

Comparative, long-term ecosystem monitoring across the Alps: Austrian Hohe Tauern National Park, South-Tyrol and the Swiss central Alps

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Abstract

To assess potential impacts of on-going environmental change on alpine biota, a long-term ecological monitoring program was launched in the Alps. Plant, invertebrate and microbial responses will be assessed across sharp snow-melt gradients several hundred metres above treeline in five study regions. This contribution summarizes the conceptual framework and explains the practical aspects of this research.

Keywords

LTER, long term ecological research, microclimate, snow, plants, animals, microbes, high elevation.

Why long term monitoring?

Plants, animals and microbes track environmental conditions so that certain organismic assemblages (communities) emerge at a certain location that reflect 'nature's' long-term answer to that given environment. For several reasons, such assemblages may not have reached at theoretical equilibrium between organismic demands and environmental provisions:

1. environmental changes may proceed faster than all or some key organisms can follow (e.g. short distance dispersal limitation, life history constraints),
2. regular disturbances (fire, herbivory, human land use) may interfere with undisturbed community-environment interactions (climate 'tracking'),
3. the right taxa may not be available regionally (e.g. long distance dispersal limitation), or
4. communities never reach an equilibrium with their environment, because of succession, that is, one assemblage creates conditions (e.g. soil conditions) that facilitate the gradual establishment of a new community, and so on.

Currently, humans induce a number of environmental changes that have no analogy in the relevant geological past, such as the continuous rise of CO₂ concentration above its last million year mean of approximately 240 ppm to the current close to 410 ppm, the steady reactive nitrogen deposition which exceeds 'pre-industrial' background rates by at least ten-fold, or the anthropogenic rise of near-ground ozone concentrations, with the first a universal and the two others regionally varying drivers. Climatic change (rising temperature and maximum vapour pressure deficit, altered precipitation regimes) have parallels in the geological past, but the current rates of change are quite exceptional. Finally, these changes act upon a landscape that experiences more anthropogenic land use pressure at global scale than ever before (with regional exceptions).

Changes in plant and animal communities and their microbial partners in response to environmental change are often hard to evidence and explain, because the changes are (1) commonly slow and thus, can not be identified by our senses, and (2) because several environmental changes may co-occur or even interact, making it difficult to isolate cause-effect relationships. This is where long-term observations come into play, both in otherwise undisturbed ecosystems or in long term experimental manipulations (FREPPAZ et al. 2012). If cleverly designed, such long-term observations may not only evidence changes in organismic communities, but also permit distilling the key drivers of these changes, provided the suite of potential influences is known or is specifically co-monitored.

In this contribution, I will briefly summarize the conceptual framework of a terrestrial monitoring program in the central Alps that aims at evidencing responses of organismic communities to climatic change in cold environments. A complementary aquatic program will include alpine lakes and small creeks that drain catchments in which the terrestrial permanent plots are nested.

Ecosystems in which life is adapted to cold conditions may be expected to show faster changes than those in already warm areas. However, topography is a strong modifier of temperature, creating warm niches in otherwise meteorologically cool terrain because of solar ground heating that interacts with slope, exposure and degree of shelter (SCHERRER & KÖRNER 2009). Yet, topography also affects snow distribution, and thus, causes sharp gradients of the lengths of the growing season over very short distances. Many species reach their range limit within a few meters across such snow cover gradients (Fig. 1). These gradients of species distribution and range limits may be seen as mirroring trends that might otherwise be observed over large elevational gradients.



Figure 1: Alpine snow-beds are topography driven snow accumulation areas which exert very steep gradients in the length of the growing season. Transects across such snow duration gradients provide 'experiments by nature' that permit exploring causes of species range limits. The isolines of snow melt date are indicating 'life zones' that may range (over a few meters) from locations where angiosperms are absent to the most luxury life conditions for a given elevation.

The Austrian National Park Hohe Tauern has launched this monitoring program under the motto 'life at the limit', assuming that high mountain terrain will exert ultimate constraints to life at one point (line) across the climatic gradients exhibited in mountainous landscapes (low temperature species range limits). These limits will differ for species in response to several temperature-related factors such as absolute minimum temperatures in winter, spring or summer, the lengths of the growing season, the temperature during the growing season, either individually or in combination. This distinction between different facets of the action of temperature is critical (KÖRNER & HILTBRUNNER 2018). It had been shown for montane forest trees that species specific flushing phenology in interaction with freezing resistance, during or shortly after the flushing, and the duration of the remaining season (permitting tissue maturation) explains the species specific elevational and latitudinal range limits of taxa (KÖRNER et al. 2016). Data of this sort are not yet available for alpine taxa.

