THE NETWORK

THE PLANET'S ALPINE LIFE ZONE
HOSTS AN OUTSTANDINGLY
RICH AND HIGHLY SPECIALISED
FLORA AND FAUNA.
ANTHROPOGENIC CLIMATE WARMING
ENDANGERS A SIGNIFICANT
PART OF THIS
UNIQUE BIODIVERSITY
TREASURE THROUGHOUT THE WORLD.

QUESTIONS AND AIMS

THE EARTH DOES AND WILL EXPERIENCE CLIMATE CHANGE

Global climate change, atmospheric warming in particular, will affect all ecosystems represented on Earth. High mountain ecosystems, however, are considered to be particularly sensitive to warming because they are determined by low-temperature conditions.

Direct effects on alpine ecosystems are the ongoing upward migration of plants which has been observed in many high mountain regions. Globally, a progressive decline of alpine habitats and their biota is expected through enhanced competition pressure on cold-adapted high-elevation species.

Indirect effects include increased slope instability if permafrost diminishes, and increased or decreased erosion if vegetation cover changes. All these processes affect biodiversity and may lead to the extinction of a variety of species. The severity of such "extinction scenarios" can only be documented by on-site long-term monitoring. Conversely, increased changes in structure and species composition of alpine ecosystems can be taken as excellent indicators for the ecological implications of climate change.

High mountains comprise cold-climate wilderness areas in all major life zones on Earth. Hence, they provide a unique opportunity for tracing the ecological impacts of global climate warming. GLORIA has established a network of currently around 400 summit sites in 120 target regions from tropical to polar latitudes on six continents. Over 75% of the GLORIA sites lie within national protected areas such as national parks or UNESCO-MaB biosphere reserves. The network will act as a warning system by providing standardised base line data for detecting both short- and long-term changes of biodiversity and habitat stability and for giving reliable predictions about oncoming impacts on alpine ecosystems world-wide.

GLORIA CONTRIBUTES TO INTERNATIONAL PROGRAMMES FOR GLOBAL CHANGE RESEARCH

GLORIA responds to international research demands, which were urged by the Mountain Research Initiative (MRI) of the International Geosphere-Biosphere Programme and by the Global Terrestrial Observing System (GTOS) already in the 1990s, and in a wider scope, by the UNEP World Conservation Monitoring Centre (WCMC) and more recent endeavours, such as through GEO BON, a global partnership to help collect, manage, analyse, and report data relating to the status of the world's biodiversity. GLORIA contributed to the European Commission's research programme and is also being conducted in close co-operation with the Global Mountain Biodiversity Assessment (GMBA) launched by the international DIVERSITAS programme. In Europe it is designed as a contribution to the European observation activities performed under the auspices of the European Environment Agency (EEA).

HOW TO JOIN GLORIA

The strength of GLORIA is its large number of observation sites. The establishment and maintenance of a globally active multi-site network is a challenge that can only be met by a world-wide community of committed ecologists. It wholly depends on researchers who are willing to establish the foundations for a long-term programme, which will yield results for future generations. GLORIA is an open process - the network can be joined at any time.

See the GLORIA web site: *www.gloria.ac.at*

If you want to participate in the GLORIA network, please, carefully consider the GLORIA Field Manual (its 5th version, published in 2014) and contact the GLORIA coordination: ~~*office@gloria.ac.at*~~
new e-mail adress: gloria.office@boku.ac.at

GLORIA'S TARGET REGIONS

Each GLORIA target region consists of an array of observation sites established on summit areas of different altitudes. Four summits within one target region must be exposed to the same regional climate and bedrock conditions, and are arranged along an elevational gradient.

