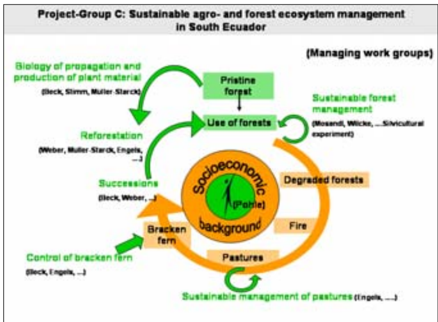
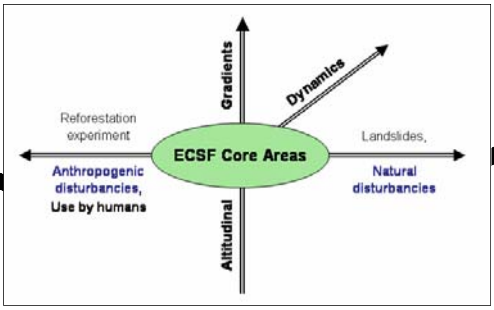
Status Report and Perspectives

of the Research Unit FOR 402 of the
German Research Foundation (DFG)

„Functionality in a Tropical Mountain Rainforest of South Ecuador:
Diversity, Dynamic Processes and Utilization
Potentials under Ecosystem Perspectives"



October 2004



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Introduction

The forests of the Ecuadorian Andes represent one of the (plant) species richest and one of the "hottest" of the biodiversity-hotspots worldwide (Brummitt & Lughadha 2003). At the same time, this country suffers the highest deforestation rate in South America (FAO, 2003). Even without human interference, the forests, as a result of high precipitation regimes and the steepness of the slopes, are subjected to an extraordinarily high "natural" dynamics which is both destabilizing (land slides) as well as stabilizing (the biodiversity) because of the dynamic momentum.

The study area of the Research Unit 402 of the German Research Foundation is situated in the Eastern range of the South Ecuadorian Andes in the deeply incised valley of the Rio San Francisco. The Research Station "Estacion Cientifica San Francisco" (ECSF) established in the years 1996 – 1999 by the foundation "Nature and Culture International" is situated on the valley-bottom at 1850 m a.s.l. near the communication road between the two province capitals of Loja and Zamora. The southern slopes (exposed to the north) are covered by a more or less dense forest, the so-called "ECSF forest", while the forest on the northern slopes (exposed to the south) has largely been cleared by the "Colonos", the new settlers, by slash and burn. Nowadays only parts of the cleared areas are still utilized, mainly as pasture land.

The interdisciplinary Research Unit which was established in 2001, has two main objectives: i) a scientific understanding of the ecosystem "tropical mountain rain forest", and based on this, ii) the investigation of the potential of this ecosystem for sustainable use by humans.

Comparing the natural forest ecosystem on the orographic right-hand slopes with the ecosystems of „agricultural lands“ and "abandoned farming lands“ on the left side of the valley mutually interlinks these two goals.

The development of the project

During the **initial period** (1997 – 2001) the facilities for field work (construction of trails, selection and equipping of plots for certain measurements and for permanent monitoring) and the necessary scientific infrastructure (herbarium, climate stations, dams, and soil laboratory) were established. Analysis of individual compartments of the ecosystem „natural forest“ was started, with research into <u>soil and vegetation</u> as well as hydrological and climatological parameters. During this first phase the <u>altitudinal gradients</u> served as guideline for research. In addition to the indispensable inventory at the initial phase of the project, functional analysis, in particular analysis of the forest structures (structure and plant life-forms) as well as of flora-fauna interactions (pollinator, seed propagator) came to the fore.

With the **establishment of the Research Unit** (2001) the research approach was broadened, structured and deepened. The research approach was widened not only by extending the investigations to other compartments of the ecosystem "natural forest" (soil fauna, insects, birds and bats, cryptogams, mycorrhiza, fungi, soil physics) but also through the incorporation of projects investigating anthropogenic disturbances (maintenance of a canal and construction of trails as well as for production of agricultural land) into the program. The search for research areas with anthropogenic impact resulted in a second gradient for the orientation of the projects, the <u>disturbance or utilization intensity gradient</u>. The studies along this gradient are partly analytical (compartments of the anthropogenic ecosystem and utilization practices), and partly orientated towards sustainable utilization possibilities. Deepening of the research approach was achieved through the continuation and extension of the ongoing measurement program, in particular of climate, soil and biotic interactions, through expansion from selective to area-wide approaches, and most of all through an appreciation of the initially neglected enormous dynamics in the natural and anthropogenic ecosystems (landslides and „slash and burn effects“).

Figure 1: Fire is a common method used in farming. The areas are burned repeatedly to stimulate the growth of grasses and to control the bracken fern. After several fires, however, the fern outcompetes the useful vegetation, forming a closed canopy. Finally the pastures are abandoned and new areas of the rainforest are cleared. © Erwin Beck.

With the onset of the **second period of funding,** the Research Unit was structured: The more than 25 scientific projects were grouped into 4 Project-Groups, each with common focal points and objectives:

- Project-Group A: Diversity of interactive organisms in the tropical mountain rain forest
- Project-Group B: Matter turnover and matter fluxes;
- Project-Group C: Sustainable agricultural and silvicultural ecosystem management in South Ecuador (NAFIS);
- Project-Group D: Climate and landscape history.
- Project Z1: Modelling

In this second period of funding, the aspect of functionality in the natural forest was particularly emphasized (question of the timberline; succession and regeneration; significance of mycorrhiza; adaptation strategies and ecophysiology of plant life forms; flora and fauna interactions; litter decomposition and biology of soils; root functions; nutrient and water relations of the soil; matter deposition by precipitation etc.). At the same time, a third dimension of ecosystem research was developed: Recent and post-glacial landscape history. In connection with the issue of sustainable use, two ecological experiments were performed during this phase: silvicultural measures, and reforestation with indigenous tree species. A series of other projects are part of these two experiments which are conducted by forestry scientists. The silvicultural measures aim at improving the growth conditions of valuable trees in the indigenous forest for opening a way to the sustainable use. In the reforestation experiment, the potential of unproductive or abandoned pasture land is examined, aiming at a reconstitution of a close-to-natural forest with nursery-grown treelets of indigenous species. This research is accompanied by socio-geographical studies in neighbouring areas where the resident population of the Shuar and the Saraguros practice traditional sustainable land-use.

Important scientific progress was made through the establishment of an network-based data base and information system (Project Z1), in which the incoming data are managed according to the requirements of the potential users, hence being effectively put at the disposal of the entire Research Unit. Decisive for the unlimited usability of the data is that (almost) all projects work in the same core zone, namely in the ECSF area, so that all results can be directly referred to each other. The first results of this new data management are a joint publication of the climatologists and plant scientists, and the compilation of concepts for the modelling of various compartments or ecosystem processes, respectively. Important elements of this data bank are the now available maps and site model, which will greatly facilitate documentation of the work during the **third period of the Research Unit**.

Current state of research

Discussing the findings of the 25 projects will go beyond the scope of a preamble. Rather the Research Unit refers to its considerable list of publications, which is attached as an appendix, as well as to its Web-Page at**: http://www.bergregenwald.de.**

Nevertheless, the synoptic presentation of the results attained in the four Project Groups led to the formulation of (hypo)theses which outline the current picture of the ecosystem ”tropical mountain rainforest in South Ecuador” and of its substitute formations in a cross-sectional manner. Details of these theses are explained in the introductory chapters of the individual Project-Groups. Parts of the findings were not unexpected: This applies in particular to the changes along the altitudinal gradients, though the increment of precipitation (up to 6000 mm/year in 3000m a.s.l.) with the altitude, for example, was nonetheless surprising. In a certain respect, the results obtained during the second period of the research unit have, however, led to some paradigm shift. Contrary to common understanding of the structures and functions of an ecosystem with keystone species and key parameters, our results indicate fundamental differences in an ecosystem of a biodiversity hotspot, such as that of the South Ecuadorian Andes. Competition and biomass production are not the determining factors in this ecosystem. So-called „keystone-species“ are not obvious. The high diversity of species is stabilized by numerous mutual interactions of organisms, by the high dynamics of the ecosystem “tropical mountain forest” and by particular abiotic factors, such as the lack of nutrients and light. Limitation of nutrients, in particular of phosphate, explains the fact that there is no chance for a few individual species with a superior nutrient-intake capacity to suppress other species by ample biomass production. The lack of light leads to enhanced elongation growth of the trees and also is supportive of the various plant life forms of light parasites (winders, lianas and epiphytes).

Outstanding findings of Project-Groups B and D are, on the one hand, the exceptionally high heterogeneity of the abiotic and biotic components of the ecosystem “natural forest”, and, on the other hand, the high nutrient input by means of long-distance transport of air from regions with volcanic eruptions and from forest fires in the Amazon lowlands. As a result the nutrient balance as well as the atmospheric water input are not only spatially heterogeneous, but also temporally very variable and depend significantly on events occurring at a great distance from the research area.

