Federal Ministry of Food and Agriculture

Federal Office for Agriculture and Food

Research for international sustainable forestry (FinW)
Project update 2023

Project title (Acronym):	**KLIMNEM – Sustainable forest management in temperate deciduous forests - northern hemisphere beech (*Fagus*) and southern hemisphere southern (*Nothofagus*) beech forests**
Geographical focus:	Argentina – Central Patagonia
Cooperating partners:	University of Applied Sciences and Art Hildesheim/Holzminden/Göttingen (HAWK) • Faculty of Resource Management, Büsgenweg 1a, 37077 Götingen, Germany Georg-August-University Göttingen (GAUG) • Plant Ecology and Ecosystems Research, Albrecht-von-Haller-Institute for Plant Sciences, Untere Karspüle 2, 37073 Göttingen, Germany • Cartography, GIS and Remote Sensing Dept., Institute of Geography, Goldschmidtstraße 5, 37077 Göttingen, Germany Free University of Bozen-Bolzano (UNIBZ) • Faculty of Science and Technology, Universitätsplatz 5, 39100 Bozen-Bolzano, Italy Centro de Investigación y Extensión Forestal Andino Patagónico (CIEFAP), Ruta 259 Km 16,24, CC 14, Esquel (9200), Chubut, Argentina
Duration:	01.09.2021 – 31.08.2024
Budget:	859,963.90 Euro

Aims of the project (Map see p. 2):

The overall long-term aim of this project is to compare Central European beech forests (*Fagus sylvatica*) and the "southern beech" forests of Central Patagonia (*Nothofagus* spp.) and to deduce recommendations for a transhemispheric and transcontinental sustainable forest management of temperate deciduous and mixed deciduous forests. For this, the adaptations of forest species to climate change and their responses to extreme events and disturbances will be investigated.

In order to achieve this, the KLIMNEM project includes intensive field research in forests of Central Patagonia and the intersection with results from Central Europe, which have been elaborated within the project NEMKLIM (Nemoral Deciduous Forests under Climate Extremes; duration from

31.12.2017 to 30.06.2021, funded by the BfN with funds from the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety) in western Romania.

In the Andes of central Patagonia (as in western Romania; see Kasper et al. 2022), a "space-for-time substitution approach" is used with vegetation and tree species composition, forest structure, and various abiotic parameters being recorded along precipitation and temperature gradients. By this, natural vegetation transitions and sequences can be mapped, which provide indications of the influence of macro- and microclimatic variables that may lead to large-scale vegetation shifts in the future due to climate change. In comparison with the results of the NEMKLIM project, macroecological hypotheses can be tested and verified for their general validity, and regional deviations can be identified. For the current study area in Central Patagonia (Fig. 1), the specific objectives are as follows:
(1) The development of an **A**daptive **I**ntegrated **D**ata **I**nformation **S**ystem (AIDIS) for the Río Puelo watershed to model the past (using old maps), current, and future potential natural vegetation and to derive potentials and risks (e.g. forest fires) of the landscape; (2) the verification of the modeling results in the field and a comprehensive natural and vegetation characterization of the study area, taking into account anthropogenic and natural disturbances; (3) a vitality analysis of the main tree species to determine climate sensitivity and a comparison to main exotic tree species; (4) the development of measures for the restoration of forests and their ecosystem functions and services, taking into account the needs of the local population; (5) the derivation of concrete recommendations for action for sustainable land use, taking into account climate change for the study area, but also globally, by comparing and summarizing the results from Central Europe and Central Patagonia.