Above the treeline, it becomes near to impossible to obtain data about the actual thermal life conditions (and thus, the associated risks) of plants and animals, given that macro-climatological conditions (weather station data) do not scale to life conditions near the ground (SCHERRER & KÖRNER 2011). Hence, these life conditions need to be measured in order to explain plant and animal responses. Currently, climatic range limits of alpine taxa and the decisive underlying mechanisms are not known. Growth chamber conditions cannot mimic the actual alpine life conditions, most importantly, soil conditions and the ever variable microclimate. Hence, such tests must be undertaken under field conditions.

Where is the monitoring located?

'Experiments by nature', that is, sharp climatic gradients in the field, provide the most promising test conditions. Such gradients are often created by snow duration in so-called snow-beds as depicted in Fig. 1. Species are reaching range limits over a distance of a few meters that would otherwise be seen across kilometres of climatic contrast along elevation gradients. The central role of topography (snow melt regimes in particular) for life at alpine elevations is well established (an early account by AULITZKY 1963; later works by GALEN & STANTON 1995, KUDO et al. 1999, SCHERRER & KÖRNER 2011, SEDLACEK et al. 2015). Another advantage of such snowmelt gradients is that they can be replicated within a given macroclimatic, geological and biogeographic setting.

The monitoring program aims at capturing 'species at their limit' at multiple sites across the Alps. Locations are ca. 150 to 450 m above the regional climatic treeline (3 to 6 transects per site, each 7-10 m long and 3 m wide, with the central 1 m strip remaining undisturbed for photographic monitoring; Fig. 2). Monitoring sites were established in 2016 in the Hohe Tauern National Park, north and south of the main divide of the Alps, in Carinthia (Seebachtal 2300 m, Ankogel), Tyrol (Innerschlöss near Matrei, 2350 m), and Salzburg (Untersulzbachtal, 2380 m), with additional sites in northern Italy (Oberettes 2690 m, Matschertal, Ötztal-Alps) and in the Swiss central Alps (near Furka Pass 2460 m). The dominant vegetation under favourable growth conditions at all these sites is a *Carex curvula* heathland (the optimum reference along the snow melt gradients), with often only a few or no flowering plant species left at the centre of such snow-beds ('pessimal' end of the gradient).

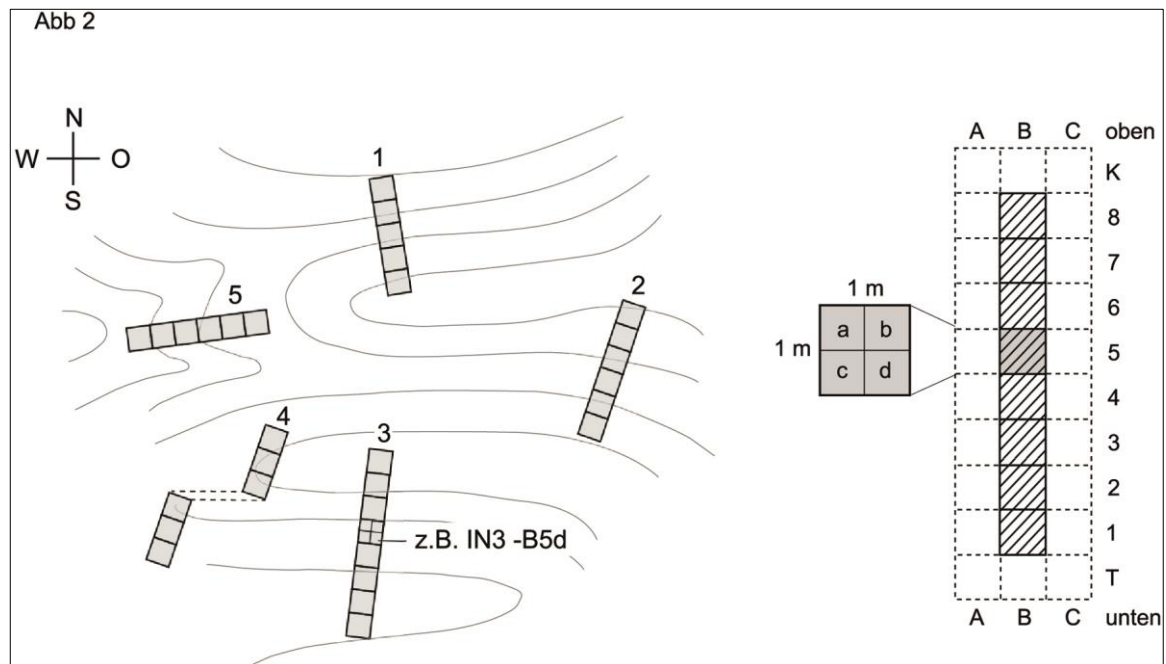


Figure 2: The study design of the monitoring program exemplified for one site with 5 snow-melt gradients (transects). Each transect consists of 3 parallel 1 m strips, with the center strip (B) serving for a photogrammetric documentation and non-destructive plant species census (no sampling). Strips A and C will be sampled following a protocol that prevents re-sampling the same subplot. For simplicity, the map illustrates the B strips only.