A further modification of our previous assumptions resulted from the analysis of older aerial photographs: Considerable areas of the lower ECSF forest are not older than 50 years. They have been cleared in the course of the reconstruction and installation of the canal inside the mountain, but have managed to regenerate, despite the temporary use of some small areas as farmland. It was probably the type of clearing (felling instead of fire) that allowed the regeneration of the forest. This explanation is suggested in the current state of discussions in Project-Group C, where the type of land-use practiced by the „Colonos“ has been studied, and its non-sustainability was investigated. The key process is the repeated use of fire which led to a stable “weed vegetation“. This explains, on the one hand, the abandonment of pastureland

Figure 2: Parasitic interaction among plants: Epiphytes use the stem of other plants to grow into a better light-climate without investing the "costs" of producing a stem by their own

© Erwin Beck.

and, on the other hand, the reason for the failure of forest self-regeneration. The resulting hypothesis that reforestation by planting indigenous trees will be the only means to restore the abandoned areas for a sustainable use is examined in the reforestation experiment mentioned above.

In a sense, the hypotheses of Project-Groups B and C (still) contradict each other with respect to the regenerative force or resilience of the ecosystem "tropical mountain rainforest": Project-Group B supposes a high resilience which is based on the gap-dynamics and the idea of a mosaic climax. Project-Group C presumes that a different ecosystem exists in agricultural and pasturelands which, after conversion to wasteland defies regeneration of the forest.

Perspectives for the third period (2005-2006)

The mentioned hypotheses - among others - constitute the basis for the planned work of the Research Unit. Here again, the preamble limits itself to the basics. At the beginning of the project, the inventory of the biotic and abiotic compartments of the ecosystem and the altitudinal gradients were in the foreground. Currently, in the second period of funding, the functional aspects and the gradient of disturbance or of human use have been given priority. In the envisaged third period of funding, interactions on the ecosystem level and historical and geological dimensions will be examined (**Figure 3**). However, this does not mean that all of the current projects related to inventory and functions of individual compartments of the ecosystem are already completed or that new projects related to this level could not be included. However, a considerable amount of data has already been compiled that modelling of individual parameters of the ecosystem looks promising. It needs hardly be mentioned that in this respect we are talking of sub-models, such as those formulated in the introduction of project Z1. Such models need verification (or correction) by current measurements in order to be used as a reliable basis for the fourth level of research which comprises prognoses and management recommendations. Therefore, long-term monitoring of important ecological parameters, which has been started a few years ago, must be continued. For the ecological experiments continuation of the monitoring is in particular indispensable.

Naturally, there is the question of further perspectives of the sub-models. Would it be possible in the near future to consolidate several sub-models into a comprehensive model, of the ECSF forest for example, or of its anthropogenic successions? The progress of the next period has to answer this question.

In an impressive synopsis of numerous climatological, soil and vegetation studies, van der Hammen (2003) presented an East-West transect through the ecosystems of the Columbian Central Cordillera. According to our knowledge, this work presently represents the most comprehensive and most exhaustive description of a zonal sequence of ecosystems, not only of the tropics. However, the objectives of the Research Unit FOR 402 go far beyond such a description as they strive for an understanding of „its“ ecosystem “tropical mountain rain forest”. This means, on the one hand, a limitation of the field studies and the models to a comparatively small geographical area and, on the other hand, the extension of the study to the local people and their impact on the ecosystem. This aspect will be more accentuated in the third period of funding by a new collaborative project (C4) in the Project-Group C (NAFIS).

The issue of extending the present research to a wider perspective involves the question of the perspective of the Research Unit itself. Some of the projects have already been completed; others will follow in the course of the third period of funding. Other projects, in particular the ecological experiments, need more time, since reforestation or measures of silviculture cannot be initiated, evaluated and assessed within in a period of only two years. This also applies to the establishment of more complex model structures. We assume that several of the projects must be continued and to that end capacity building pursued by the Research Unit will bear fruit. As to the extent of the results already achieved and those still to come, collaborative data analysis and the elaboration of results will require more time than merely another two years, as will the compilation of the management recommendations derived from them.

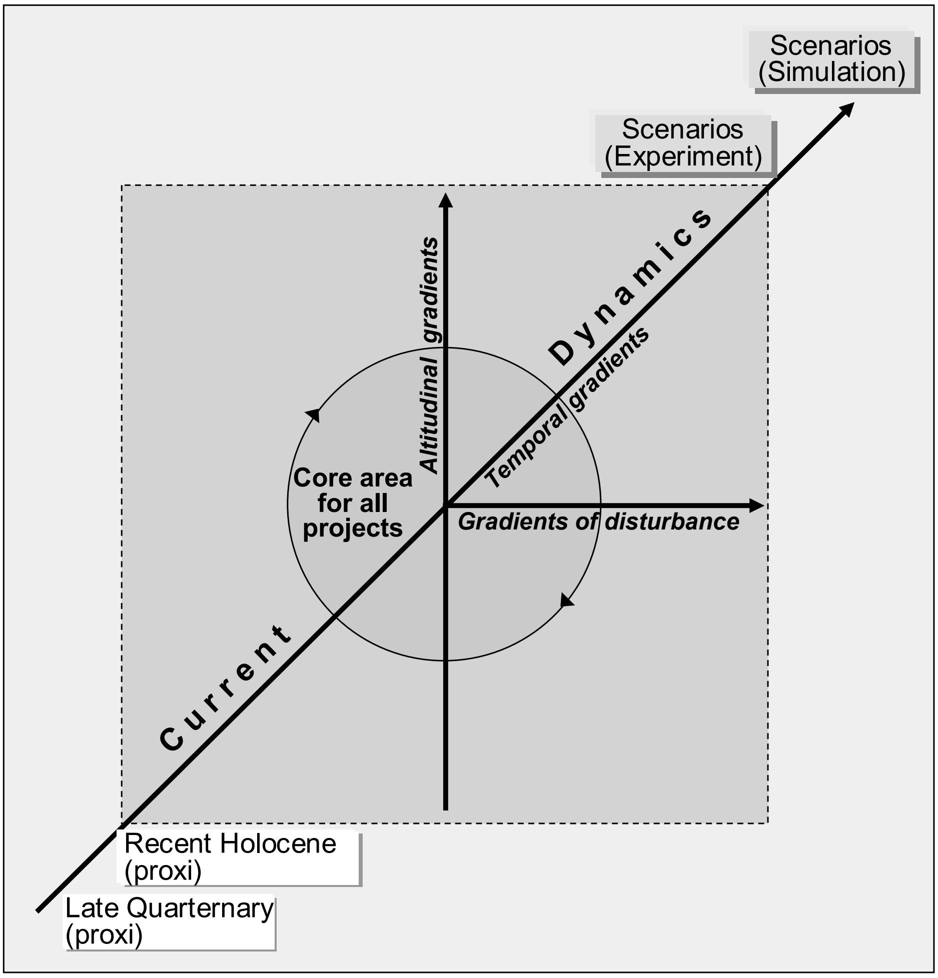

Figure 3: Guidelines for the further work of the Research Unit FOR 402 during the years 2005 and 2006

The Research Unit FOR 402 as a scientific element in South Ecuador

Right from its beginning the Research Unit has sought contact to the universities of the area in Loja and Cuenca. Many students of the Universidad Tecnica Particular de Loja (UTPL), the National University of Loja (UNL) and the University of Azuay (Cuenca) have already joined the projects of the Research Unit and have been awarded their academic degree in the frame of that collaboration. Some Ecuadorian students are close to finishing their doctoral thesis. The traditional Ecuadorian academic degree of an "Ingeniero" is considered an accreditation for enrolling as a doctoral student in German Universities (Ecuadorian universities do not offer Ph.D. programs), however, the education system in Ecuador has other emphases. Because of this, and because of language problems which must not be underestimated, a doctoral degree for an Ecuadorian Ph.D. student in Germany takes more than three years.

In the previous years, contacts, especially with the two Universities of Loja, could be substantially strengthened. The Research Unit is well integrated into the local university life, not only through the support of research facilities, such as, for example, a tree nursery at UNL or the molecular-biological and the soil science-laboratories at UTPL, but also through the participation of the German scientists in teaching activities. The Research Unit organizes an annual status symposium in Loja. The symposium, which is always well attended, presents the ongoing work of the Research Unit to the public. At the „II. Congreso de Biodiversidad de los Andes y la Amazonia" in Loja last year, the Research Unit arranged a special symposium but also contributed by several short lectures, posters and two plenary lectures to the main program. Ecuadorian scientists increasingly appreciate the opportunity to visit the Institutes of their counterparts in Germany. A highlight in this regard was in summer 2003, when the Vice Chancellor of the UTPL, Dr. M.L. Romero visited several German Universities.

Meanwhile the Research Unit has achieved considerable scientific, in particular ecological reputation, mainly in South Ecuador. Its local political appreciation became obvious in the negotiations on the reconstruction of the water supply-canal of the power plant (Empresa). After hard but finally successful negotiations the construction of the tunnel for the canal was postponed because of the ongoing research activities. In the now submitted proposal for the next period of funding, the prospective canal works in the very East of the ECSF-forest have been well taken into account. Also noteworthy was the difficult procedure for the implementation of the silvicultural experiment in a small part of the ECSF forest. Initially, this project met with considerable resistance of the local population, but finally was tolerated, thanks to the confidence that the Research Unit now enjoys in the public and by the authorities.