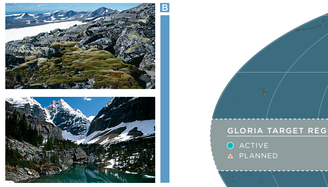
ACTIVE TARGET REGIONS ACROSS THE PLANET'S MAJOR LIFE ZONES

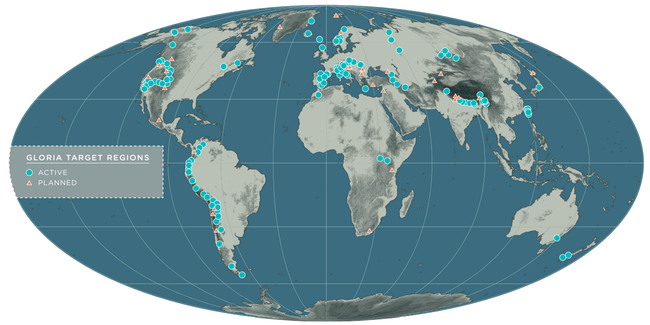
A THE POLAR LIFE ZONE The region, where all land, including coastal areas, is 'alpine' tundra or glaciated environment. Pronounced warming is expected to accelerate species migration, but also uncloses new areas through glacier retreats. Several GLORIA sites are established in the Arctic of Alaska, Greenland, Iceland and in the northern Russian Urals.

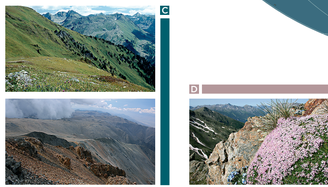
Zackenberg, *Greenland* | **Tröllaskagi,** *Iceland* | **Brooks Range Central/Atigun Syncline,** *Alaska, USA* | **Polar Urals,** *Russia.*

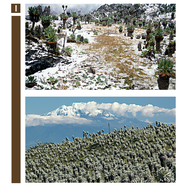
B THE BOREAL LIFE ZONE The large northern forest zone, where even lower mountains tip into alpine climate conditions and where vast areas of permafrost soils are thawing. Several GLORIA sites in Canada, USA, Scandinavia, Scotland and Russia belong to this biome type as well as Tierra del Fuego on the southern hemisphere.

Selawik Wilderness Refuge, *Alaska, USA* | **Northern Interior Mountains/Atlin, Lina and Johnson Range**, *Northern BC, Canada* | **Monts Chic-Chocs/Quebec,** *Canada* | **Monts Groulx/Quebec,** *Canada* | **Streymoy,** *Faroe Islands* | **Vågåmo/Blåhø,** *Norway* | **S-Scandes/Dovrefjell,** *Norway* | **S-Scandes/Søln,** *Norway* | **S-Scandes/Fræna,** *Norway* | **Sylarna/Jämtland,** *Sweden* | **N-Scandes/Latnjajaure,** *Sweden* | **Cairngorms,** *Scotland, UK* | **North Urals,** *Russia* | **South Urals,** *Russia* | **Tierra del Fuego,** *Argentina.*









C THE COLD-TEMPERATE CONTINENTAL LIFE ZONE Cold winters, warm to hot summers and water shortage are determining these large mountain regions in the western United States of America and in Central Asia. Many sites are already active in North America, Asian Russia, few on the southern hemisphere, and setup is commencing in southern Central Asia.

Rocky Mountains: Glacier National Park, *Montana, USA* | **Pioneer and Pintlar Range,** *Montana, USA* | **Absaroka-Beartooth Wilderness,** *Wyoming, USA* | **Yellowstone National Park,** *Wyoming, USA* | **Rocky Mountain National Park,** *Colorado, USA* | **Niwot Ridge,** *Colorado, USA* | **Great Sand Dunes National Park,** *Colorado, USA* | **Ruby Range,** *Colorado, USA* | **San Juan Mountains,** *Colorado, USA* | **Sangre de Cristo Mountains,** *New Mexico, USA* | **White Inyo Mountains - carbonatic,** *California, USA* | **White Inyo Mountains - siliceous,** *California, USA* | **Great Basin National Park,** *Nevada, USA* | **Altaiskiy Biosphere Reserve,** *Russia* | **Altai/Katunskiy Biosphere Reserve,** *Rep. Altai, Russia* | **Kuznetskiy Alatau Nature Reserve,** *Russia* | **Sayano-Shushenskiy Biosphere Reserve,** *Russia* | **Ubsunurskaya Kotlovina Biosphere Reserve,** *Russia* | **East-Pamir/Gorno-Badakhshan,** *Tajikistan* | **Eastern Ladakh,** *India* | **Mt. Aragats,** *Armenia* | **Sierra de Famatina,** *Argentina* | **Southern Patagonia,** *Argentina.*

D THE TEMPERATE LIFE ZONE Alpine regions in this moderate seasonal climate are typical for central Europe such as the Alps, where GLORIA was initiated, the Carpathians, Pyrenees and for the Caucasus.

