Creative Use of Mountain Biodiversity Databases: The Kazbegi Research Agenda of GMBA-DIVERSITAS

Geo-referenced archive databases on mountain organisms are very promising tools for achieving a better understanding of mountain biodiversity and predicting its changes. The Global Mountain Biodiversity Assessment (GMBA) of DIVERSITAS, in cooperation with the Global Biodiversity Information Facility, encourages a global effort to mine biodiversity databases on mountain organisms. The wide range of climatic conditions and topographies across the world's mountains offers an unparalleled opportunity for developing and testing biodiversity theory. The power of openly accessible, interconnected electronic databases for scientific biodiversity research, which by far exceeds the original intent of archiving for mainly taxonomic purposes, has been illustrated. There is an urgent need to increase the amount and quality of geo-referenced data on mountain biodiversity provided online, in order to meet the challenges of global change in mountains.

Aims

The Global Mountain Biodiversity Assessment (GMBA), a cross-cutting network of DIVERSITAS, aims to encourage and synthesize research on high-altitude organismic diversity, its regional and global patterns, and its causes and functions (Koerner and Spehn 2002; Spehn et al 2005). Existing and emerging electronic databases are among the most promising tools in this field. Gradients of altitude and associated climatic trends, topographic and soil peculiarities, fragmentation and connectivity among biota and their varied geological and phylogenetic history are the major drivers and aspects of mountain biodiversity, and electronic archives provide avenues for testing their impact on life at high elevations.

This research agenda was developed at a GMBA workshop in the Central Caucasus in July 2006. It capitalizes on expertise from different fields of biology and database experts, and was developed in cooperation with the Global Biodiversity Information Facility (GBIF).

Enhancing awareness of the central role of geo-referencing in database building and use is one of the central tasks of this agenda. Once achieved, this permits linkage of biological information with other geophysical information, particularly climate data. The mountains of the world exhibit different climatic trends along their slopes, with only few factors, such as the decline in atmospheric pressure, ambient temperature and clear sky radiation changing in a common, altitude-specific way across the globe. None of the other key components of climate, such as cloudiness and, with it, actual solar radiation or precipitation and associated soil moisture show such global trends, and hence are not altitude-specific. The separation of global from regional environmental conditions along elevational transects offers new perspectives for understanding adaptation of mountain biota. Similarly, information on bedrock chemistry and mountain topography offers test conditions for edaphic drivers of biodiversity and species radiation in an evolutionary context across geographical scales.

Data-sharing for the mountain research community

Many research projects generate biodiversity datasets that may be relevant for the wider scientific community, government and private natural resource managers, policymakers, and the public. GBIF has a mission to make the world's primary data on biodiversity freely and universally available via the Internet (www.gbif.org).

The principle of open access

The UN Convention on Biological Diversity has called for free and open access to all past, present and future public-good research results, assessments, maps and databases on biodiversity (CBD Dec. VIII/11). Furthermore, all 47 current member countries and 35 international organizations in GBIF have committed themselves to "improving the accessibility, completeness and interoperability of biodiversity databases," and to "promote the sharing of biodiversity data in GBIF under a common set of standards." Added value comes from sharing data (Arzberger et al 2004a, b), but sharing requires respect of author rights and observation of certain rules as defined by GBIF standards (Stolton and Dudley 2004). Quite often it is only through the linking of data that scientific advance is achieved. Hence protective habits are counterproductive, given that an individual database commonly does not contain sufficient information for developing and testing theory and furthering broad understanding. Moreover, many taxonomic databases rely on the collective work of generations of scientists in a country.

Data sources and data structure

There are 1) individual-based data (primary occurrences, an individual at a place at a particular time), and 2) taxon-based data (biological taxon characteristics such as morphology, physiology, phylogeny, ecology, genetics). These may refer to: a) vouchered primary occurrences,

b) observational data, or c) literature data. The quality and use of primary species and species-occurrence data are highlighted in Chapman (2005a–c).

A full, best-practice database entry should include the following types of data:

- Organismic data (conventional taxonomic information);
- Geo-information (coordinates, altitude);
- Habitat information (edaphic, topographic, atmospheric);
- Date and time of observation/collection/recording;
- Reference to a voucher or archive code;
- Name of collector/observer/recorder;
- Metadata provide information on datasets, such as content, extent, accessibility, currency, completeness, accuracy, uncertainties, fitness-for-purpose and suitability-for-use and enable the use of data by third parties without reference to the originator of the data (Chapman 2005b).