Today, it can be stated that the Research Unit has succeeded by its continuous efforts and by backings from various Ecuadorian authorities and the foundation NCI in gaining acceptance in this region. For the Ecuadorian public, the Research Unit has become an appreciated element of the scientific life, as well as of the biodiversity scene in Ecuador.

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Speaker of the Research Unit: Prof. Dr. Erwin Beck, University of Bayreuth

Project-Group A: Interactive organismic diversity

Since the beginning of research on the approximately 1000 hectares of the ECSF-site, important groups of organisms were extensively studied (trees, climbers and lianas, mosses, lichens, fungi, birds, grasshoppers, bats, butterflies and moths, mites). Nevertheless, coverage of some species-rich groups is still lacking, such as specific epiphytes on tree stems or in the canopy as well as important decomposers, such as collemboles, nematodes and protozoans. From our results it has becomes clear that the mountain rain forest of South Ecuador is characterized by an outstanding diversity of species. The results also suggest that the worldwide unique diversity of some of the investigated groups is not only the outcome of the present habitat, climate and soil (steep altitudinal gradient over 1500 m, exposed and protected areas, nutrient limitation) or to the history of the Andes (immigration from tropical-neotropical, antarctic-australian and holarctic areas) but also to a multiplicity of mutualistic interactions between the organisms. The plants of the pristine forest, especially the trees, are pollinated almost exclusively by animals (birds, bats, and insects). As a result, specific spatial-temporal niche formation and niche occupation emerged, contributing to diversification and also to redundancies which in turn stabilize the system. The same holds for the symbiosis of roots and fungi (mycorrhizas) which was found in all investigated woody plants of the mountain rain forest and in the epiphytic orchids and even the epiphytic liverworts. The close relationship of the symbiotic fungal partners suggests a fungal network in the soil and the roots which likewise stabilizes the species community. Coevolution of plants, mycorrhizal fungi and pollinators are very probable (e.g. Ericaceous plants/sebacinaceous fungi/hummingbirds). Not only nitrogen but also phosphate as organically-bound P reaches its highest concentrations in the root harbouring soil horizons, but nevertheless frequently become growth limiting factors. Thus, fast growing species, with a high demand of nutrients, are less competitive. As a consequence, numerous plant species can spring up and coexist in close vicinity. They profit from the extensive mycorrhizas whose fungi readily mobilize phosphate and nitrogen from organic litter compounds. A high degree of interactions also appears in the realm of soil animals. Instead of earthworms, woodlice and millipedes, collemboles, oribatids, nematodes and protozoans dominate in the humic soil horizons, forming frass communities when associated with soil bacteria and fungi.

Figure 4: Symbiontic interaction among plant and animal: A hummingbird pollinates the flowers of a Verbenacee, getting nectar and simultaneously ensures reproduction of the plant. © Doris Wolff

Based on species composition and structure, five forest types could be differentiated along an altitudinal transect from 1850 to 2600 m a.s.l, four of which are typical of ridges while the fifth was addressed as ravine forest. The epiphytic moss communities on the trunks, as well as the occurrence of special moth species, oribatid mites and fungi are in good correspondence with these forest types. The highest species density of nesting birds was observed at the forest edge. The same holds for epiphytic mosses and lichens which profit from the great variety of microclimates.

The results obtained up to now led to the following hypotheses which constitute the guidelines of the studies in the coming period of funding:

1. **The tropical mountain rain forest of South Ecuador is different from the hitherto known models, as competition for resources and biomass production are not the essential factors. So-called „keystone-species“ are not detectable. Instead, the high biodiversity is fostered by a multitude of mutualistic organismic interactions.**
2. **The extremely high diversity of plant species is sustained through the limitation of nutrients and light. Instead of a high biomass production, this situation gives rise to an enhanced elongation growth of the trees and a high degree of epiphytism.**
3. **Structural and organismic differentiation of the various species communities is a result of the steep altitudinal gradient between 1000 and 3000 m and is even reinforced by the frequent land slides and gap formations.**
4. **The extremely high species diversity also has its origin in the immigration of organisms from the tropical-neotropical, antarctic-australian and holarctic flora regions before and during the uplift of the Andes and the explosive evolution of new species (radiation) in the highly differentiated microhabitats.**

Further research (Fig. 5) must focus primarily on the biology of species. Besides continued observation of the undisturbed situation, the successions in gaps and on banks, the feeding behaviour of various groups of animals and its consequences for the whole ecosystem shall be studied as well as the compatibility of symbiotic fungi with different plant groups. Experimental approaches are indispensable for those aims. Using molecular approaches to phylogeny, findings related to paleogeographic spreading and evolution of organismic groups should be reached. Finally, modelling should lead to a better understanding of the very complex systems.

Speaker of the Project-Group: Prof. Dr. Ingrid Kottke, University of Tübingen

Project Group A: Interactive organismic diversity

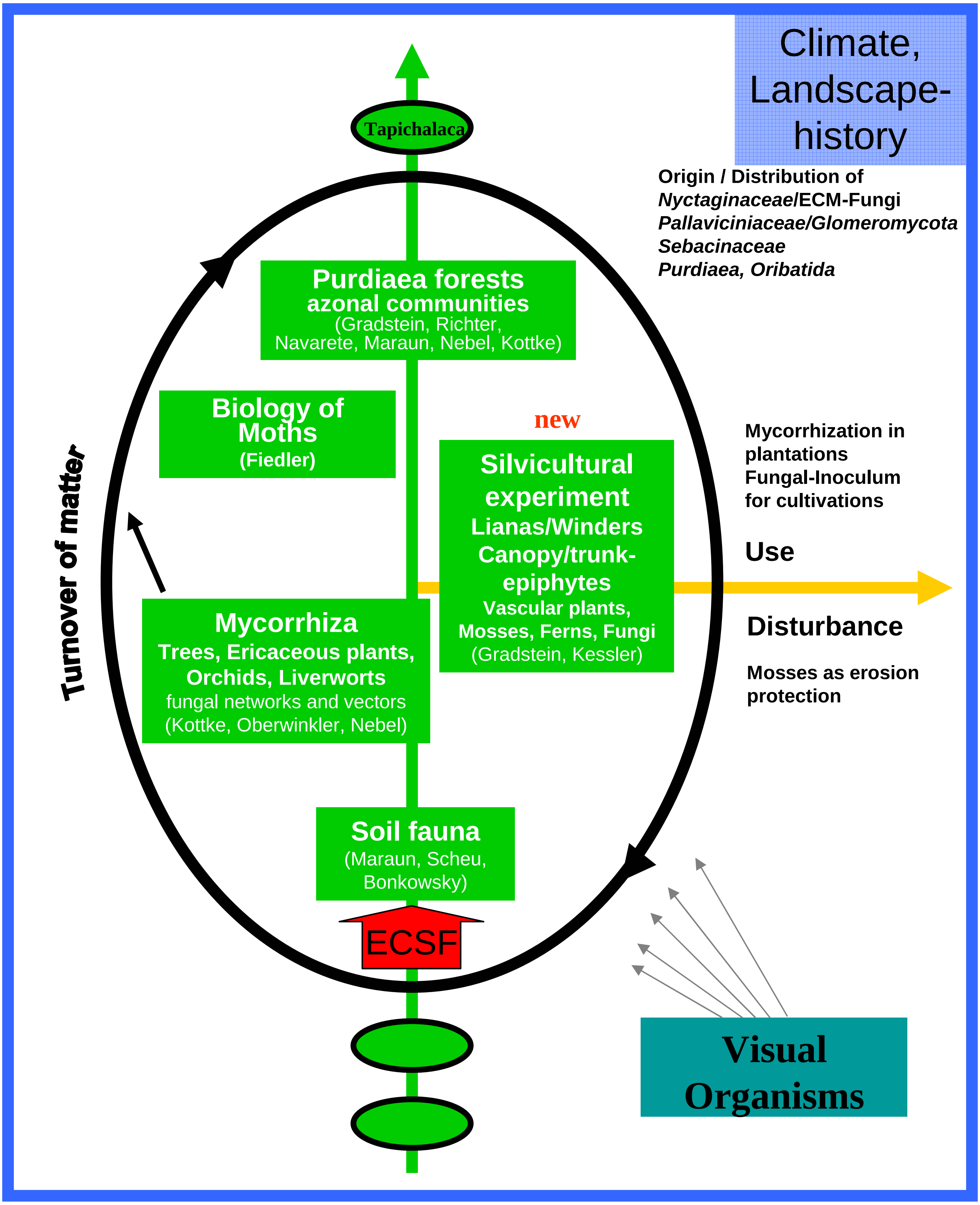

Figure 5: Synopsis of Project-Group A

Project-Group B: „Matter Turnover and Matter Fluxes“

In the initial phase of the Research Unit, investigation of matter turnover and matter fluxes required primarily methodological work, i.e. adaptation and establishment of methods for the quantification of water and matter fluxes and the selection of suitable areas in the ECSF site. The components of water relations and matter balance were identified at a mesoscale level of differentiation. To this end, besides the hydrological, pedological and phytosociological inventories, detailed studies of the composition and dynamics of matter turnovers and fluxes in the selected areas were carried out in the natural forest. Concomitantly, vegetation analysis and orientating soil profiling was performed in the areas used as pastures as well as in the abandoned areas.