Northern Apennines, *Italy* | **S-Alps/Dolomites,** *Italy* | **S-Alps/Alpi Orobie,** *Italy* | **W-Alps/Mont Avic,** *Italy* | **Central Alps/Texelgruppe,** *Italy* | **SW-Alps/Mercantour,** *France* | **Central Alps/Swiss National Park - carbonatic,** *Switzerland* | **Central Alps/Swiss National Park - siliceous,** *Switzerland* | **W-Alps/Alps of Valais-Entremont,** *Switzerland* | **N-Alps/National Park Berchtesgaden,** *Germany* | **NE-Alps/Hochschwab,** *Austria* | **NE-Alps/Nationalpark Gesäuse,** *Austria* | **Triglav National Park/Julijske Alpe,** *Slovenia* | **W-Carpathians/High Tatra,** *Slovakia* | **E-Carpathians/Rodnei Mts.,** *Romania* | **Krkonose and Karkonosze National Parks,** *Czech Republic/Poland* | **Central Pyrenees/Ordesa,** *Spain* | **Siliceous Central Pyrenees/Valles Tena y Bielsa,** *Spain* | **Central Caucasus/Kazbegi region,** *Georgia* | **Southern Andes/Araucarias Biosphere Reserve/Parque Nacional Conguillío,** *Chile.*

E THE WET-TEMPERATE LIFE ZONE In its warmer subtype, located on eastern sides of continents, small and highly special alpine areas in Australia's snowy mountains are part of GLORIA, as well as sites in the humid Japanese Alps, and in the extensive summer-rain region at the eastern rim of the Himalayas. In its colder subtype, on western margins of continents or islands, sites are set up on New Zealand, in northern Spain, and in the southwestern corner of Canada's British Colombia.

Kosciuszko National Park, *New South Wales, Australia* | **Qionglai Shan/Yakou Shan,** *Sichuan, China* | **Hida Mountains/Norikura,** *Japan* | **Southland/Mount Burns,** *New Zealand* | **Otago/Pisa Range,** *New Zealand* | **Canadian Coast Range,** *S-British Columbia, Canada* | **Vancouver Island,** *British Columbia, Canada* | **Cantabrian Range,** *Spain.*

F THE MEDITERRANEAN CLIMATE LIFE ZONE Spatially small, but rich in species, this regions host many fragmented and isolated mountains with a very particular and endangered mountain life. Summit sites are established in southern Europe in Spain, France, Italy and Greece, and on Iranian and North African mountains, where many endemic high-altitude species occur, as well as in California's Sierra Nevada.

Sistema Iberico/Sierra de la Demanda, *Spain* | **Sistema Ibérico/Moncayo,** *Spain* | **Sistema Central,** *Spain* | **Sierra Nevada - West,** *Spain* | **Sierra Nevada - Northeast,** *Spain* | **Corsica/Monte Cinto,** *France* | **Crete/Lefka Ori,** *Greece* | **Central Apennines/Majella,** *Italy* | **Southern Apennines/Matese mountain,** *Italy* | **Central Alborz,** *Iran* | **Sahand-NW Iran,** *Iran* | **High Atlas West,** *Morocco* | **Sierra Nevada/Carson Range/Tahoe Basin area,** *California, USA* | **Sierra Nevada/Mt. Langley,** *California, USA* | **Sierra Nevada/Dunderberg,** *California, USA* | **Sweetwater Mountains,** *California, USA.*

G THE HOT DESERT LIFE ZONE Even the middle of the Sahara, and far more prominent, the arid Andes from Peru to Bolivia and northern Chile and Argentina have high mountains that host alpine biota. GLORIA sites, so far, are only set up in transition zones to desert areas in the Andes and southwestern North America.