Mountain-specific aspects

Given the significance of topography and elevation in mountains for local biotic conditions, reported geographical coordinates using GPS should at least provide a resolution of seconds. Elevation should always be obtained independently of GPS. Chapman and Wieczorek (2006) provide Best Practices for Georeferencing (assigning geographic coordinates to) a range of different location types. Should coordinates be missing, the BioGeomancer Classic online tool (www.biogeomancer.org) may be able to reconstruct these from locality, region or names.

Elevation data can have the following structure:

- Point data (for vouchers, data loggers, climatic stations): report as precisely as possible, with uncertainties given. In most cases a precision of 10 m elevation is enough, although earlier GPS data will offer less precision.
- Stratified range elevation data, which offer entries for certain taxa in a step by step elevational catena (eg 100-m steps). If this is not available, at least the elevational center of the variable/taxon should be provided.
- Full range or amplitude data (maximum and minimum elevation) with uncertainties. Range data are critical for making up lists of species for different elevational bands. The mid-point is insufficient.

Note that such information becomes almost useless if uncertainties in the observation are not identified. One way of getting around this is to quote the data within range width (100 m, 200 m, 1000 m). Uncertainty associated with geo-referenced localities along elevational gradients can be measured with post-hoc 3-dimensional geo-referencing (Rowe 2005).

Additional information (some useful examples in a mountain context)

- Plants: Biological attributes such as size (height), life form, flower features, current phenology, seed size, growth form, and other special attributes. These data can sometimes be obtained from taxonomic sources and stored in relational databases.
- Animals: Biological attributes such as size (width, length, etc), trophic habit, interactions (prey, mutualistic species, host, phenology, life stage).
- Abundance or frequency measures (eg random sample of quadrats). Information on rareness, conservation status, dominant associates, population structure, if available.

Visions and suggestions for scientific use of mountain biodiversity e-data

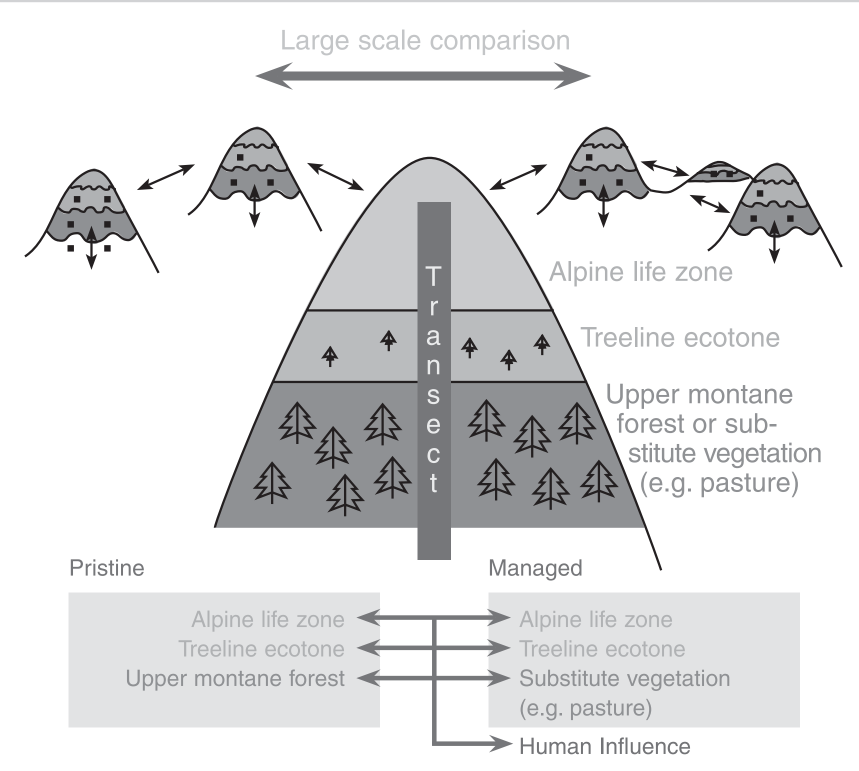
The power of openly accessible, interconnected electronic databases for scientific biodiversity research by far exceeds the original intent of archiving for mainly taxonomic purposes, as will be illustrated by the following examples. Each example starts with a scientifically important question or hypothesis **(what?)** and continues by providing a motive (**why** would we want to know this?) and suggestions about **how** to approach this task by data mining and data linking. The application of a common mountain terminology (a convention) is an essential prerequisite for communication (Figure 1).