In the **second period of funding**, research was focussed on functional interactions. Analyses were performed on various scale levels (compartments, plots, catchment areas) along altitudinal transects and gradients of increasing human utilization. From these studies important conclusions could be drawn on matter turnover within the compartments and fluxes between the compartments, on the temporal dynamics of fluxes in the ecosystem and on the heterogeneity of these fluxes and of material functions.

Figure 6: The soil scientists use chutes to collect precipitation of the entire stand to investigate the matter input into the forest.
© Jens Boy.

Progress was mainly achieved in the quantification of turnovers and balances in the research areas. The matter input into the natural forest showed considerable aseasonal fluctuations. Periods of high and low matter input occur affecting the nutrient supply to the forest vegetation. Probably these fluctuations correlate with El Niño/La Niña phenomena as well as with the long-distance transport events of matter-packets from volcanic eruptions and large-scale fires in the Amazon region. The litter in a forest ecosystem serves not only as nutrient source for the vegetation but also as a C-store. The average amount of litter (9.1 t ha^{-1}) equalled the annual litter production. However, the amounts on the individual plots were extremely variable. Areas with similar amounts of litter did not exhibit dependency on location, height, sloping or standing biomass. Using simulation models, gaps of runoff data could be closed. For the years 1998 to 2002 the average runoff in the three catchments (Q1-Q3) could thus be determined as 38 to 49 % of the average annual precipitation of 2363-2592 mm. The annual evapotranspiration from the three catchments was determined as 1273 up to 1883 mm that are 54 to 73 % of the precipitation.

Characteristic for the investigated area is a high level of heterogeneity at the levels of compartments, plots and catchment area. This applies to the spatial structures of the vegetation (crown architecture, leaf area index – LAI-, interception evaporation) as well as to the internal turnovers (litter quantities) and material functions (pore size distribution, content of rocks) of the soil. The spatial variability of hydrological key functions in combination with irregular precipitation events results in characteristic sequences of flow patterns as a function of soil depth. Characteristic depth profiles of hydraulic conductivities together with the high spatial variability lead to downhill-interflow events, which finally shape the dynamics of the catchment areas. The formation of preferential flow systems depends *inter alia* on the intensity of disturbances and hence on the history of the site; such flow systems have considerable effects on the water budget and, by the accruement of corresponding patterns of matter transport and physicochemical reactions, on the matter budget of the area. The latter is still subject of ongoing investigations.

A functional connection that still needs to be studied in more detail exists between the spatial structuring and the dynamics of measurable events at the ecosystem level. The first measurements after a notably dry season showed a pronounced humid-dry dynamics in the soil, the extent of which was completely unexpected. Some trees even exhibited clear symptoms of drought stress. Seasonal variation of fine root biomass in the soil is, in contrast, much less pronounced, whereby a slight decrease in periods of high precipitation was observed. However, substantial seasonal fluctuations of fine root necromass were found which indicates a considerable dieback of the root systems during periods of high rainfall.

Time series measured at a high resolution aim at three goals: A comparative analysis of the effects of increasing intensities of disturbances, the capture of signals and their modulations on their way through the ecosystem and the evaluation of simulation models by comparison with parameters of the real systems. Established time series from the catchments have already been analyzed and compared with the results of simulation models. Apparently, there is a specific aggregation level for each ecosystem parameter at which the complexity of the time series peaks. Surprisingly, the specific aggregation levels found in small catchments correspond well with those of large catchment areas, but the complexity of the signals clearly depends on the size of the area.

In a number of ecologically relevant parameters, a clear dependence on the altitudes and the steepness of the altitudinal gradient was observed. Examples are the aboveground productivity of the mountain forest, litter production, phytomass stocks, LAI, microbial biomass, soil gross respiration, biomass of fine roots at a given site, turnover and annual production of fine roots, fine root necromass, contents of C, N, P and S as well as of all metal ions except Ca in organic soil layers, C/N-, C/P- and C/S-ratios in the O- and A-horizons, litter decomposition and the total content of nitrogen in the top soil. For details, the reader is recommended to the publications of the Research Unit. The data support the thesis of an increasing allocation of biomass from the aboveground to the belowground organs of trees (i.e. from shoot to root) with increasing altitude, resulting in a decrease of the aboveground carbon input into the vegetation. This attenuation of tree growth is in line with a decreasing availability of Ca, K, Mg and P corresponding to a decreasing nutrient release by mineralisation with increasing altitude. The high root necromass near the timberline suggests that the longevity of the fine roots declines with the altitude. Apparently the limited availability of soil resources (nutrients or water) causes the high turnover of the roots.

Figure 7: At an altitude of 3100 m a member of the roots group paints the roots of two different trees to determine their architecture.
© Nathalie Soethe.

First results were also obtained concerning the effects of utilization and disturbances on ecological functions of the investigated area. Plots were established on the south-facing slopes that have been cleared for agricultural purposes, mapped and the site characteristics were analyzed The soils of these slopes resembles those of the natural forest on the opposite side of the valley, ranging from brown soils to soils with pronounced bleaching (from soaking) until gley soils. All layers may be traced back to landslides more or less long ago. Characteristic parameters of the soils carrying pastures are significantly more alkaline pH-values and higher stocks of exchangeable Calcium and Magnesium. After abandoning, the mineral topsoil layers re-develop slowly towards their initial state. No differences in the total carbon stocks of the upper soil layers could be detected which could be attributed to the mode of land-use.

Generally, landslides seem to play an important role in the development of the ecosystem. The exact mechanisms are, however, still unclear. Steep catchment areas, in the natural forest showed particularly high effective water conductivities.

Models of water-, matter- and energy-balances were developed in the course of the second period. First of all, these models are required for the interpretation of the measured data, for filling data gaps and for the quantification of fluxes, which were not accessible by direct measurements (e.g. soil water fluxes and evapotranspiration). Further models will be used for process and system analysis. Examples of models are:

- The calculation of annual fluxes with TOPMODEL and NAMOD in small catchment areas
- The modelling of flow tracks in a soil profile with high content of rocks and
- The spatial modelling of matrix potentials at various soil depths using geostatic methods.

As the results from the models require evaluation, the data provided by the experimentally working groups is very important. To this effect, adjustments of the program of measurements were carried out and will be pursued.

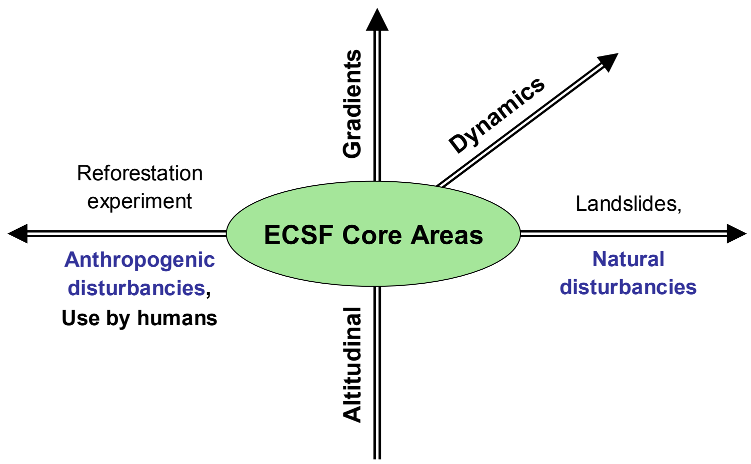

Figure 8: Logistic organization of the Project-Group B on the basis of altitudinal, temporal and disturbance gradients.

The future **objectives** and the **collaborative research of the project-group B „matter balance" concentrate** first on the further clarification of the principles and processes of water and matter budgets in the natural forest along altitudinal gradients. Another emphasis on the dynamics in disturbed and anthropogenically used areas at the same altitudes at which the measurements in the natural forest have been and are still performed. The various modes of land-use by the local population will be taken into consideration. To that end, a close cooperation with project-group C is necessary. Based on the silviculture experiment in the natural forest, processes contributing to the water- and matter-budgets will be studied in areas of different intensities of utilization and disturbance and in the reforestation plots. Figure 8 shows the logistic organization of the interdisciplinary research in the project-group B along the altitudinal, temporal and disturbance gradients. Figure 9 shows the positioning of the individual working-groups in relation to the investigated parameters.

The planned studies of the Project-Group B „matter budget“ are geared towards the following **Hypotheses**:

1. **Altitude (temperature) and water budget are decisive factors for the turnover of bio-elements in the undisturbed ecosystem.**
2. **The internal cycles of matter are superimposed by inputs from long distance transport phenomena. The current dynamics of element transport in the catchments are characterized by coactions of atmospheric constraints with spatial structures of the above-ground vegetation, of the root systems and soils as well as their distribution in the catchment areas (altitudinal gradients).**
3. **Land use leads to drastic changes in ecological structures and functions with corresponding consequences for matter turnovers. Matter fluxes react sensitively to**

these disturbances and are therefore useful indicators for the sustainability of utilization systems.