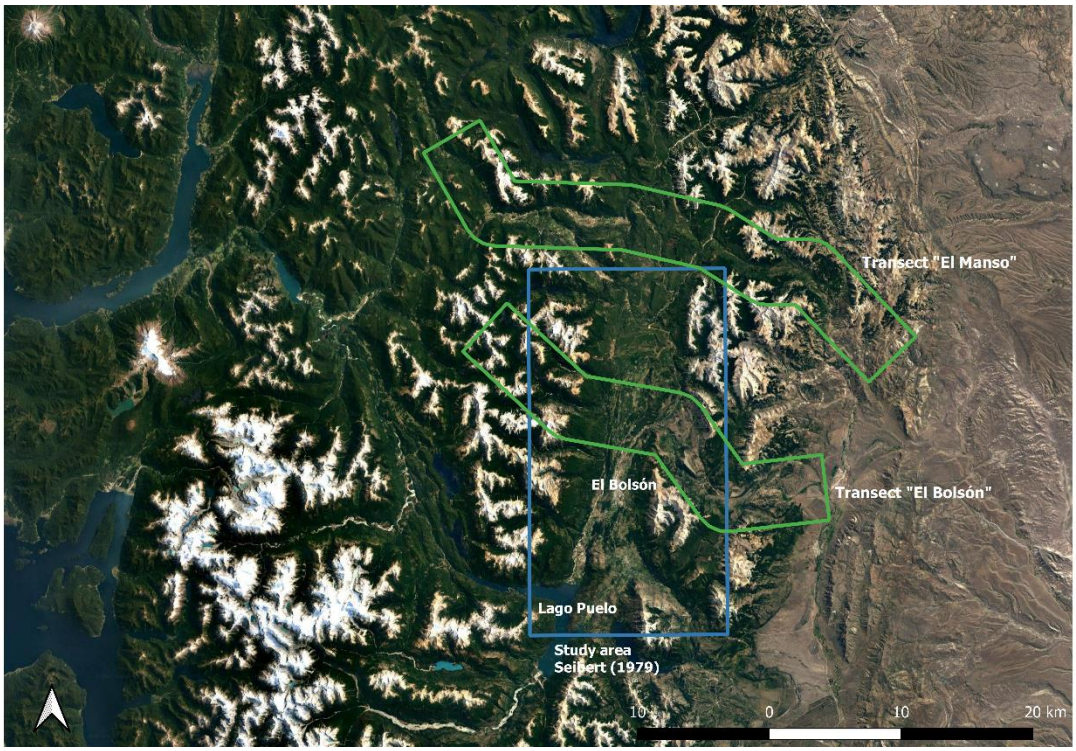


Fig. 1. Study area in central Patagonia with the two sampled transects north of the city El Bolsón. The blue frame outlines a vegetation map prepared by Paul Seibert in 1979 (Seibert 1979). The “El Bolsón”-transects largely lies within the 1979 vegetation map. Google Earth © Image Landsat/Copernicus.

The intensive field work focuses on two transects of about 70 km from the Chilean border to the Patagonian lowlands (Fig. 1). The transects were divided into four sectors each, representing a precipitation gradient from humid (sector 1, west) to semiarid (sector 4, east) and being separated by 10 to 15 km from each other. In the four sectors, different expositions (north and south exposition) along an elevation gradient from about 500 m to 1600 m a.s.l. are investigated. Thereby, the elevation gradient simultaneously re-presents a temperature gradient. After data collection in the 1st transect in the El Manso River valley was largely completed in March 2022, data collection in the 2nd transect near the community of El Bolsón followed between December 2022 and March 2023. Along the elevation gradients, a forest structure survey was conducted every 200 meters in elevation and a vegetation survey was conducted every 100 meters (Fig. 2). These survey plots were supplemented by microclimatic sensors (TMS-4 data loggers, Hygrochron-iButtons) to record air and soil temperature in the stands and by additional plots for dendrochronological analyses. In the following, previous results of the data collection in both transects are presented.