Mountains—a laboratory for understanding basic questions of evolution: How is mountain biodiversity generated, evolved, assembled?

What? The origin and assembly of mountain biota have to be understood in a historical context. For a given mountain area: where did its taxa arise, and how were taxa assembled over time? How many of the extant species resulted from the radiation of lineages that evolved within the area as opposed to the radiation of lineages that were introduced from other areas or even continents or other ecosystems? How important has long-distance dispersal been for the assembly of mountain biota, and how and when did evolutionary lineages migrate from one mountain area to others? What are the main sources of long-distance dispersal events? Has the capacity of long-distance dispersal itself been a factor in the rapid radiation of alpine lineages?

Why? Mountains are islands of varying size, and thus present a good opportunity to ask questions about genesis of mountain biota, the impact of competition from oth-

FIGURE 1 The GMBA concept of vertical and horizontal comparison of mountain biota.



er biota on speciation rates, and adaptive evolution. Where arid climates have developed at lower elevations, alpine areas can act as "conservation areas for phylogenetic lineage" for lowland lineages (see Hershkovitz et al 2006). Mountains have acted (and will act) as refugia for species survival during extreme climatic events, including for ancient phylogenetic lineages. Rapid rates of speciation have been documented in recent phylogenetic studies for genera in high-elevation areas (eg Hughes and Eastwood 2006). Rapid evolution is also a factor for predictions related to climate change.

How? Combine data from phylogenetic and phylogeographic databases, regional species lists, classification by elevation (eg selection of alpine species), geographic distribution and species range limits. Information on resilience of a species to change (life form, life cycle characteristics, reproduction, and phenological data).

Are there common elevational trends in mountain biodiversity? What drives them?

What? The overarching issue is to challenge the common notion that species richness in alpine areas is necessarily low. Life conditions change with elevation in global but also in very regional ways, and equal steps in elevational climatic change are associated with decreasing available land area per step (belt; Koerner 2000). Furthermore, land surface roughness (habitat diversity) commonly increases with elevation. Finally, mountains represent archipelagos of contrasting connectivity and island size. How is biodiversity influenced by these 4 aspects of elevation (climate, area, fragmentation and roughness)?

Why? The wide amplitude of climatic conditions and topographies across the world's mountains offers an unparalleled opportunity for developing and testing biodiversity theory. How does species richness in mountains change with latitude or elevation; do reductions in species richness on opposite-facing slopes parallel altitudinal gradients and/or similar temperature gradients (Figure 1)? Ratios of trends in various taxonomic groups make it possible to distill biotic interdependencies or at least correlative associations. Such biodiversity ratios can serve as predictive tools. The climatic relatedness of emerging trends can assist in projections of climate change impacts.

How? The major tool is selective comparison of stratified biodiversity data for various organismic groups across elevational transects of major mountain systems. Key problems to be solved are the confounding between altitude-specific (global) and region-specific (local) climatic trends and the geological age and spatial extent of mountain systems. Links with fine resolution GIS and world climate databases are essential.

Are there typical elevational trends in organismic traits across the globe?

What? Across the globe we observe the independent evolution of certain traits as elevation increases (convergent evolution). Are these trends and traits related to common elevational gradients under environmental conditions (eg temperature) or do they reflect specific climatic trends that are not common to all mountains (eg precipitation), and would they thus also be found at respective gradients at low elevations? Would common edaphic conditions (eg presence of scree) alone explain certain trends? Typical traits to be explored are size and mass of organisms, special functional types such as the cushion plant life form, giant rosettes or woolly plants, certain reproductive strategies, plant breeding systems, pollinator types, hibernation, dispersal characteristics, diffusivity of egg shells, etc.

Why? Most of these traits cannot be modified experimentally and thus presumably reflect long-term evolutionary selection. Many of these trends relate to the basic functioning of plants and animals. We need to separate taxonomic relatedness from independent environmental action. A functional interpretation would require a mechanistic explanation: are cushion plants abundant at high elevations because of loose, poorly developed substrate, insufficient moisture, strong wind, too low temperature, short seasons, or certain combinations of these? Is high pubescence truly and generally more abundant at high elevation, and if so, under which high-elevation environmental conditions does this trend become enhanced?