The **eight projects of project-group B follow the guidelines of these hypotheses**. Each of the projects is orientated towards an altitudinal gradient in the natural forest and towards a disturbance and land-use gradient at comparable altitudes, with an emphasis on the ECSF sites. Studies concerning the impact of traditional use will be carried out on a satellite area in the tribal region of the Saraguros near El Tibio.

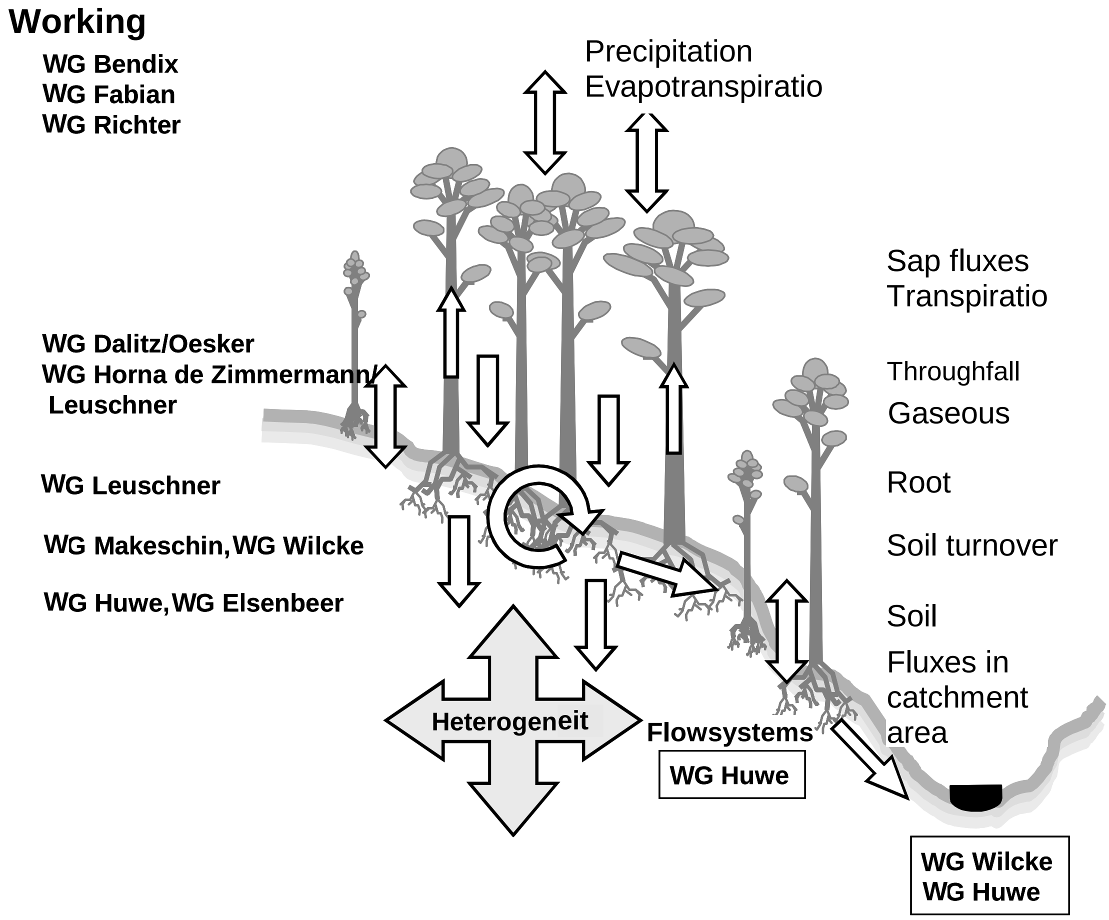

Figure 9: Placement and interconnection of the working groups of Project-Group B in the pristine forest. The arrows indicate fluxes in the ecosystem.

Speaker of the Project-Group: Prof. Dr. Dr. Franz Makeschin, University of Dresden

Project-Group C: "Sustainable agro- and forest ecosystem management in South Ecuador (NAFIS)[1]"

Ecuador harbours ecosystems with the highest number of species worldwide and hence presents one of the hottest „hotspots" of biodiversity. It is, however, largely threatened by non-sustainable modes of land use (according to the FAO report „State of the World's Forests", 2003, Ecuador has the highest rate of deforestation of South America). The objective of the project-group C of the Research Unit is to **contribute to the improvement of land-use systems** in the Andes of South Ecuador and concomitantly to the preservation of their biodiversity. To that aim, the whole range of montane land-use systems is currently considered and scientifically examined. Land-use encountered in the investigated area of South Ecuador extends from completely protected forests, sustainably used natural forests, reforested former pastures, active pastures, home gardens and small crop fields. The model region around the Estacion Científica San Francisco (ECSF) offers adequate study areas, and corresponding facilities for small scale experiments could be established along an intensity-gradient of land-use, showing the following **options** of land-use:

- I.1 Pristine forest completely protected from any use
- I.2 Sustainably used natural forest
- II. Reforestation of abandoned pastures
- III. Abandoned pastures, in succession to a steady weed vegetation
- IV. Silvicultural used pastures
- V. Intensively used pastures
- VI. Intensively used crop fields and home-gardens

The working groups engaged in project-group C have examined the various options of land-use in close cooperation with the colleagues of the other Project-Groups:

In the scope of project C1, the phenology of 10 indigenous tree species in the natural forest (option I.1) was examined. Flowering and fruit production of these tree species were studied over a period of three years. Interesting interconnections of the rhythmically recurring phenological phases with climatic parameters were discovered. With regard to option II (reforestation), important basic principles regarding the propagation of indigenous tree species by seeds and scions (cuttings) could be established. Furthermore, this project presented deeper insights into the course of successions on abandoned pastures (option III). Here, the important role of bracken fern in the destruction of pastures after repeated use of fire was analysed. Knowledge of the biology of this fern provides the basics for the development of effective control of that powerful weed. Project C1 also investigated the history and development of secondary forests as the late stages of successions in the investigated area. As a result, individual parts of the ECSF forest can now be clearly assigned to different types of secondary forest, resulting from different modes of clearing of the pristine forest.

Within the scope of project C4 three experimental sites were established which allow statements for options I.1, I.2, II and III to be made. In the

[1] NAFIS: From the German title: „**N**achhaltiges **A**grar- und **F**orstökosystemmanagement **i**n **S**üdecuador

Project-Group C: Sustainable agro- and forest ecosystem management in South Ecuador

Increasing intensity of use
Decreasing naturalness

(Project period 01.03.2005 – 28.02.2007)

Options of use by humans	I Pristine Forest a) untouched b) Used	II Reforestation	III Succession (abandoned pastures)	IV Alley cropping	V Clearing and use as pastures	VI Homegardens /Agriculture
Managing working group	WG Weber	WG Weber	WG Beck WG Weber	AG Weber		WG Pohle
German colla-borators and focal points of research	**Mosandl** *Sivicultural measures* **Beck** *Biology of impor-tant species* **Stimm** *Seed production* **Müller-Starck** *Genetic differentiation of indigenous trees* **Pohle** *Ethnoecology* **Makeschin** *Turnover of matter, site-classification*	**Weber** *Reforestation* **Stimm/ Müller-Starck** *Plant material/ Gen. Certification* **Beck** *Biology of bracken* **Kottke** *Mycorrhiza* **Pohle** *Ethnoecology* **Makeschin** *Turnover of matter, site-classification*	**Beck** *Biology of bracken, succession studies* **Weber/Stimm** *Seed production/ Seed germintion* **Pohle** *Ethnoecology* **Makeschin** *Turnover of matter, site-classification*	**Weber** *Alley cropping* **Pohle** *Ethnoecology* **Makeschin** *Turnover of matter, site-classification*	**Pohle** *Ethnoecology* **Makeschin** *Turnover of matter, site-classification*	**Pohle** *Ethnoeckology* **Makeschin** *Turnover of matter, site-classification*
Ecuadorian Partners	**Aguirre (UNL)** **Maza (UNL)**	**Lucero (UTPL)**	**Lucero (UTPL)**	**Lucero (UTPL)**	**Lucero (UTPL)**	

Figure 10: Organization matrix of Project-Group C

natural forest of the ECSF, following an inventory of tree layer in three Quebradas an experiment aiming at sustainable use of the natural forest was initiated (option I.1).

Based of the findings of project C1, the propagation of 14 indigenous tree species were examined in a newly established tree nursery, aiming at large-scale plant production for reforestation (Fig. 11). The plantlets were already used at the ECSF-site for the reforestation experiment described in the following.

In the reforestation experiment useful information for option II is being collected. A total of 432 plots each 10.75 m x 10.75 m have been established on three areas belonging to different succession stages (pasture, fern and shrub vegetation). The plots were planted with 5 indigenous and 2 exotic tree species in pure or mixed stands. A total of 9600 trees were planted. Half of the plants were repeatedly freed from competing weeds, while the other half grew without this protective measure. A sufficient selection of untreated areas will serve as controls for the planted plots, and will allow the monitoring of the uncontrolled development of abandoned pastures (option III). The experimental design represents a multi-factorial split facility on 3 areas, with 9 treatments (tree species and control areas), 2 variants with weed control and 8 repetitions (3 x 9 x 2 x 8 = 432). Thanks to the discrete commitment of the local coordinator Dr. Sven Günther, comprehensive experimental facilities are now available for the coming research period.