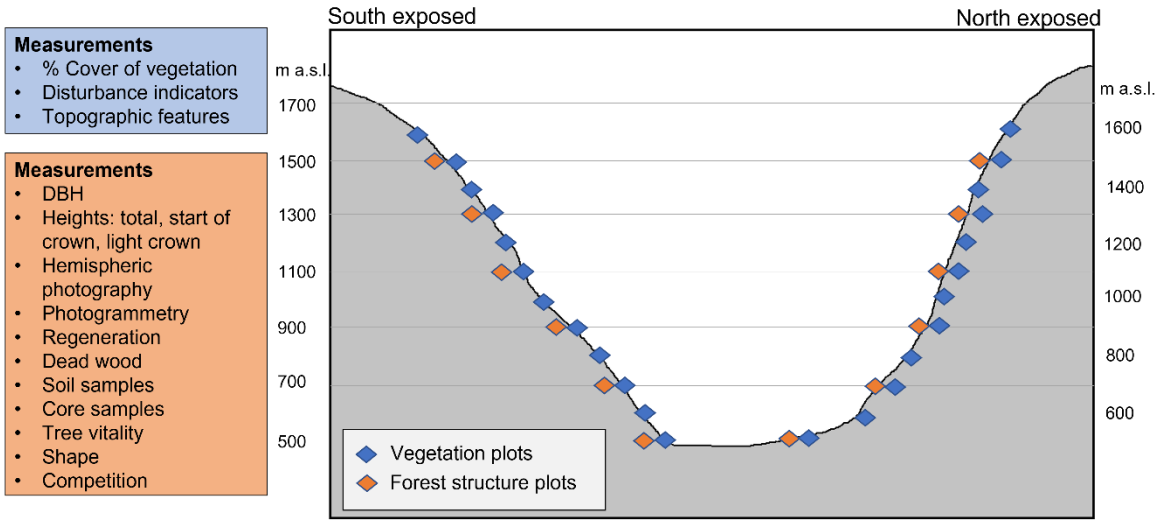


Fig. 2. Arrangement of the forest structure and vegetation sruvey plots and the conducted measurements along the elevation gradients in two different expositions.

Initial results:

For developing a comprehensive data information system, basic data on climatology and forest structure were collected within the two transects. These data are used to validate freely available global climate data sets (CHELSA, WorldClim) and satellite-based data on vertical forest structures (Global Ecosystem Dynamics Investigation (GEDI) Mission), which are to be used for modeling future developments of the vegetation in the study area. Evaluations show that there are strong uncertainties with respect to the underlying global climate datasets CHELSA and WorldClim, as both datasets show large deviations from each other as well as from existing data of the few available weather stations. These uncertainties are particularly pronounced in complex topographies and primarily concern precipitation. A better coverage by more weather stations and data loggers is necessary for reliable predictions of a future development. Nevertheless, both climate data sets show first trends. For example, climatic habitats appear to be declining for *Nothofagus pumilio* (Lenga), while they are expanding for *Austrocedrus chilensis* (Cípres). For the use of remote sensing data to estimate forest structure and above-ground biomass, preliminary results show good correlations between field measurements and GEDI estimates at sites with less than

25% slope. The effect of slope increases the error primarily in estimates of ground-level vegetation cover (0-5 m) and secondarily in tree canopy height. In addition, it was found that tree height is underestimated by GEDI when the forest floor is covered by a dense bamboo understorey.

Three main forest communities could be distinguished from vegetation surveys: 1) Subalpine deciduous forests with *Nothofagus pumilio* (Anemono antucensis Oberd. 1960 and Machrachaenio-Nothofagetum pumilionis, Eskuche 1973), 2) dry scrub with *Nothofagus antarctica* (Lomatio hirsutae-Nothofagetum antarcticae, Eskuche 1969), and 3) mixed forest with *Nothofagus dombeyi* and *Austrocedrus chilensis* (Austrocedro-Nothofagetum dom-beyi, Eskuche 1968). Climatic variables have a greater influence on differences in vegetation composition than land use. Elevation has the greatest influence, being strongly negatively correlated with temperature, followed by precipitation and slope exposition. A comparison of the distribution foci of different species along the elevation gradient between vegetation surveys conducted between 1960 and 1980 in the study area and the current surveys within the framework of KLIMEM revealed interesting patterns: early successional tree and shrub species that are capable of vegetative reproduction currently show a unimodal distribution with an occurrence maximum between 600 and 1200 m a.s.l.. In the past, however, many of these species had their distributional maximum at higher elevations or were sparsely present across elevational gradients. In contrast, former mid-elevation optima of key tree species either flattened or shifted downward along the elevation gradient. In contrast, a shift in species distribution to higher elevations due to increasing temperatures under climate change was not observed. Nevertheless, the results may indicate indirect effects of climate change in that disturbances, such as forest fires, became more frequent at mid-elevations due to drier conditions and by this promoted early successional species.

