	group-selection	Eutric Cambisole	*13: Cardamino-Fagetum tilietosum*
Celerina	1871	NE	34	*Pinus cembra*	coniferous	middle-aged timber tree	group-selection	Podzole	*59: Larici-Pinetum cembrae*
Lantsch	1474	W	16	*Picea abies*	coniferous	middle-aged timber tree		[not determined yet]	*65: Erico-Pinetum silvestris*
National Park	1899	S	11	*Pinus mugo*	coniferous	polewood	forest reserve	Calcaric Fluvisole	*67: Erico-Pinetum montanae*
Lens	1063	SE	75	*Pinus sylvestris*	coniferous	young timber tree	unmanaged	Haplic Calcisole	*64: Cytiso-Pinetum silvestris*
Visp	695	N	80	*Pinus sylvestris*	coniferous	polewood	unmanaged	Calcaric Phaeozeme	*38: Arabidi turritae-Quercetum pubescentis*
Chironico	1365	N	35	*Picea abies*	coniferous	old timber tree	group-selection	Podzole	*47: Calamagrostio villosae-Abietetum*
Isone	1220	NE	58	*Fagus sylvatica*	broad-leaved	young timber tree	unmanaged	Podzole	*4: Luzulo niveae-Fagetum dryopteridetosum*
Novaggio	950	S	68	*Quercus cerris*	broad-leaved	polewood	unmanaged	Podzole	*42: Phyteumo betonicifoliae-Quercetum castanosum*

The design is such that sampling of throughfall, litterfall, soil matrix, soil solution and ground vegetation are tightly networked to allow better detection of correlations between the status of and temporal changes in these components (Figure 3).

All trees, sampling devices and sampling locations are georeferenced.