Figure 11: View into the greenhouse of the Research Unit at the UNL. Members of the afforestation group optimize conditions for germination of indigenous tree species.
© Bettina Leischner.

In project C2 the use-options V and VI, namely the extensive land-use, was given closer consideration. An inventory of different home-gardens and animal husbandry systems (option VI) as well as the analysis of pasture systems (use-option V) resulted in valuable findings regarding the land-use knowledge of the local population. By interviews, land-use practices applied in the natural forest (option I.I) became visible. A particularly significant finding was that various ethnic groups preserve different conceptions of land-use and consequently follow different land-use concepts. Obviously the ecological diversity of the region corresponds to its cultural diversity. Approaches to improved land-use systems must take this cultural diversity into consideration in order to develop appropriate concepts of biodiversity protection and to improve land-use practices in line with the criteria of sustainability.

In the **future orientation of NAFIS** (Project-Group C), use-options IV and V (silvicultural and pure pasture systems), which until now have not been examined, will be given special attention. To this end, use will be made of the competencies of the Research Unit in this field and of the local Ecuadorian Universities (UTPL and UNL), which enjoy direct contacts with various land users, will be involved.

The basis of the present rural economy in South Ecuador is the continuous conversion of pristine forest into pasture land. The pastures which are mainly planted manually require more and more upkeep in the course of time. Especially the bracken fern which vigorously emerges as a pasture weed benefits from the commonly used technique of burning and finally cannot be controlled in advanced stages of succession. As a result the pastures are abandoned and new areas are cleared (Hartig & Beck, 2003). This particular ruinous practice of pasture farming is performed by the settlers (the Colonos; Pohle, 2004).

The following **hypotheses** will serve as guidelines for the individual projects:

<u>Thesis 1:</u> The present land-use system in South Ecuador is not sustainable

An effective pushing back of the bracken fern requires detailed knowledge of the biology of this particularly aggressive pasture weed. Based on sound data of its propagation strategies and its ecological requirements, the development of an effective weed control strategy appears feasible that prolongs the potential use of the pastures and in this way contributes to sustainable land-use.

Indigenous knowledge of the environment and sustainable use of the biodiversity are well established in the local ethnic groups (Shuar and Saraguro) in South Ecuador (Pohle, 2004). This leads to the conclusion that sustainable land-use in the South Ecuadorian forests is possible, so long as this knowledge can be made available and is used site-specifically.

*Figure 12: Shuar-woman with a Tsem-Tsem (*Peperomia *sp.), a wild grown plant used as medial remedy against stomach aches.*
© Andrés Gerique.

<u>Thesis 2:</u> A sustainable land-use in South Ecuador is possible

With the involvement of indigenous knowledge and based on scientific experiments as well as on an on appropriate site classifications, it should be possible to develop concepts

- for a sustainable use of the natural forest (natural forest management),
- for a pasture management that saves resources, and
- for the re-utilization of degraded areas through reforestation (justification of the ecological experiments).

The findings acquired so far indicate the great extent to which the tropical mountain rainforest has adapted to the climate and to the soil situation; they at least partly explain the high stability and resilience of this ecosystem warranting sustainability.

Thesis 3: Land-use systems should give respect to naturalness. The criteria of sustainability will be achieved the better and faster the more elements of the natural forest can be incorporated in land-use systems.

Incorporation of elements of the natural forest in current land-use systems should improve their sustainability. As indicators of sustainability, various criteria may be employed [e.g. stability, resilience, independence of energy supply (in the form of fertilizers and biocides), maintenance of biodiversity, preservation of closed cycles of matter, prevention of soil degradation, multiplicity of possible uses].

The hypothesis can be tested by assessing the individual examined land-use systems (natural forest use, reforestation, silvicultural systems, and pastures) according to these criteria and by comparing them with the extensively investigated natural forest.

The interconnections and the special significances of the individual projects of the project-group C are illustrated in Figures 12 and 13.

Speaker of the project-group: Prof. Dr. Reinhard Mosandl, Technical University of Munich

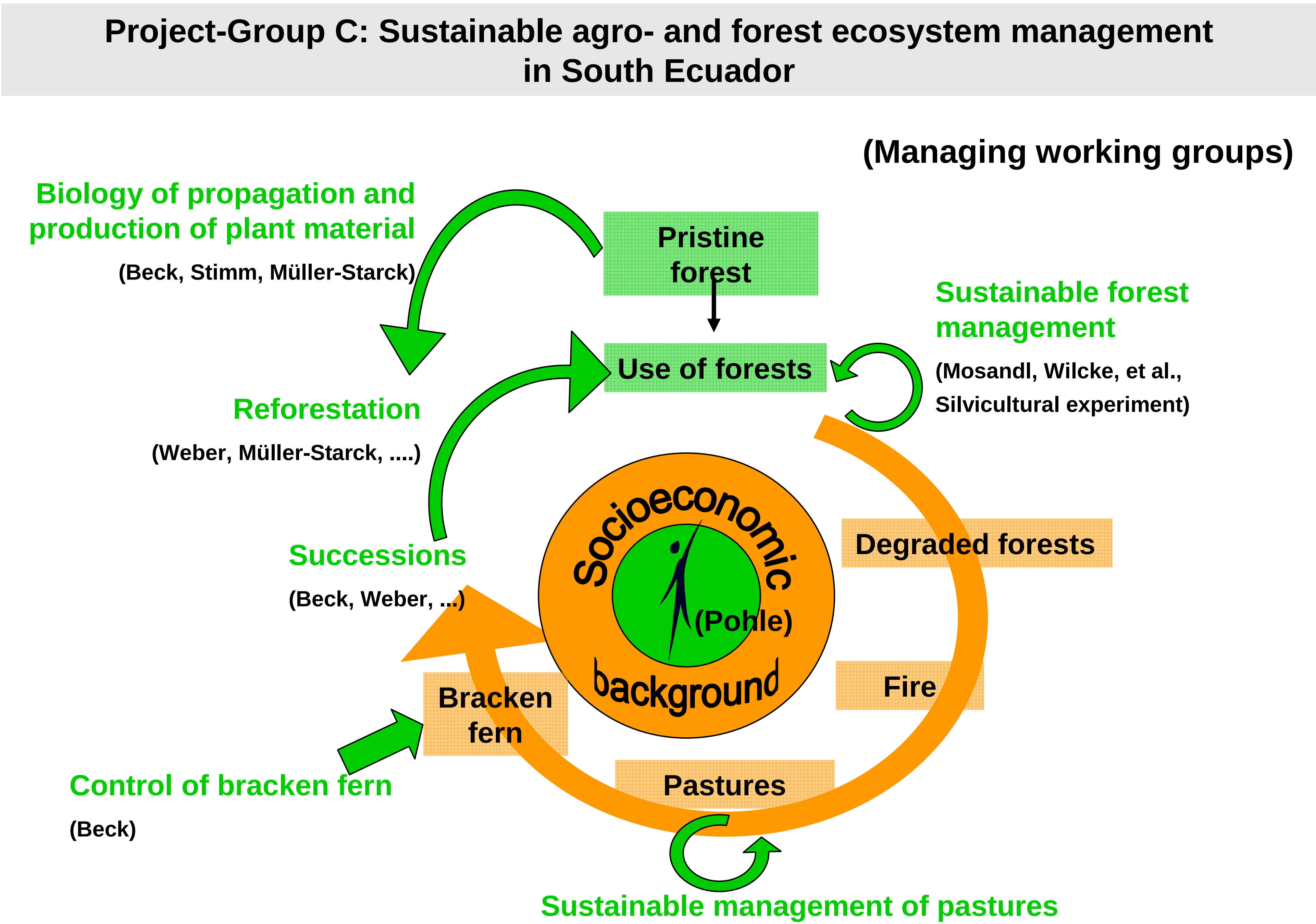

Figure 13: Interconnections between individual projects in Project-Group C

Project-Group D: „Climate and landscape history“

Climate and in particular inputs of atmosphere-borne water and plant nutrients are the important parameters which effect the dynamics of the investigated ecosystem. One should, however, bear in mind that the current state of the ecosystem is also a result of long-term environmental changes that left their footprints at least since the late quaternary and which are barely known. Through the increasing human interference drastic changes in the investigated area and its vicinity are to be expected. The feedback effects of those changes on the local and regional climate as well as on the interconnected water, nutrients and energy cycles are as of yet unknown.

In the second period of research, the follow-up of the assigned climate monitoring (D3-D5) was in the foreground, along with the inventory of atmospheric water and nutrients input and their dynamics. In the course of transfer and new installation of climate stations, the recording of climate factors at the upper tree line was initiated. Initial methodological problems (e.g. radar calibration, quality of data analysis, cloud classification, adaptation of the mesoscale model MM5, logger control of the mist collector etc.) could be solved, and the work was continued as scheduled, despite various drawbacks (*inter alia* surge damages in 2003 strongly damaging most instruments installed by the projects D4-D5). Investigation of the climate change and landscape history during the Late Holocene started in the second research period (project D2).