What is monitored?

This program aims at assessing plant, animal and microbial species diversity in exactly the same permanent quadrats placed along a micro-topography gradient. Life under optimal climate (long 'warm' season) for the given elevation will be compared to life under least favourable conditions at the same elevation (extremely short, but not necessarily less warm conditions during the snow free period). Climatic warming may change snow duration (the date of release from snow), but it will not change the spatial patterns of snowmelt (FRIEDEL 1961, KÖRNER 2003). A similar program focussing on summits and their floristic changes over time has established a global network (GLORIA) that revealed substantial increases of plant species numbers for most European summits at decadal resolution (GOTTFRIED et al. 2012, PAULI et al. 2012).

The data collected as part of this new monitoring program include:

1. environmental conditions (temperature in the top soil near the meristems of all graminoids and many herb taxa), snow duration, soil physical parameters (water content – what potential responses, grain size distribution, pH and basic soil chemistry including ^{15}N signals in the soil organic fraction),
2. plant and soil animal (invertebrate) species identity and abundance (various techniques including photographic records of permanent plots, Berlese samples),
3. soil microbe spectra (molecular techniques),
4. wild animal presence (ungulates, predators; using automatic cameras).

The associated aquatic program will monitor water chemistry, planktonic and benthic biodiversity. The basic idea of coordinated monitoring by standard protocols follows the LTER concept (Long term ecological Research; VANDERBILT & GAISER 2017) and as discussed in an earlier attempt for elevational gradients in the Alps (Becker et al. 2007).

When will the monitoring take place?

Since many of these cues undergo rapid variation, high temporal resolution is critical in order to prevent misinterpreting inter-annual peculiarities of weather conditions (Fig. 3). The data by WALKER et al (1994) are a good example of such variation for above ground plant biomass that fuels the trophic chain, including aquatic systems. Given the work load and costs, the timing of the terrestrial census is adjusted to specific tasks:

1. fast and continuous records, all year (soil temperature and snowmelt regime)
2. wild animal monitoring during the growing season of each year (10" intervals during daylight)
3. annually at peak season (defined by phenology) above-ground plant biomass
4. presence and abundance of plants, animals and microbes will be assessed at one (non-destructive, photo-monitoring) to several year intervals (e.g. five to ten years for soil organisms), also below ground plant biomass will be assessed with longer intervals (because of its destructive nature).
5. air dried soil samples and above-ground plant biomass (dried at 80 °C) will be archived for multi-decadal re-visitation.

We do not expect rapid changes, but changes that materialise over decades or even centuries. Therefore, the assessment is highly standardised, locations are permanently marked, plot sizes are normed. This should permit future generations of researchers to perform re-assessments by applying identical protocols on the very same, replicated test sites. In addition, the archived soil and above-ground plant biomass samples (ca 40 samples per site from 20×20 cm sampling area) will be archived for future inspection and application of novel (e.g. molecular) methods. These archives will be located in a regional museum, given the needed institutional continuity, and will be accompanied by documents that explain all codes and applied procedures (protocols).

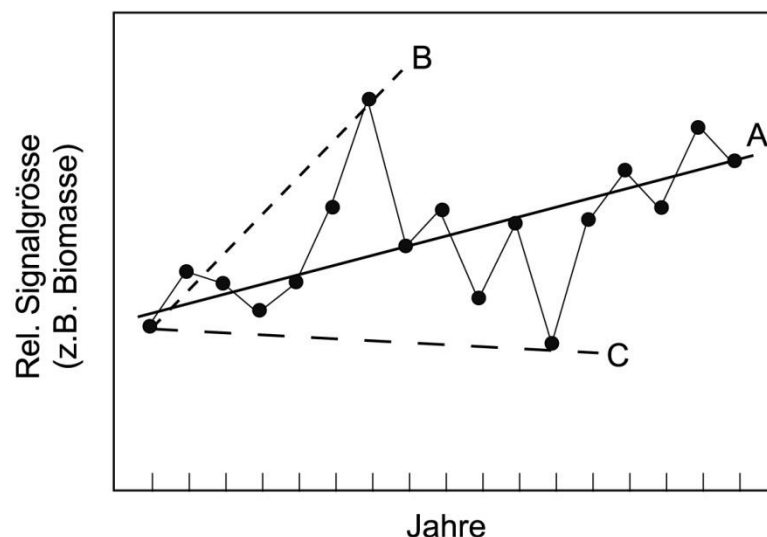


Figure 3: The problem of temporal (inter-annual) variation in ecological long-term monitoring research. Since signals may differ substantially from year to year, multi-year census intervals may reveal misleading long-term trends.