Structurally, some differences and parallels between both transects were found:

- Shrub stages with *N. antarctica* and *Lomatia hirsuta* occurred more rarely or not at all in the El Bolsón transect compared to the El Manso transect, suggesting less effects of forest fires in the El Bolsón transect. Here, other shrub species dominated in combination with *N. dombeyi* or *A. chilensis.*
- While *N. dombeyi* was found only in more humid areas in transect 1 (sector 1 and shaded slopes of sector 2), the sunny slopes (north exposed) of sector 2 in the El Bolsón transect are also more dominated by *N. dombeyi*. Mixed stands of *A. chilensis* and *N. dombeyi* could be found in El Bolsón even at 900 m in sector 3, north exposed.
- *N. pumilio* begins in north exposed sites in sector 2 of the El Manso transect only from 1500 m elevation upwards. In the El Bolsón transect the *N. pumilio* belt begins at northern exposed sites at 1300 m elevation across the sectors 1, 2, and 3.
- The highest calculated stand volume was found in the El Manso transect with 745 m^3/ha at 900 m elevation in sector 1, southern exposition with a basal area of 53.9 m^2/ha. At the same elevation and exposition, the values were comparable in the El Bolsón transect with 701 m^3/ha at a basal area of 63.3 m^2/ha (both *N. dombeyi* forests). However, the highest volume stock could be measured in the transect El Bolsón in sector 2, 700 m elevation, north exposed, with 1016 m^3/ha at a basal area of 105.6 m^2/ha in a *N. dombeyi* pole-wood.
- With 162.9 t/ha the largest amount of coarse woody debris was recorded in the transect El Bolsón in sector 1, north exposition and 900 m elevation. The amounts here are comparable to the counterpart in the transect El Manso (143 t/ha). The fine woody debris, which can largely influence the spread of forest fires, shows relatively homogeneous values with mean values around 6 t/ha in the El Bolsón transect comparable to the transect "El

Manso". The highest values were measured in sector 2 with a maximum of 21.8 t/ha at 1100 m altitude (north exposition). In comparison, the maximum in El Manso was 11.1 t/ha at 500 m elevation (north exposition) in sector 1. Overall, in the El Manso transect the amount of deadwood decreased from west to east, while in the El Bolson transect especially the fine and medium woody debris showed on average the highest values in sector 2 with higher values in north exposition.

Soil conditions proved to be relatively homogeneous, especially in the El Manso transect. However, the carbon stock showed a strong increasing variation with elevation and strong differences in the *N. pumilio* forests depending on exposition and vegetation composition. Important factors influencing carbon stocks were litter quality (negative influence), aboveground biomass (positive), proportion of fine roots (positive), soil moisture (negative), and soil depth (positive).

First results of the iButton readings from 01.03.2022 to 01.03.2023 in the El Manso transect show that the microclimate generally follows the macroclimate, as the mean annual temperature decreases linearly with altitude. For every 100 m of elevation, the temperature decreased by 0.48 °C. The highest daily temperatures were measured with 27.7 °C on 04.02.2023 in a gap in an *A. chilensis* stand at 600 m elevation in sector 2 at north exposition. The lowest temperature was recorded with -9.5 °C on 26.05.2022 in a *N. antarctica* shrub in sector 4 at 1100 m elevation at a plateau site.