Figure 14: The Dry-Forest 'El Bosque' northeast of Vilcabamba with the typical cloud above the ridge of the plateau of the Podocarpus National Park. Some of the data loggers of the dendroecology group are located here.
© Paul Emck.

The research led to a significantly new understanding of the climate dynamics and the atmospheric water and nutrient inputs, rendering partly unexpected results. One example is the daily maximum of precipitation at sunrise that cannot be explained solely by the local energy budget and flow dynamics but rather indicates precipitation genesis under large-scale control mechanisms (projects D3 and D4). Expectedly, rainfall increases with altitude, however to an unexpected extent that is due to a substantial contribution from horizontal precipitation and cloud-combing especially in the upper regions of the investigated area (projects D3, D4 and D5). The altitudinal gradients established from punctual measurements cannot be applied universally to the entire investigation area, as analyses of cloudiness and precipitation distribution (project D4) show small scale spatial patterns arising from wind- and leeward expositions, respectively. Such patterns change with the airflow situation partly resulting in extraordinarily high precipitation yields in windward exposition. Joint investigations by plant scientists and climate researchers showed that the reproductive cycle of several tree species is affected by the solar radiation as modulated by the degree of cloudiness and the resulting temperature fluctuations. A closer examination of atmospheric energy fluxes therefore seems desirable. Input of plant nutrients via precipitation (project D5) was unexpectedly low, but showed a typical altitudinal gradient. However, events occurring outside the investigation area (e.g. volcanic eruptions) significantly increase the input in a non-periodical mode. Based on the geo-ecological investigations of the tree line ecotone (project D3), the hypothesis could be substantiated that the only slightly sloping Páramo sites, as well as flat spurs and crests in the upper regions of the investigated area are edaphically too wet for trees. Dendroecology has proven as useful tool for the analysis of the climate and landscape history in the ECSF-area as first evaluations of micro sections (project D2) of wood from various tree species showed clear annual rings and density fluctuations.

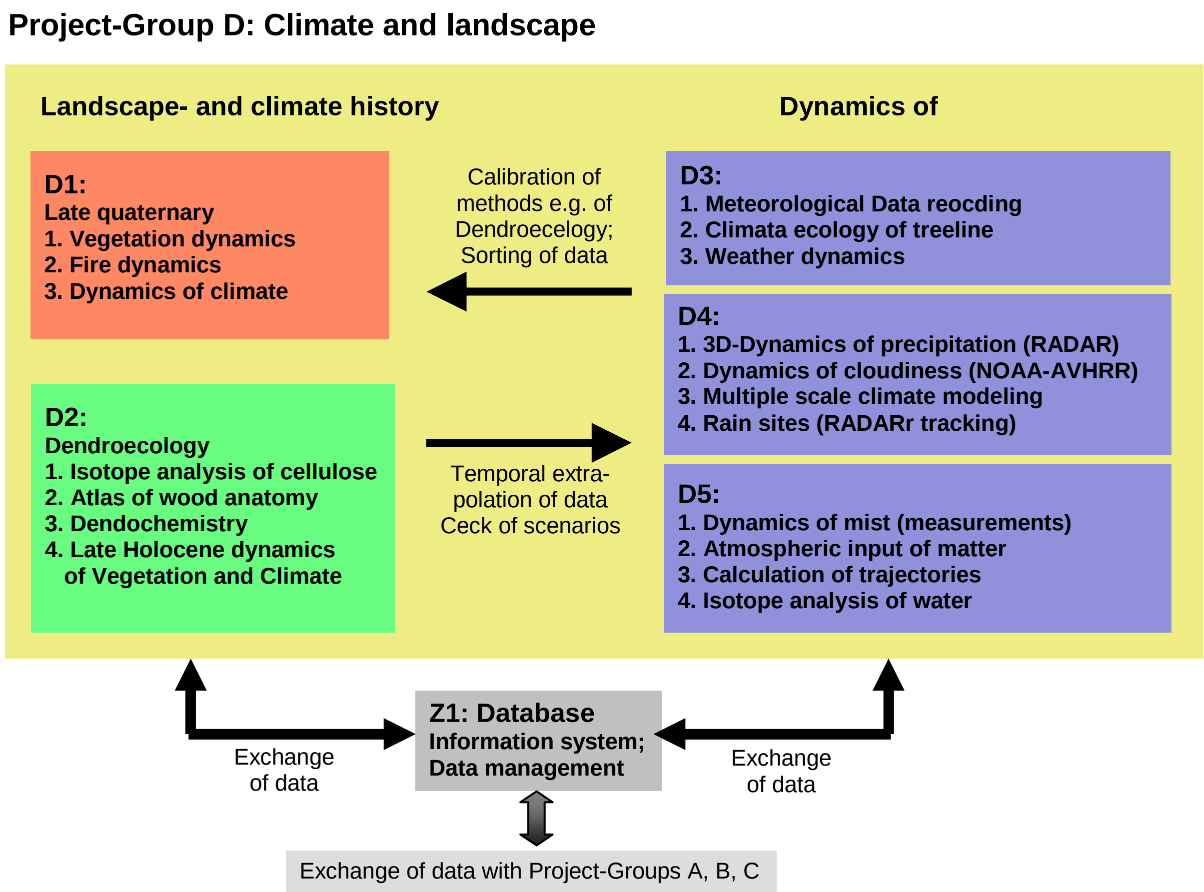

Figure 15: Synopsis of Project-Group D

From the previously reported findings, **two sectorial hypotheses** were established as guidelines for the continuation of the research in the **third period of research**:

1. **Atmospheric fluxes (climate, water, energy, nutrients) into the ecosystem are governed by local as well as superior atmospheric processes, both of various scale lengths.**
2. **Tropical mountain rain forests react very sensitive to natural and anthropogenic changes of the environment of both short and long duration.**

Hypothesis 1 concerns projects D2 to D5 in particular. In addition to the ongoing monitoring, of climate parameters the dynamics of locally effective atmospheric processes must be examined at various scales in order to comprehensively understand the weather dynamics (understanding of processes). For future analyses the following points are prominent:

(a) Derivation of flow-dependent patterns (specific weather situations and of their interactions) at various scales (ECSF-sites – San Francisco valley – Andean range – Amazon/Pacific), using
(b) measured data, model cascades and tracking techniques as well as
(c) the identification of provenance regions of atmospheric trace elements and water with trajectories and isotope studies and
(d) area-wide spatial modelling of atmospheric fluxes in the ECSF ecosystem.

Collaboration with Project-Groups A and B promises deeper insight into interactions of abiotic and biotic environmental factors. Task (d) contributes to the profiling aim „modelling" of the Research Unit (cooperation especially between projects D4, B4 and B5) and is closely related with the data base project Z1.

Hypothesis 2 in particular addresses not only the question of historical landscape genesis (landscape and climate history), but also the effects (feedback effects) of anthropogenic impacts on the ecosystem, especially on atmosphere and biosphere. Through the projects D1 and D2 the Research Unit gives respect to the fact that landscape dynamics of the research area from the postglacial up to the Recent Holocene is largely unexplored and that therefore future developments are hardly predictable. In particular the cooperation between the already established project D2 and the new project D1 should allow for various proxy data (deposits of pollen, spores, charcoal in bog/lake sediments and their chronological dating, as well as dendro-ecological analyses) which give information about the climate between the Late Quaternary and the Recent Holocene as well as findings about former impact of humans on the investigated area. A deeper understanding of the dynamics and sensitivity of the tropical mountain ecosystem vis à vis natural and anthropogenic changes in the environmental is expected. With the planned cascade models (projects D4, B4 and B5) scenarios can be calculated, based for example on findings in the reforestation experiment (Project-Group C), which allow the identification of feedback effects between anthropogenically manipulated areas and atmospheric parameters. In this way, Project-Group D, in cooperation with Project-Group C, will contribute to the development of basic principles for a sustainable management of the investigated areas.

Speaker of the Project-Group: Prof. Dr. Jörg Bendix, University of Marburg

Project Z1: “Modelling”

Project Z1 is the network-based **data and information system** of the Research Unit, which started its work at the University of Marburg during the previous year. In the beginning, not only data base relevant technical problems were to be solved, but also copyright related points had to be agreed upon since the members of the Research Unit were to commit themselves to specific rules concerning data exchange. A very important part of the data base is the now available ortho-photo map of the whole region in different scales and resolutions, as well as an isohypsis-related model of the ECSF sites.

The results of the second research period indicate that comprehensive modelling of the whole ecosystem of the core area will not be realizable during the coming two years, not even on one single spatial scale. For attaining medium-term realizable model concepts at various space and time scales, the body of the data must be further extended and elaborated, and better insights in the major exchange and turnover processes of the ecosystem must be gained.

