Regional impact assessments of multiple environmental changes for plant diversity

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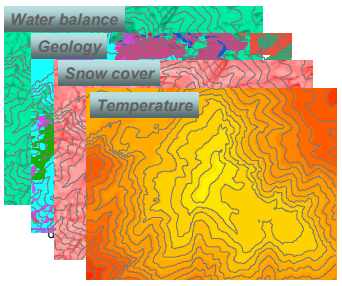
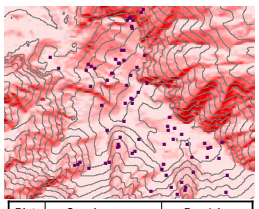
Abstract Climate changes, the withdrawal from traditional land use practices, and invasion of alien plant species expose biodiversity to unprecedented stresses. The assessment of these impacts is challenging, particularly its interacting effects. Habitat distribution models (HDM) in combination with comprehensive spatial data on environmental condition provide an opportunity to assess the consequences of multiple pressures for biodiversity. Here we present the results of two regional modeling studies by emphasising feasibility, potentialities and pitfalls of the models being applied. Scenarios of the impact of climate change and the abandonment of traditional pastures in alpine areas were developed for the north-eastern Calcareous Alps in Europe. Another impact assessment was carried out for a Chilean island where alien species pose severe threat to montane rain forests being rich in endemic plant species. The results of these studies showed that ecosystems are differentially vulnerable to environmental changes, that it is essential to consider multiple pressures, and that the models being applied can answer only part of what would be necessary to define effective measures for biodiversity conservation. By summarizing the experiences from both we present a framework for future developments of statistical habitat distribution models covering issues of data availability, scale and precision, model formulation and scenario building.

Building Habitat Distribution Models (HDM)

Spatial environmental data



Spatial species data



Plot-ID	Species name	Pres/abs (abundance)
001	*Pinus mugo*	0 (0)
001	*Helictotrichon parlatorei*	1 (5)
001	*Carex sempervirens*	1 (3)
002	*Soldanella austriaca*	0 (0)
002	*Pritzelago alpina*	1 (1)
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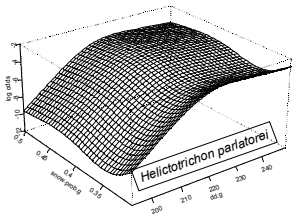
Statistical model formulation



Scenario/Impact assessment

	Land use Scenario 1 (e.g. same as present)	Land use Scenario 2 (e.g. pasture abandonment)
Climate Scenario 1 (e.g. Annual mean temperature increase by xx °C)	Scenario 1 1	Scenario 1 2
Climate Scenario 2 (e.g. Annual mean temperature increase by xx°C / less precipitation by xxx mm/year)	Scenario 2 1	Scenario 2 2

Critical Issues & Future Development

•Availability and precision
Statistical habitat distribution models rely heavily on available data and its precision. Data and models of environmental conditions are improving in precision, resolution and availability. Although an implementation in HDM is improving their predictive capacity it is not improving inherent characteristics of the modeling framework itself. Scenarios are only useful if they are plausible and this can only be judged when interpretable environmental predictors are used.

•Spatial Scale
It is inherent to ecological systems, that processes and/or their significance differ among spatial scales. The decision which grain size (and often extent) of spatial environmental data is chosen in HDM is rather driven by the available data than by ecological rational.

•Correlation among predictors
Environmental variables, particularly those derived from digital elevation models, often correlate substantially. Disentangling effects of diversity loss is thus often hampered leading to vague inferences about direct or indirect causes and possible mitigation efforts.

•Realised niche
HDM are parameterised using observations of species occurrences or abundance in existing communities. Thus, intrinsic to HDM is that only the realised niche of species is modelled. In the presence of disturbance and perturbation (e.g. due to climate change) the realised niche may be of limited use.

•Biotic interactions
The circumvention of the limitations of realised niche modeling by the incorporation of biotic interactions is central to HDM. However, concise framework for more realistic community assembly within HDM is still lacking.