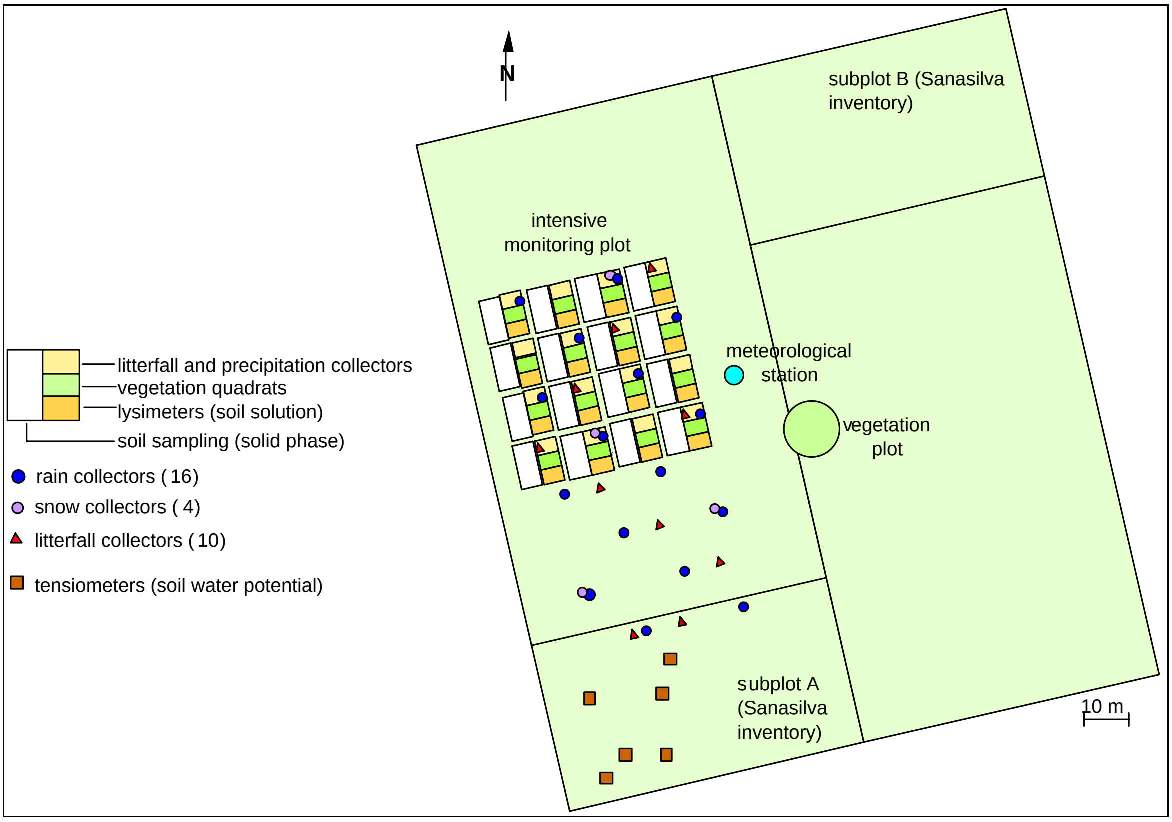

Figure 3. Sampling design of the LWF plot in the Swiss National Park

7. NETWORK MANAGEMENT

The network is managed by the staff of the LWF group based at the WSL. The group consists of more than 20 scientists and field and laboratory technicians. These are involved full- or part-time in the LWF programme and belong to various research sections of the WSL, as LWF tries to synergetically benefit from the competences of the staff at the WSL institute. Nine plots are fortnightly maintained by local foresters; in these cases, collected water, plant and soil samples are mailed to the WSL laboratory. Maintenance conditions are settled in a contract between the WSL and the local forest service. The annual costs of the external maintenance of the plots amount to SFr. 5'000 per plot. The remaining plots, the closest to the WSL, are managed by the LWF staff. LWF runs with an annual budget of ca. SFr. 3'000'000 (including overhead costs).

QUALITY ASSURANCE

The LWF data will be used for comparisons between sites (in Switzerland and in Europe) and over time, and special attention must be given to the data quality. At each step of data acquisition, potential errors need to be identified and reduced to an acceptable level.

8. SAMPLING METHODOLOGY

The sampling methods (statistical design, equipment, etc.) used in the core projects of LWF were selected on the basis of recommendations of expert groups of the UN/ECE (ICP Forests manuals, Programme Coordinating Centres, 1994) and statisticians at the WSL (e.g. Ghosh et al., 1995) as well as careful study of the literature (e.g. Thimonier, 1998a).

Field assesments and data collection

Possible biases in field assessment of parameters such as crown condition are reduced thanks to annual training and intercalibrations of the teams before the inventory is conducted at the national level. Comparability of crown condition assessments obtained by the different countries participating in ICP Forests is also checked regularly in international comparison exercises. Recording of the data in the field directly in the computer noticeably reduces errors in data entry thanks to internal automatic checks (e.g. vegetation data: Kull & Rösler, 1999). Automatic data recording on modular data-loggers equipped with a GSM-module for digital data transfer (e.g. meteorological data) also considerably improves the quality of the data (Jakob et al., 2000).

9. LABORATORY ANALYSES

The WSL laboratory in charge of the chemical analysis of plant, soil and water materials regularly participates in international ring tests (e.g. Mosello et al., 1996, 1998; Bartels, 2000) and uses standard and certified materials to calibrate its analytical equipment. Blank samples or replicate samples are also given regularly by the LWF projects. The certification of the WSL laboratory is in progress.

All samples are archived, at least until validation of the chemical analyses (water samples) or for an indefinite period when storage facilities are available (soil and plant material). The plausibility of the analyses is then evaluated e.g. by checking if the measured values are within the expected range (detection of outliers) or, in the case of water samples, by calculating ion balances and comparing measured and reconstructed conductivity (Mosello et al., 1996). If the results are unsatisfactory, a replicate of the sample is returned to the laboratory to be re-analyzed.

10. DATA STORAGE

LWF data are permanently stored in an integrated project database (Relational Oracle Database). To manage the geographic data, a spatial database module (e.g. ArcSDE from ESRI Inc.) is used. In long-term and multi-disciplinary projects such as LWF, changes in measurement requirements, and subsequently changes in the configuration of the measurement devices and in the entire data processing chain, are most likely to occur. In order to deal easily with such changes, the LWF database developers used a generic approach requiring only few changes to the application parameters (Jakob et al., in press). Geographic information systems (GIS) associated to the Oracle database enables analyses, simulations and visualizations of the data.