How? The compressed width of climatic belts in mountains offers 'experiments by nature' to test such hypotheses over short geographical distances (Koerner 2003) by comparing trends in traits across a suite of mountain transects in areas of contrasting geological/evolutionary history and different climates. A test across different phylogenetic groups would reveal taxonomic relatedness. A comparison across different latitudes could separate seasonality and absolute altitude (pressure) effects because low temperatures such as those at treeline are found at 4000 m near the equator and 500 m above sea level at the polar circle.

Are biotic links and biodiversity ratios among organismic groups tighter with elevation?

What? Functional interactions between organisms (trophic, mechanical, physiological and pathogenic) drive coexistence and competition among taxa. Do these ties become looser or tighter as elevation increases? For instance, does generalist pollination increase with elevation? Are such links (eg mycorrhization, predation, facilitation) becoming simpler (multiple vs unique partner organisms)?

Why? Alpine areas provide a unique opportunity for understanding how coevolution developed. Functionally, the maintenance of species richness and mutualism is known to be critical for maintaining plant fitness in harsh environments. As biodiversity of montane environments usually decreases with elevation, it may be more and more difficult to find a host for any specialized organism, and having a wider range of hosts could be favorable. Biodiversity ratios are a promising (to be explored) tool for rapid inventory works (the diversity of key taxonomic groups as indicators).

How? Comparisons of altitudinal patterns of diversity of species assemblages, use of known data on mutualistic species (eg specific pollinators, prey, mycorrhiza), linking data for different taxonomic groups (eg butterflies vs. angiosperm diversity).

Are there functional implications of mountain biodiversity?

What? What is the contribution of mountain biodiversity to ecosystem integrity, ie slope stability? What is the functional redundancy in traits among organisms in a given area, what is their sensitivity to stress and disturbance (insect outbreaks, avalanches)?

Why? Ecosystem integrity on steep mountain slopes and in high-elevation landscapes is mainly a question of soil stability, which in turn depends on plant cover. The insurance hypothesis of biodiversity suggests that the more diversity (eg genetic diversity, morpho-types) there is, the less likely it is that extreme events or natural diseases will lead to a decline in ecosystem functioning or a failure of vegetation to prevent soil erosion. In steep terrain, more than anywhere else, catchment quality is intimately linked to ecosystem integrity. The provision of sustainable and clean supplies of water is the most important and increasingly limiting mountain resource.

How? Old vs new inventory data, recent loss or gain of certain plant functional types (eg trees). Recent land cover change (remote sensing evidence, NDVI). Apart from information on composition of vegetation and functional traits of taxa (eg rooting depth, root architecture, growth form), geographical information is needed (geomorphology: slope, relief, soil depth; climate, precipitation, evapotranspiration, extreme rain events, snow cover duration). Comparison of different mountain regions (eg presence/absence of woody/non-woody vegetation). Spatial land cover information can be used to develop scenarios at landscape scale.

What are the socioeconomic impacts on mountain biodiversity?

What? Humans shape mountain vegetation by clearing land, grazing, abandoning, collecting, etc, which may increase or decrease mountain biodiversity (Spehn et al 2005) and, through this, affect slope processes, erosion, water yield and inhabitability. Are areas with traditional burning regimes, in combination with grazing, poorer in species of flowering plants, butterflies, and wild ungulates than grazed areas in which burning is not a tradition? Do these trends interact with precipitation? Is high human population density at high elevations related to the specific loss of woody taxa? Is the biological richness of inaccessible microhabitats (topography-caused 'wilderness') a measure or good reference of potential biodiversity of adjacent, transformed land?

Why? Of all global change effects, land use is the predominant driver of changes in mountain biodiversity. By comparing areas of historically contrasting land use regimes we can learn how these human activities shape biota. Ratios of wilderness biodiversity to adjacent managed biodiversity indicate

Mountain terminology and GMBA concept of comparative mountain biodiversity research

GMBA distinguishes between three elevational belts and a transition zone:

- The ***montane*** belt extends from the lower mountain limit to the upper thermal limit of forest (irrespective of whether forest is currently present or not).
- The ***alpine*** belt is the temperature-driven treeless region between the natural climatic forest limit and the snowline that occurs worldwide. Synonyms for "*alpine*" are "*andean*" or "*afro-alpine*".
- The ***nival*** belt is the terrain above the snowline, which is defined as the lowest elevation where snow is commonly present all year round (though not necessarily with full cover).
- The ***treeline ecotone*** is the transition zone between the montane and alpine belts.

the actual impact of land use. The abundance of red list taxa or medicinal plants can be related to human population pressure and land use intensity.