Tab. 1: Models of ecosystem parameters

Model designation	Subject	Scale	Researcher/Project
MM5	Simulation of meteorological elements (*inter alia* upper limiting conditions for CLM)	a) 45 – 14 km grid cell b) Ecuador	Palacios/Bendix, **D4**
CLM	Calculation of water and energy fluxes between soil, vegetation and atmosphere	a) 500 m grid (standard) higher resolution possible b) Radar range (60 km radius around the Pico de Antenas)	Rollenbeck/ Göttlicher/Bendix **D4, Z1**
TOPORAD	Calculation of potential / present topographic solar radiation intensity (*inter alia* upper limiting condition for CLM)	a) 500 m grid (standard) higher resolution possible b) Radar range (60 km radius around the Pico de Antenas)	Rollenbeck/ Göttlicher/Bendix **D4, Z1**
NuCM	Simulation of nutrient cycles in natural forest and forest management experiment	Microcatchments (approx. 10 ha)	Boy/Sequeira/ Wilcke **B5**
DyDOC	Simulation of the carbon budget in the natural forest and of pastures and as well of the area of the forest management experiment	Microcatchments (approx. 10 ha)	Wilcke **B5**

However, already in the ongoing research period, individual models for sub-compartments of the ecosystem were developed and adapted to the ECSF core region (in Project-Groups B and D) and further models are in preparation (Table 1). A central cross-sectional task of the

Research Unit will be to evaluate the model concepts in the relevant Project-Groups and to identify synergy-effects of the individual models. Upscaling will play a central role since the individual models work at different scales and resolutions, e.g. of a single tree, of a catchment or of the ECSF core area.

A core group from the Project-Groups A (Fiedler), B (Huwe, Küppers, Wilcke, Leuschner) and D (Bendix, Fabian) will tackle two theme complexes which may be addressed as pilot studies in the field of ecosystem modelling:

1. Statististical modelling of connections between significant abiotic and biodiversity parameters, using a selected species-rich group of organisms as an example.
2. Numerical process modelling on various scales of selected fluxes of matter and energy between soil, vegetation and atmosphere.

Ad 1:

Using classical statistical procedures such as multiple regression models and Bayes estimation treatment the diversity and composition-patterns of moth species will be put in context with abiotic variables (e.g. temperature gradients etc. as provided by Project-Groups B and D) as well as with biotic elements provided by other projects (which have been at least partly completed; e.g. vegetation, avifauna). The model equations should allow statements on the biodiversity of other, not yet investigated tropical mountain forests and, in terms of an indicator function, on organism groups that are difficult to record. To that end, the degree of covariance of biodiversity of various groups of organisms will be examined, i.e. if an assessment on biodiversity can at all be made with reasonable effort in such an extremely species rich tropical mountain rainforest and which taxa may be suitable for it. This statistical modelling has a pilot character for all groups of organisms investigated by the Research Unit.

Various statistical models and numerical process models will be applied in the second complex (groups B and D) in order to simulate fluxes of matter and energy within and among, respectively, atmosphere, vegetation and soil. To this end, the research will be conducted on a single-tree level, on plot level, in micro catchments and exhaustively on the whole investigated area. Research at the various levels ranges from the simulation of atmospheric water input via the canopy and the stem flow all the way up to the modelling of the carbon budget. With a sub-model all relevant groups will at least simulate the water flow from the soil via the vegetation into the atmosphere (*evapotranspiration*). In addition to the specific aims of the projects, the problems of scale transitions shall be addressed, using evapotranspiration as an example (see figure 16).

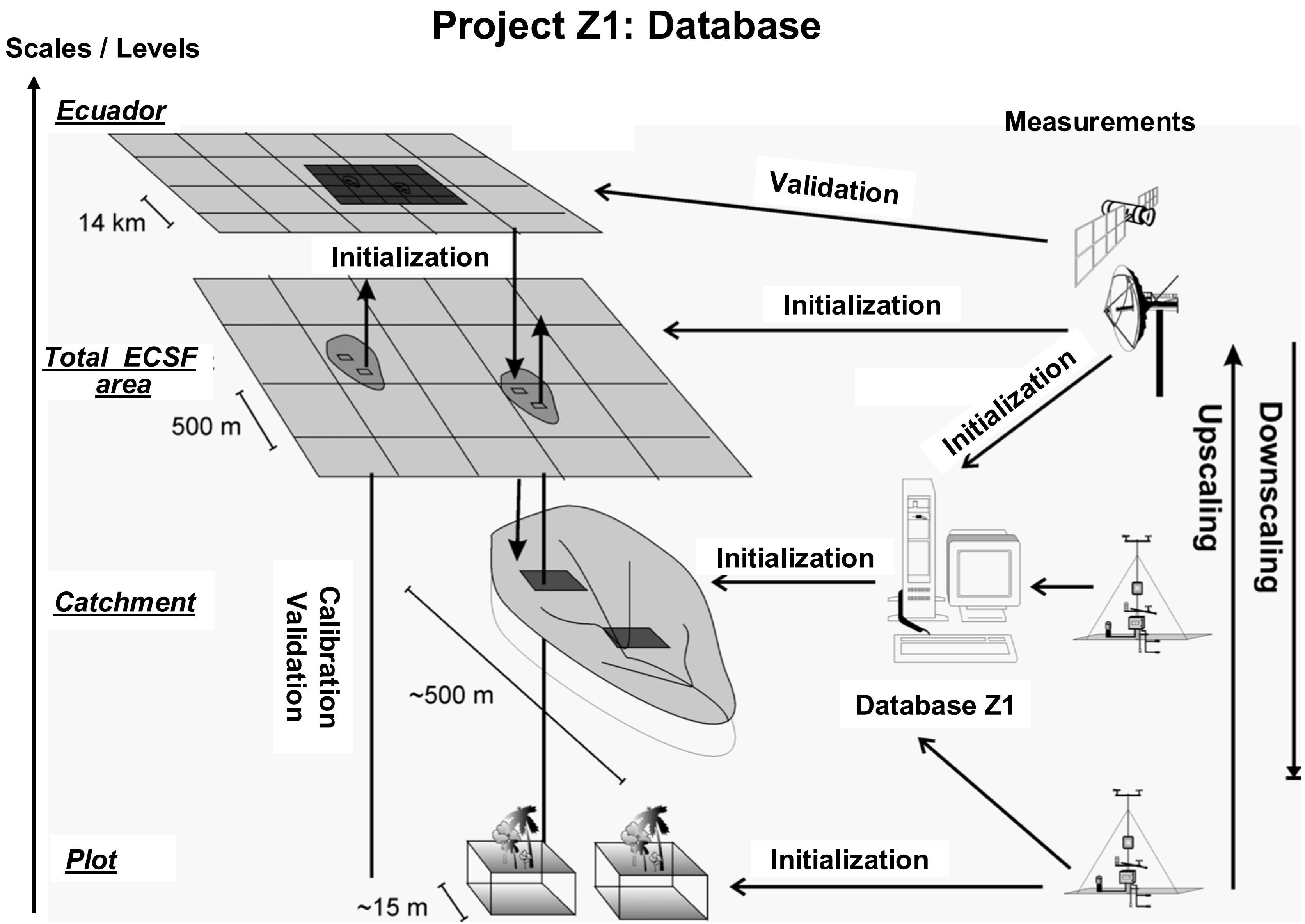

Figure 16: Scale cascade by process modeling in groups B and D

All models require directly (logger) or indirectly (remote sensing) measured data for initialization (limiting conditions), calibration and validation, which are available via the central data base (project Z1). The planned models e.g. for the simulation of evapotranspiration, have to address the plot level (~15 m), the catchment level (~500 m) and the regional level (grid model 500 m). An accurate initialization becomes more difficult with increasing scale length, since on the one hand, the data obtained from a single point are no longer representative for the larger grid element, and on the other hand, no initialization data are available for a number of grid elements. The area-related data extrapolated from remote sensing scenes (satellite data, rain radar data) can fill specific gaps for simulations at the whole area level (e.g. realistic transmission data of clouds for radiation transfer) but are too coarse for modelling at the plot level. The scale dimensions of the individual levels are selected in such a way that the modelled evapotranspiration at the lower level (e.g. the catchment level) covers approximately one grid element of the superior level (e.g. the region model). Thus, the lower level represents a useful tool for the calibration (or validation) of simulation results at the hierarchically higher level. At the same time, data or model based results of higher levels can serve as initialization data for downscaling to the catchment level in locations where logger mediated punctual measurements are not possible. The comparison of model-created results over the whole cascade of scales will allow prospects about the possible coupling of various models in perspective of a comprehensive model of the ecosystem at a later phase.

Figure 17: Pristine forest near ECSF.
© Erwin Beck.

Furthermore, the initialization in particular at the regional level requires various vegetation- and soil-related parameters (e.g. leaf area index etc.), which at present are not available to the Research Unit (lower limiting conditions). In the data base project (Z1) this information should be gathered from remote sensing data (Landsat, SPOT, ASTER, MODIS) and from the digital relief analysis, respectively. To this effect, *in-situ* measurements and plot analyses (e.g. *in-situ* LAI measurements and soil data) should be combined with the data from remote sensing for an upscaling.

Moreover, modelling has a central significance for the Project-Group C. Using validated and adapted models, the effects of land-use changes (e.g. forest management experiment, reforestation experiment) on abiotic components (site climate, soil water budget etc.) can be simulated for prognoses in terms of scenarios for individual areas or for the whole region.

Prof. Dr. Jörg Bendix, University of Marburg

Appendix: Publications of the Research Unit

Publications published in peer reviewed journals

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