•Pseudovalidation
The difficulty to have independent data for model validation mitigates against the development of reliable scenarios (e.g. climate change impact). Palaeodata and cross-geographic prediction have been tested and may provide possible ways to go in future.

•Nonparametric responses
Parametric response functions do not accommodate the existing complexity of species in relation to their habitat. More data driven smooth functions are flexible tools but prediction beyond the data domain (as in scenarios) is still a statistical challenge.

•Interactions
A species' niche is the result of multiple interacting factors. Most used statistical models can handle interactions in one or the other way. However, interactions are very data demanding and/or the statistical treatment is simplistic. An appropriate representation of interaction among environmental variables in combination with bearable parsimony has yet to be developed.

•Predictor selection
The selection of significant predictors in ecological models like HDM is still an issue for further development. In particular when models are applied to develop scenarios are predictor selection procedures crucial.

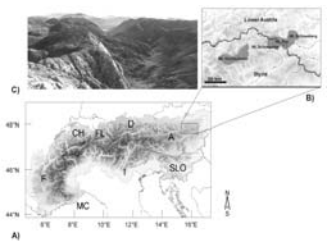
•Response time lags
Most biotic systems considerably lag behind environmental changes they are faced with. Common HDM forecast potential changes of suitable habitats for species and not the species itself. On the other hand dynamic models are in its infancy, particularly for larger areas. Though HDM are still an excellent way to assess potential changes, the temporal domain involved would allow deriving much more precise measures and priorities for conservation efforts.

•Interactions among pressures
Biodiversity is exposed to a multitude of threats. Interactions among pressures are complex, e.g. land use shapes migration paths for those species being pushed north- or upwards by climate warming. Including all possible environmental pressures in HDM allows an integrated assessment and unravelling of relative effects. The availability of spatially explicit data with appropriate resolution and detail is improving and will lead to much more reliable scenarios in future.

•Modeling domain
HDMs are limited to the environmental domain of the calibration data. Partial environmental gradients in particular can lead to linear responses which fail when predicted beyond their domain. So far this was often due to a limited calibration data set. Distributed databases with appropriate metadata for modeling is certainly a high priority if we wish to improve scenarios derived from HDM.

Experiences from regional case studies

CASE 1 Alpine plant diversity prone to climate change and land use

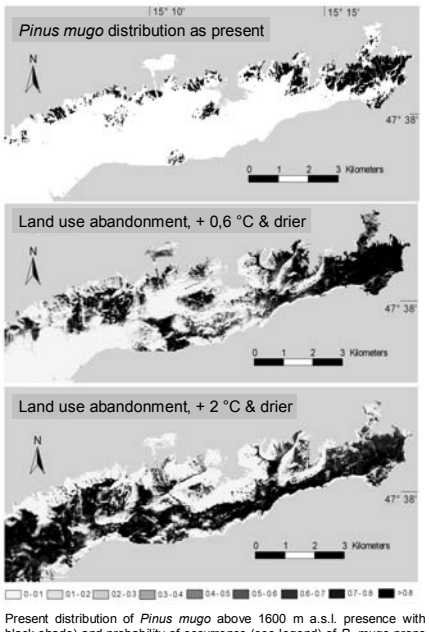


Aim Assessing potential response of alpine plant species distribution to different future climatic and land use scenarios.

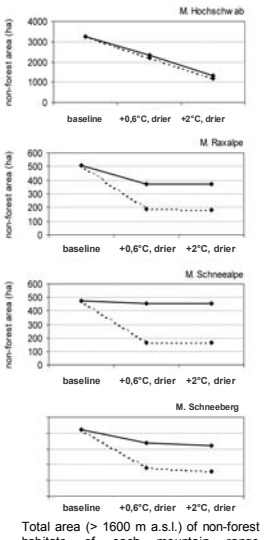
Location Four mountain ranges totalling 150 km² in the North-eastern Calcareous Alps of Austria.

Methods Ordinal regression models of 85 alpine plant species based on environmental constraints and land use determining their abundance.