The problem of phenology

Because different plant and animal species start their season at different calendar dates, though most commonly in the same sequence in a given year, seasonal timing of the assessment is key. It would be near to impossible to standardize (adjust) sampling time for each 1 m² permanent quadrat for identical developmental (phenological) stage. So the common sampling date per site will have to remain a compromise. Our criteria for the yearly assessment date is that the climatically most constrained micro-habitats along such snowmelt gradients had a chance to reach full plant canopy development. Since typical snow-bed taxa exert opportunistic phenology, that is, they enter the seasonal developmental cycle whenever snowmelt permits, the beginning of the assessment must be at a time that accounts for the 'seasonal late comers'. Otherwise we would compare mature states at the edge of the snow-bed and premature states in the core of it. Since the latest snow melt in the test areas is commonly between the second and third week of July, the second week of August has been found to be a good compromise, for a time window during which the edge populations did not yet enter seasonal senescence, while populations in the snow-bed centre stopped growing and mostly completed flowering. The onset of fruit dispersal by *Gnaphalium supinum* in quadrats close to the 'pessimal' end of the transects is a good pheno-marker.

In contrast to the opportunistic life strategy of snow-bed taxa, plant species at the edge of the snow-bed, often on ridges, would be at risk if they adopt an entirely opportunistic phenology strategy (they may lack snow cover during late winter and flush and flower at the 'wrong' time, that is too early, and thus, may undergo freezing damage (BAPTIST et al. 2010). Such taxa often use photoperiod as a reliably environmental cue (KELLER & KÖRNER 2003). Snow melt gradients may thus, run into a mismatch between adaptive (genetically controlled) phenology and melting date in case of a rapid climatic change - an area currently explored by MATTEODO et al. (2016),

CARBOGNANI et al. (2016). The net consequence of such microclimate effects is likely to be a change in species distribution, as explored in our long term monitoring. There is evidence that snow-beds have already undergone changes that find an expression in changed species distribution and species abundance (BAHN & KÖRNER 2003).

Current state of monitoring

Permanent plots were established in 2016, when the thermal site characterisation started, with the first year-round data now permitting a comparison of edge and center conditions across snow-beds as well as across sites (NEWESELY et al. 2018, this volume). These data also permit nesting life conditions at the test sites in a pan-European assessment of ground temperatures in alpine grassland (KÖRNER et al. 2003). The terrestrial group performed the sampling for the base-level ecosystem assessment in August 2017 (Fig. 4, Fig. 5), with all samples and data as listed above now under processing.



Figure 4: A sample of a single transect at the site Innergshlöß, at 2350 m elevation. Mobile meter-grid nets assist sampling teams to locate permanent quadrats and the sub-quadrates nested in each grid window. Such grids also serve the photo-documentation of permanent quadrats in transects.

A large number of automatic cameras is monitoring wildlife (and domestic animal) abundance in the test areas at different elevations since July 2017. These data are essential to estimate natural and domestic herbivory pressure. Sites that have a history of domestic animal grazing (largely sheep; Innergshlöss, Furka and Oberettes) will be equipped with 25 x 25 cm ground baskets (3 cm mesh) from 2018 onwards to prevent grazing, and thus, also permit quantifying biomass losses to ungulate grazing. In 2017 these sites were fenced in the weeks before biomass harvesting. The aquatic group has all installations in place. At some sites such data are already available for several years (see FÜREDER 2018, this volume).

The way this monitoring program is conceptualized will ensure that the data not only meet the public interest in learning about climate-change influences on high elevation biota, but that the data collected also meet high scientific standards that will permit advancing high elevation biology and ecology. Environmental monitoring should always produce good science, to double-justify public spending and academic engagement. Such well replicated and standardized assessments will also permit scaling beyond the boundaries of small regions, and thus, will attract the wider conservation science community and environmental policy.



Figure 5: An example of plant biomass analysis for an 'optimum' quadrat and for a quadrat close to a snow-bed centre. Sampling of plant biomass at peak season (20 x 20 cm squares in the second week of August) and biomass sorting are done in such a way that all above ground plant dry matter that had accumulated in the current season (even if it had already senesced during that season) is included. This way, 'accumulated' seasonal dry matter becomes a proxy of annual above ground net primary production (NPP). Because of in-season biomass losses (e.g. by herbivory or seed distribution) the 'true' NPP will always be slightly higher. Below ground plant biomass, invertebrate and microbial samples are harvested from the same spot by means of soil cores. Mosses, lichens and woody structures from dwarf shrubs are disregarded, because growth in these tissues cannot be attributed to the given season. Note the graminoid (grasses, sedges, rushes) dominance at the favourable end of the transect and the herb dominance near the 'pessimal' end. Fueling the food web, NPP is one important starting point to explain invertebrate and microbial communities across these sharp climatic gradients.

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