Andes-este de Provincia de Salta, *Argentina* | **Tropical Andes/Sajama,** *Bolivia* | **Death Valley National Park,** *California, USA.*

H THE SEASONAL TROPICAL LIFE ZONE The vast and extremely high mountain ranges such as Himalaya's southern sides and the southern part of East Asia, exposed to monsoonal summer rain, as well as the Puna region of the Peruvian, Bolivian and Northeast-Argentinian Andes are climatically and ecologically diverse and suffer marked glacier retreat. Both mountain systems are already endowed with a number of monitoring sites.

Jhomo Kungkhar, *Bhutan* | **Mt. Jomolhari,** *Bhutan* | **Tampela Area,** *Bhutan* | **Hengduan Shan/Da Xue Shan/Birong Region,** *NW-Yunnan, China* | **Hengduan Shan/Ma Ji Wa,** *NW-Yunnan, China* | **Hengduan Shan/Meilishui,** *NW-Yunnan, China* | **Hengduan Shan/Ruizila Mountain Pass/Gonka/Deqin,** *NW-Yunnan, China* | **Mt. Kanchenjunga,** *Nepal* | **Himalaya/Langtang National Park,** *Nepal* | **Manang Area within Annapurna National Park,** *Nepal* | **Dashueiku Mountains,** *Taiwan* | **Hohuan and Qilai Mountains,** *Taiwan* | **Nanhu Mountain,** *Taiwan* | **Shancha Mountain,** *Taiwan* | **Syue Mountains/Shei-Pa National Park,** *Taiwan* | **N-Argentinian Andes/Cumbres Calchaquíes,** *Argentina* | **Cordillera Apolobamba,** *Bolivia* | **Tuni-Condoriri/Cordillera Real,** *Bolivia* | **Parque Nacional Tunari,** *Bolivia* | **Cordillera Huaytapallana,** *Peru* | **Tropical Andes/Cordillera Blanca/Huascaran Biosphere Reserve,** *Peru* | **Páramo Pacaipampa/Cachiaco,** *Peru* | **Parque Nacional Río Abiseo,** *Peru* | **Tropical Andes/Cordillera Vilcanota,** *Peru.*

I THE HUMID TROPICS Some regions even feature snow-capped mountains near the equator. "Every day summer and every night winter" conditions require special adaptation for mountain plants, which are monitored at GLORIA sites in the Páramo Andes of Ecuador, Colombia and Venezuela and on eastern African mountain peaks.

Reserva Ecologica El Angel, *Ecuador* | **Pichincha,** *Ecuador* | **Parque Nacional Podocarpus, Ecuador** | **El Altar,** *Ecuador* | **Reserva Ecológica Antisana,** *Ecuador* | **Cordillera Oriental/Sierra Nevada del Cocuy,** *Colombia* | **Cordillera Oriental/Páramo Chingaza,** *Colombia* | **Cordillera de Mérida,** *Venezuela* | **Mount Elgon,** *Uganda* | **Ruwenzori,** *Uganda.*

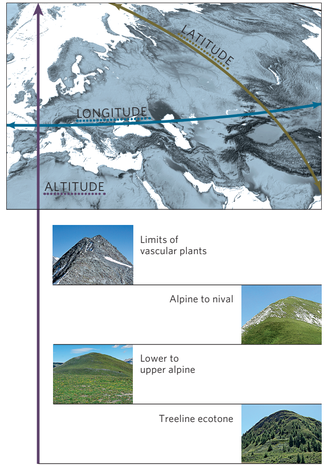
THE METHOD

ON-SITE LONG-TERM OBSERVATIONS OF HIGH MOUNTAIN ECOSYSTEMS AND THEIR SPECIES COMPOSITION ARE A CRUCIAL REQUIREMENT FOR TRACING THE IMPACTS OF GLOBAL WARMING ON ALPINE BIODIVERSITY AND FOR ASSESSING THEIR MAGNITUDE AND THE VELOCITY OF CLIMATE-DRIVEN PROCESSES. GLORIA FOCUSES ON A STANDARDISED SETUP OF PERMANENT OBSERVATION SITES THAT IS APPLICABLE IN ALL MAJOR MOUNTAIN SYSTEMS ON EARTH.