11. PROJECTS

The LWF is organised into a set of core measurements and a series of research projects which are designed to provide answers to specific questions in relatively short periods of time. Its long-term focus makes LWF a perfect platform for environmental research providing scientists with basic data necessary for understanding the functioning of the ecosystem. LWF is thus encouraging the implementation of specific research projects on the plots. The emphasis of the monitoring and research projects carried out on the LWF platform lies in four main areas: air pollution, climate change, biodiversity and ecosystem health (Table 2). Active partnership with Swiss and international research institutes and universities is promoted. An example of cooperation associates the WSL with the Swiss Paul-Scherrer Institute (study of the isotopic composition $\delta^{18}O$ of tree-rings and link with climatic variations, Saurer et al. 2000). Examples of partnership with foreign institutes are collaboration with the Penn State University (ozone research, Innes et al., 2001), or with the University of Padua (Cherubini et al., submitted). One of the latest collaboration joins researchers from the WSL with the University of Montana, with the objective of calibrating and testing the BIOME-BGC model (a simulation tool to calculate fluxes and pools of carbon, nitrogen and water in ecosystems; Thornton, 1998) on the LWF sites. In order to help interpret data collected on the LWF plots, data from other networks are analysed (e.g. meteorological data of the Swiss network; Rebetez and Beniston, 1998; Rebetez, 1999; Rebetez, in press). LWF scientists are also actively involved in national and international experimental projects using facilities such as open top chambers for ozone research (e.g. Ghosh et al., 1998; Skelly et al., 1998) or CO2 natural springs (dendrochronological study of tree growth under elevated CO2 concentrations; Tognetti et al., 2000).

12. CONCLUSION

After some years of measurements (up to 6 for some plots), the different ecosystem components at the LWF sites and their initial status have been soundly characterized (e.g. Dobbertin et al., 2001b). The measurement period is too short to draw conclusions about long-term variations, but available data allow in-depth exploration of functional or cause-effect relationships between ecosystem components.

Table 2. Core projects (*) and platform-based projects implemented on the 17 LWF sites. The LWF plot code corresponds to the first 3 letters of the plot name (see Table 1).

ecosystem component	indicator	LWF-plots where data are available	frequency of monitoring	selected publications
tree	crown condition *	all	every year	Brang 1998, Dobbertin & Brang 2001
	growth (circumference at 1.30 m) *	all	every 5 years	
	fine-scale growth (girth band)	Vor	hourly	Dobbertin (in press)
	growth (tree-rings)	all except Lan		
	canopy structure (leaf area index, light)	all except Lan	every 5-10 years	
	needle retention	Vis	once	Pouttu & Dobbertin 2000
	phenology	Bet, Vor	weekly (spring, fall)	Vasella & Brügger 2001
	foliar concentrations *	all except Lan	every 2 years	
ground vegetation	floristic composition, regeneration *	all except Lan	every 2 years	Innes & Kräuchi 1995, Innes et al. 1998
soil and forest floor	chemical and physical properties of the solid phase *	all except Lan	every 10 years	Webster et al. 1996
	soil solution chemistry *	Bea, Bet, Cel, Lau, Nov, Oth, Sch, Vor	continuous (2 weekly)	
	soil water potential *	Alp, Bea, Bet, Cel, Jus, Lau, Nat, Neu, Nov, Oth, Sch, Vor	continuous (2 weekly)	
	litter and fine root decomposition, microbial activity	Bea, Bet, Nov, Sch, Vor		
	root and soil status in the rhizosphere of individual trees	Bea, Bet, Cel, Lau, Nov, Sch, Vor, Oth		
woody debris	volume	Alp, Bet, Chi, Iso, Jus, Lau, Neu, Nov, Oth, Vor	once	Bretz Guby & Dobbertin 1996, Dobbertin & Kaennel Dobbertin 1998
above ground nutrient fluxes	throughfall and incident precipitation *	Alp, Bea, Bet, Cel, Chi, Jus, Lau, Nat, Neu, Nov, Oth, Sch, Vis, Vor	continuous (2 weekly)	Thimonier 1998b
	litterfall *	Alp, Bea, Bet, Cel, Jus, Lau, Nat, Neu, Nov, Oth, Sch, Vis, Vor	continuous (4 weekly)	
fungi, mycorrhiza	mycorrhizal diversity	Bea, Bet, Lau, Vor	once	
	root and bud rot of forest trees	all except Lan	once	Dobbertin et al. 2001a
insects	species diversity	all		Vonwil 2000
climate	global radiation, PAR, UV-B, wind speed and direction *	all except Lan	continuous (10 minutes)	Rebetez 1996
	precipitation, relative humidity *	all except Lan	continuous (60 minutes)	
ambient air quality	ozone concentrations	Bet, Nov, Oth, Sch, Vor	continuous (weekly)	
	ammonia and nitrogen dioxide concentrations	Bea, Bet, Cel, Chi, Jus, Lau, Nat, Nov, Oth, Sch, Vor	continuous (2 weekly)	
stand history	tree-rings, documentation of forest management	all except Lan	once	Cherubini & Dobbertin 1997

LWF data, together with baseline data collected by other Swiss monitoring networks (e.g. air, soil or water quality networks) will be used to develop an ecological risk assessment framework, which will help identify the current and potential threats to forest ecosystems (Kräuchi, submitted).

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