Results A regionalised GCM scenario for 2050 (+0.65°C, -30 mm August precipitation) will only lead to local loss of potential habitat for alpine plant species. More profound changes (+2°C, -30 mm August precipitation; +2°C, -60 mm August precipitation) will bring about a severe contraction of the alpine, non-forest zone, due to range expansion of the treeline conifer *Pinus mugo* and many alpine species will loose major parts of their habitat. Maintenance of summer pastures facilitates the persistence of alpine plant species by providing refuges, but existing pastures are too small in the area to effectively prevent the regional extinction risk of alpine plant species.

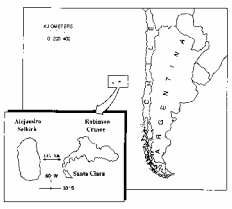


Present distribution of *Pinus mugo* above 1600 m a.s.l. presence with black shade) and probability of occurrence (see legend) of *P. mugo* prone to climate and land use change; exemplified by a part of the mountain range of M. Hochschwab, the westernmost of the study area. *Pinus mugo* is successively covering alpine areas leaving only scattered non-forest habitats. Disappearance at the lower limit reflects competitive exclusion by subalpine forest trees.



Total area (> 1600 m a.s.l.) of non-forest habitats of each mountain range considered which remain after *Pinus mugo* reaches its potential distribution which can be expected from different climate and land-use scenarios. Full line: land use as present; dotted line: land use abandonment.

CASE 2 Island plant diversity prone to introduced aliens

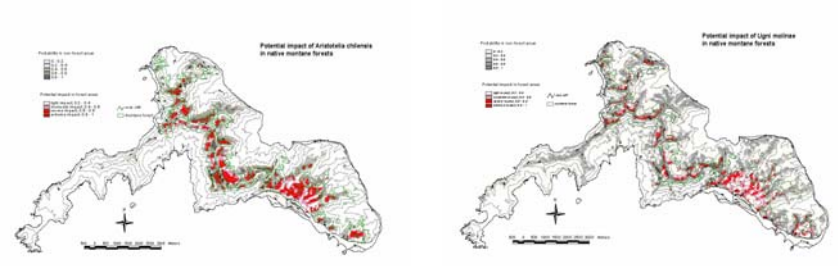


Aim Assessing the threat invasive plant species may pose to the native, highly endemic vegetation of Robinson Crusoe Island.

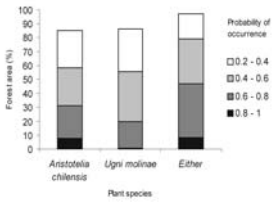
Location Juan Fernandez Archipelago, a Chilean national park and Biosphere Reserve, is 700 km west of continental Chile.

Methods We used logistic regression models with environmental variables or its surrogates (altitude, solar radiation, topographic similarity index, slope position) to estimate the potential distributions of the worst invaders.

Results Native vegetation has been affected most severely by *Acaena argentea*, *Aristotelia chilensis*, *Rubus ulmifolius*, and *Ugni molinae*, leading to a significant decrease of endemic plants in the montane forests and native shrublands. The distributions of all studied species except *Rubus ulmifolius* are significantly ($p < 0.05$) controlled by the environmental factors we examined. Inferring from potential distributions of *Aristotelia chilensis* and *Ugni molinae*, 50% of the native montane forest could be invaded or replaced (with a probability > 60%) by these plants.



Potential impact of the alien plants *Aristotelia chilensis* and *Ugni molinae* in native montane forests on Robinson Crusoe Island.



Proportion of native forests sensitive to invasion by the alien plants *Aristotelia chilensis* and *Ugni molinae* on Robinson Crusoe Island. Probabilities derive from the logistic model of the two species superimposed on the map of actual vegetation.

More details on the two case studies:
Dirnböck T, Dullinger S, Grabherr G. 2003: A regional impact assessment of climate and land use change on alpine vegetation. - *Journal of Biogeography* 30: 401-418.
Dirnböck, T., Greimler, J., Lopez S., P., & Stuessy, T.F. 2003: Predicting future threats to the native vegetation of Robinson Crusoe Island, Juan Fernandez Archipelago, Chile. - *Conservation Biology* 17: 1650-1659.

Regional impact assessments