GLORIA'S MULTI-SUMMIT APPROACH

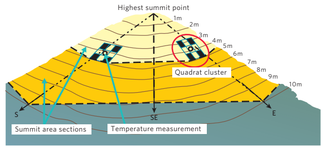
The Multi-Summit Approach, GLORIA's basic method, represents the minimum requirement for a particular mountain study region (target region). The main considerations in designing this approach were comparability, simplicity and economy for an effective network with a large number of sites, which can be established even under expedition conditions. A detailed field manual can be obtained from *www.gloria.ac.at*.

The GLORIA approach considers the four principal dimensions: latitude, longitude, altitude and time.



Target regions are spread over the horizontal dimensions and four summit sites in each region over the vertical dimension. They are re-surveyed at regular intervals of 5 to 10 years.

THE GLORIA SUMMIT SITE - plot types on different spatial scales



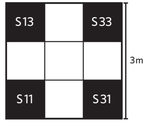
SUMMIT AREA SECTIONS

Each summit is divided into eight sections: all vascular plant species are recorded in each section to detect invasions of plants from lower elevations and the disappearance of species.

QUADRAT CLUSTERS

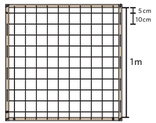
QUADRAT CLUSTERS

Four quadratic clusters that are arranged in a 3 m x 3 m grid are to be installed in the four main cardinal directions. The four corner quadrats are used for detailed monitoring.

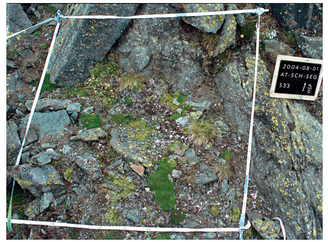


1 M² QUADRATS

In these quadrats, species cover and top cover of surface types are visually recorded to detect changes in species composition and abundance. In addition, cover of the more common species is sampled by point-framing with a grid frame of 100 crosshair points. As a not obligatory supplementary method, species presences are counted in each of 100 1 dm² subplots.

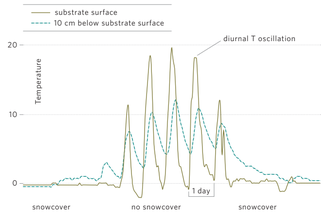


EXAMPLE OF A 1M² QUADRAT



TEMPERATURE MEASUREMENTS

Soil temperature is recorded in the centre of each 3 m x 3 m quadrat cluster in one hour intervals to compare changes of the temperature and snow regimes. Soil temperature, though not directly comparable with air temperature, is highly relevant for alpine plant life and soil microorganisms. Moreover, measurements below ground surface is a feasible and invisible way of obtaining climate data.



Low magnitude of diurnal temperature fluctuation around 0°C indicates snow cover.

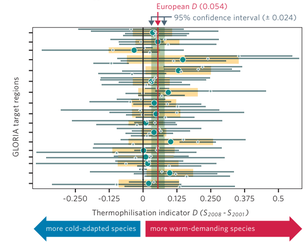
GLORIA REINVESTIGATIONS

GLORIA plots are monitored at intervals of 5 to 10 years. Globally fixed intervals, however, are difficult to arrange due to logistic and financial constraints. For example, the first broad-scale re-recording campaign on the European level was conducted in 2008, 7 years after the first recording cycle, the second resurvey is planned for 2015. Most sites in North America were resurveyed at 5-year intervals.

RECENT RESULTS

Pan-European GLORIA resurvey studies showed a widespread alteration of the species composition in alpine vegetation, caused by uphill-colonisation of more warm-demanding species and a concurrent decline of high-elevation species within the past decade. This leads to a thermophilisation of the specialised and cold-adapted vegetation of high mountain areas and, over a longer term, to a shrinkage of alpine habitats and biota[1]. Moreover, summits in temperate and boreal regions showed an increase in species numbers, whereas Mediterranean mountains showed a decline in species richness[2]. The latter effect can be interpreted as a combination of warming effects and higher aridity. Ongoing resurveys in North America and in Australasia indicate measurable species turnovers and shifts in plant life forms, such as increases in shrubs and graminoid species.