Climatic influences on the growth of the main native tree species will be evaluated by dendroecological studies. In addition, responses to climatic changes will be compared with common alien tree species. In both transects more than 1000 increment cores of three native (*N. dombeyi*, *N. pumilio*, *A. chilensis*) and two alien tree species (*Pinus radiata*, *P. poderosa*) have been collected. Preliminary results on the native tree species show that climatic sensitivity of the basal area increment of the three species increased significantly between the periods 1942-1981 and 1982-2021, and growth synchrony became higher, driven climatic factors. *N. pumilio*, however, shows a lower climate sensitivity at moist sites. The annual basal area increment in mm^2 $year^{-1}$ decreased significantly over the last 40 years in all *A. chilensis* stands, except at the driest site, which was also the oldest stand. This could provide evidence of possible drought acclimation or adaptation. Similar trends were observed in old *N. dombeyi* stands at drier sites (Sectors 3 and 4), where microrelief characteristics may play an important role in modulating growth. At the wetter sites of *N. pumilio*, a significant increase in growth was recorded during the current observation period, with opposite effects to the more exposed and drier sites in the east. Here, the first differences in the sensitivity of the tree species depending on the site conditions are already becoming apparent, which will contribute to a desired risk analysis of tree species.

In order to restore degraded forests, for example after large-scale forest fires, plantings of new native target tree species are planned. Seedlings are currently grown in a greenhouse. In addition, a master's thesis investigated factors influencing the regeneration of *N. dombeyi* at different height classes. Tree layer cover as a measure of light availability, grazing intensity, forest management intensity, amount of dead wood, and topographic variables were considered as influencing factors. It was found that *N. dombeyi* can significantly benefit from low to medium grazing intensity and from open mineral soil, so that the establishment of agroforestry systems, especially in areas close to settlements, can be considered a potential option for linking different land use systems. The findings will be incorporated into future recommendations for action.

Key statements and policy advice:
Since data collection was only completed by the end of March 2023 (microclimatic measurements will continue at selected sites for another year), no evidence-based recommendations for policy and land use are yet available.
The following preliminary statements can be made based on the results to date:

- The use of global and remote sensing-based climate and forest structural data for current and future modeling of the study area is associated with significant uncertainties due to the complex topography in the northern Patagonian Andean forests. An extension of the sparse existing network of weather stations and data loggers is necessary here. The elaboration of correction factors for steep slopes to estimate vertical forest structure and aboveground biomass will improve the quality of satellite-based vegetation maps in the future.
- Both studied transects show a comparable temperature (= elevation) controlled succession of forest communities. However, a comparison with earlier vegetation surveys, e. g. by Seibert (1979), does not show any "upward" shift of species occurrences due to increasing temperatures. Rather, shifts "downwards" could be observed, especially of early successional species, which presumably react to an increased disturbance frequency such as more frequent forest fires in mid altitudes. This suggests an indirect influence of climate change.
- Dendroecological studies show increasing climate sensitivity of native tree species, but this is highly dependent on site conditions and prior acclimation and adaptation. Evidence suggests that the main tree species, *N. dombeyi* and *A. chilensis*, show declines in growth under dry weather conditions, especially in humid areas, while *N. pumilio* appears to benefit from warmer temperatures in humid conditions.
- Analyses of the regeneration of *N. dombeyi* indicate the suitability of land-use concepts that combine timber and pasture use, since the tree species rejuvenated especially at a medium grazing intensity and in the presence of open mineral soil.

The presentation of the preliminary KLIMNEM results at a workshop on February 22 and 23, 2023 in the El Manso valley for the exchange of ideas and research interests underlined the importance of the collected data also for other research institutions in the region. An intensive exchange of data and an intensification of collaborations for the future are currently being pursued. This also includes research institutions in Chile.
The results will be incorporated into concrete management concepts that will provide various local stakeholders with information on the future selection of tree species and land use, taking into account various risk factors (including the risk of forest fires).