How? Linking thematic databases for land cover type, population density and climate with regional biodiversity inventories. Global comparisons across different climates and land use histories should permit distilling certain overarching trends. Comparison of intensively used high-elevation rangeland in regions of contrasting natural biodiversity should illustrate the significance of regional species pools for biodiversity in transformed landscapes (eg Caucasus vs Alps). A comparison of rangeland biodiversity in geologically young (steep) mountain regions with that in geologically old (smooth) mountain landscapes could reveal interactive influences of landscape roughness and land use on biodiversity.

Effective conservation of mountain biodiversity under global environmental change: how best to assess effects of current efforts and future trends?

What? Which is the minimum altitudinal range required for protected areas in mountain regions? What are the minimum habitat size and requirements for long-term viable (meta-)populations under high mountain conditions and under future climate change? Which are the best diversity/area relationships in high mountain environments for conservation purposes? What is the relevance of connectivity through gene flow for geographically isolated populations on high mountains? Which are suitable indicators and the most likely drivers of biodiversity change in protected areas in mountains?

Why? With many global mountain biodiversity hotspots increasingly threatened, efforts are underway to preserve these unique biota, largely by establishing a system of protected areas on mountains (Koerner and Ohsawa 2005). Relevant variables for conservation biology such as minimum range, viable population size, and connectivity become especially critical in high mountain environments, where range sizes are generally small and where populations are often geographically isolated. In combination with population, genetic, ecological, and phylogeographic data for species of high conservation concern, analysis of such comparative data from different mountain ranges should provide guidelines for critical habitat sizes and minimum coverage of elevational ranges, with the overall task of maximizing the evolutionary potential through phylogenetic diversity and of capturing unique elements of mountain biota (see Box).

How? For conservation planning it will be important to integrate occurrence data across multiple organismic groups from different mountain areas, which need to be analyzed in combination with other biotic and abiotic data using information such as in the Global Database of Protected Areas of IUCN and WCMC.

Open access and a GBIF portal to shared mountain biodiversity data

The Global Biodiversity Information Facility (GBIF) has already established biodiversity information networks, data exchange standards, and an information architecture that enables interoperability and facilitates mining of biodiversity data. GBIF's technical expertise is an essential prerequisite for this project and we welcome the idea of creating a specific GBIF data portal on mountain biodiversity. GMBA in turn can help to encourage mountain biodiversity researchers to share their data within GBIF, in order to increase the amount and quality of geo-referenced data on mountain biodiversity provided online. These tasks are also in line with the implementation of the program of work (PoW) for the Global Taxonomy Initiative (GTI) and for mountain biological diversity of the Convention on Biological Diversity (CBD).

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Ecotourism in Old-growth Forests in Turkey: The Kure Mountains Experience

Forests are crucial for the well-being of humanity. They provide foundations for life on earth through ecological functions, by regulating climate and water resources and serving as habitats for plants and animals. Forests also furnish a wide range of essential goods such as wood, food, fodder and medicines, in addition to opportunities for recreation, spiritual renewal and other services (FRA 2003). Forestland covers 21,188,746 ha, which corresponds to approximately 27% of the surface area of Turkey (OGM 2007). Forests are among the most popular ecotourism destinations because of their unique values for tourists interested in nature in local values and culture. It is therefore critical to adopt a sustainable development approach in the management of mountains and forests, where biodiversity must be conserved in the long term to minimize the negative impacts of tourism. This is increasingly being acknowledged by governmental institutions and non-governmental organizations in some areas of Turkey. We report here on the development of ecotourism and the support of local communities and other stakeholders in the Kure Mountains, emphasizing awareness-raising activities and benefits to the local economy.

Ecotourism in Turkey

The Kure Mountains, located in the provinces of Kastamonu and Bartın—one of the largest protected areas in Turkey with old-growth forest formation—have been visited by growing numbers of tourists since 2000. There are no statistical visitor data about the Kure Mountains, but tourism statistics for Kastamonu (2000–2006) give a picture of the increasing numbers of tourists in the region (Table 1).

It is encouraging that there are different environmentally sensitive