1 | Gottfried et al. 2012, *Nature Climate Change*, 2
2 | Pauli et al. 2012, *Science*, 336



Shift towards more warm-demanding species composition at the majority of GLORIA sites across Europe between 2001 and 2008 (modified from *Gottfried et al. 2012, Nature Climate Change*).

ADDITIONAL ACTIVITIES

GLORIA MASTER SITES

On master sites, scientific investigations are carried out which are too extensive and too expensive for a practicable Multi-Summit Approach; they complement the summit observations. Such master sites are based on existing research capacities and infrastructures and should be established within protected areas. The activities involve monitoring, experimental and modelling approaches, and may include studies on primary productivity, nitrogen deposition, microbial activity of soils, plant propagation, grazing and land use changes, snow and permafrost patterns in relation to vegetation and species distributions. Examples of existing master sites are: Schrankogel (Tyrol, Austria), White Mountains (California, USA), Glacier National Park and Biosphere Reserve (Rocky Mountains, Montana, USA), and experimental sites in the Ecuadorian Andes.

OTHER INDICATORS

The Multi-Summit Approach focuses on vascular plant diversity. Cryptogam species (bryophytes and lichens), however, can be directly included in the recording procedure on an optional basis, where expertise and sufficient time is available. Supplementary surveys of more mobile organism groups, which were initiated in some target regions, require different methods and sampling designs. Ground-dwelling invertebrates can be recorded within the summit area, but other arthropods, reptiles and amphibians must be recorded along larger transects around the summit sites. A number of extra supplementary approaches were applied or are under development, either at GLORIA master sites or on a regional level in particular standard GLORIA target regions. Besides the consideration of alpine animal groups, these include downslope plant surveys for determining regional altitudinal plant species ranges, studies on alpine soil variability and ecology, as well as socio-economic/ecological, cultural and ethnobotanical aspects in a GLORIA target region. Such additional approaches are also described in the 5th version of the GLORIA Field Manual.

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CONTACT

COORDINATION GROUP

Harald Pauli, Andrea Lamprecht, Sophie Nießner, Armin Oppelt, Klaus Steinbauer, Manuela Winkler and the honorary founding members Michael Gottfried and Georg Grabherr

Email: *office@gloria.ac.at*
www.gloria.ac.at

Austrian Academy of Sciences (ÖAW),
Institute for Interdisciplinary Mountain Research (IGF)
University of Natural Resources and Life Sciences (BOKU),
Center for Global Change and Sustainability (ZgW/N), *Vienna*

For a full list of all persons and institutions involved see the GLORIA website: *www.gloria.ac.at*

PAST AND CURRENT SUPPORTERS OF GLORIA

European Commission in the 5th (GLORIA-Europe) and 6th (ALARM, GLOCHAMORE) RTD Framework Programmes | Austrian Federal Ministry of Science and Research | Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management | University of Vienna | Austrian Academy of Sciences/ Institute for Interdisciplinary Mountain Research (IGF) | University of Natural Resources and Life Sciences (Vienna)/ Center for Global Change and Sustainability | MAVA Foundation for Nature Conservation (Switzerland) | MaB programme of the UNESCO | European Environment Agency (EEA)/ European Topic Centre on Biological Diversity | Andean Environmental Agenda of the Comunidad Andina (CAN) and the Consorcio para el Desarollo Sostenible de la Ecoregión Andina (CONDESAN) | Swiss Development Cooperation/Andes Programme | International Centre for Integrated Mountain Development of the Hindu Kush-Himalaya region (ICIMOD).

NGO's and private organisations focusing on biodiversity research and conversation, such as *The Nature Conservancy*, *Conservation International*, *National Geographic Society*, *Wildlife Conservation Society*, *Missouri Botanical Garden*, and the *Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT)*.

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IMPRESSUM

GLORIA COORDINATION
Austrian Academy of Sciences, IGF &
University of Natural Resources and Life Sciences, ZgW/N
Silbergasse 30,
1190 Vienna, Austria

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