References
Kasper J., Leuschner C., Walentowski H., Petritan A.M., Weigel R. (2022) Winners and losers of climate warming: Declining growth in *Fagus* and *Tilia* vs. stable growth in three *Quercus* species in the natural beech–oak forest ecotone (western Romania). *Forest Ecology and Management* 506: 119892, doi: https://doi.org/10.1016/j.foreco.2021.119892

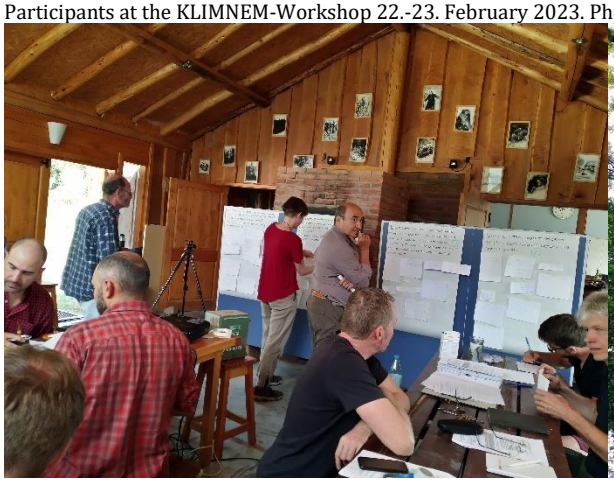
Seibert P. (1979) Die Vegetationskarte des Gebietes von El Bolsón, Prov. Río Negro, und ihre Anwendung in der Landnutzungsplanung. Bonner Geographische Abhandlungen 62: 1-96.

Impressions

Dismounting iButtons in the El Manso transect. Photo: Steffi Heinrichs

Evaluation of a soil profile in sector 2 (northern exposition, 800 m a.s.l)in the transect El Bolsón. Photo: Steffi Heinrichs

Participants at the KLIMNEM-Workshop 22.-23. February 2023. Photo: CIEFAP



Discussion of research gaps during the KLIMNEM-Workshop. Photo: Steffi Heinrichs

Large crowns of *Nothofagus dombeyi* (Coihue) in the Valle El Leon, Chile as an extension of the El Manso transect. Photo. Steffi Heinrichs

Deadwood in sector 2, north exposition of the El Bolsón transect. Photo: Steffi Heinrichs

Forest structure survey. Photo:Steffi Heinrichs

Burned *Pinus radiata* stand in sector 4, El Bolsón-Transect Photo: Steffi Heinrichs

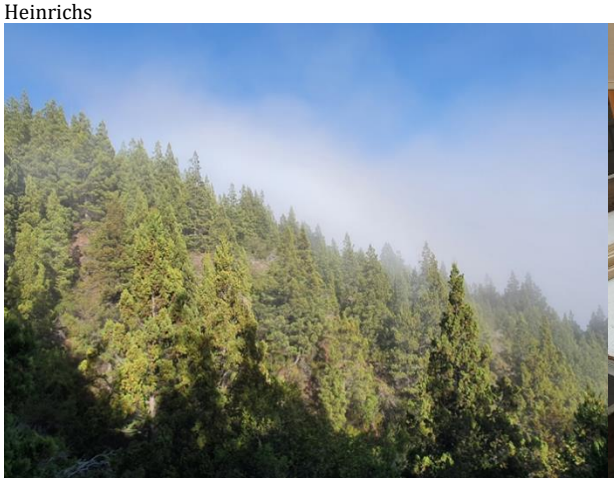
Mutisia decurrens in sector 4, 900 m a.s.l. in the El Bolsón transect. Photo: Steffi Heinrichs

Shrub stage in sector 4 El Bolsón transect, north exposition at 800 m a.s.l. Photo: Steffi Heinrichs

View from sector 2 of the El Bolsón transect. Photo: Steffi Heinrichs

In sector 4 of the El Manso valley (transect 1). Photo: Steffi Heinrichs

Exkursion at the KLIMNEM-Workshop in the El Manso valley. Photo: Steffi Heinrichs



View at *Austrocedrus chilensis* stands, sector 2, north exposition, El Manso transekt. Photo: Natalia Zoe Joelson

Grinding of increment cores. Photo: Ernesto Juan Reiter

Two *Nothofagus pumilio* forests (south exposition) in the El Bolsón" transect that clearly differ in forest structure: left in sector 3 at 1500 m a.s.l. and right in sector 2 at 1100 m a.s.l. Structural and biomass models will be developed by combining remote sensing and field data. Photos: Ariel Neri Winter