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Relationships Between Landform and Phyto-Diversity in the Turtmann Valley, Switzerland

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Abstract

Landscape variety, landform diversity and vegetation richness are closely linked in high mountain regions and build a complex interacting ecological system. The main focus of this study is to analyse these relations between phyto-diversity and landform using a DEM from very high resolution data (HRSC) of the Turtmann valley, Switzerland. During field campaigns in 2005 and 2006 vegetation, especially the number of species was mapped in 2x2m² and 10x10m² plots considering certain topographic classes. Additionally, particularly topographic parameters and indices were derived from a DEM (HRSC). First statistical analysis showed fair correlations between height, curvature, wetness, distance to ridges and solar radiation with the number of species. A prediction of plant diversity by stepwise multiple linear regression s of remote sensing derived parameters showed moderate results with R² of 0.45. With R² of 0.35 partial least square regressions (PLS) as well showed average correlations between species richness and landform parameters.

KEY WORDS: Landform, biodiversity, species richness, vegetation, HRSC, Swiss Alps

1. Introduction

Biodiversity is of great ecological interest. Finding regions with high biological diversity is necessary to explore the diversity functioning and its relationships in complex geo- and ecosystems. High mountain regions are one of these hotspots of biodiversity, because they exploit the third dimension over a relatively small area creating different topoclimatic conditions over short distances and therefore, generate high biodiversity. Actual maps of biodiversity within high mountains are relevant to identify areas of a particularly high biodiversity. As area-wide mappings during field campaigns are very time-consuming and costly, observations with remote sensing could serve as a continuous source for extracting diversity information indirectly by means of spectral as well as topographic data. Until now most research activities focused on large or regional scale biodiversity maps based on remote sensing data. Nagendra and Gadgil (1998) and Ivits-Wasser (2004) assessed biodiversity by large scale landscape classification. Waser et al. (2004) predicted species richness of lichens in Switzerland with aerial photographs at a regional scale. Wohlgemuth (1998) created a swiss floristic species richness map below the timberline derived among others by geomorphometric landform parameters based on a digital elevation model (DEM). In Tyrol, Austria Gottfried et al. (1998) modelled biodiversity distribution patterns at a local scale in the alpine and nival zone from DEM derived landform parameters.

Creating diversity maps from remote sensing data seems to have a great potential. As landform parameters like exposition, slope, curvature are important factors determining the habitat conditions of vegetation, the derivation of these parameters by a DEM provides a proxy for certain climatic, hydrologic or soil conditions. By means of these abiotic conditions specific, plant diversity patterns can be explained and modelled even at a local scale. Therefore the main focus of this study is to analyse and model the relation between phyto-diversity of vascular plants and landform at a local scale using a DEM from very high resolution data (HRSC) of the Turtmann valley. The concept of this investigation as well as first results and further investigations will be presented in this paper.

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2. Study area

The Turtmann valley is an alpine catchment located in the southern mountain range of the Valais Alps between the Matter valley and the Anniviers valley in Switzerland (Fig. 1). The main stream of the valley, a tributary of the Rhone River, drains a 110 km² catchment at altitudes between 620 m and 4200 m a.s.l. The valley is 20 km long and the main glacial trough is oriented from north to south. The trough is up to 300 m wide and surmounted by 15 hanging valleys to the west and east. Ground levels of the hanging valleys increase from 2300 m to 2600 m. The Turtmann valley is a high alpine valley with a typical vegetation zonation of the Central Alps. Larch-cembran pine forests (Larici-Pinetum cembrae) grow from the bottom of the valley up to 2000 to 2100 m, followed by the subalpine dwarf shrubs and the alpine grassland up to 2700 m. Above 2700 to 2800 m only sparse rock or not any vegetation is found. The study area above the tree line contains the five hanging valleys Meidtälli, Rotigtälli, Bortertälli, Grüobtälli and Niggelingtälli. A typical ascending sequence starts with a subalpine dwarf-shrub belt (Rhododendro-Vaccinion, Loiseleurio-Vaccinium or Juniperion nanae) as the lowest vegetation types in the hanging valleys. Nutrient rich alpine pastures (Poion alpinae) but mostly widespread nutrient poor grasslands (Aveno-Nardetum) alternate, followed by the Carex curvula high-elevation grassland (Caricetum curvulae). Further up the closed vegetation coverage opens to a sparser vegetation form like snow bed vegetation (Salicetum herbacea) and siliceous scree vegetation (Androsacetalia alpinae) until habitat conditions are that extreme that vegetation lacks. Lithology in the study area is composed of palaeozoic schists and gneisses and mesozoic dolomites, limestones, and marbles of the penninic nappe Siviez-Mischabel. The inner alpine location of the Turtmann valley is characterised by continental climatic conditions. Mean annual air temperatures are between 8.5°C in the Rhone valley (Sion) and 3.8°C at 1825 m (Evolène). Mean annual precipitation is about 500-600 mm (surrounding stations) (data from www.meteoschweiz.ch).

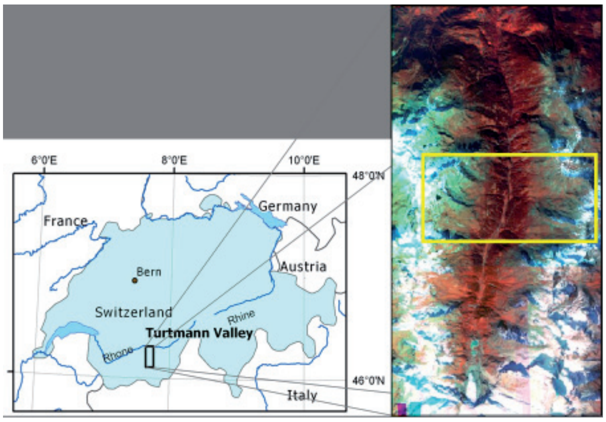

Figure 1: Study Area: Turtmann valley, Valais, Switzerland (right: HRSC data, RGB 421).

3. Data used

The High Resolution Stereo Camera (HRSC) was originally developed for the mission "Mars Express" by the German Aerospace Centre (DLR), but was then adapted for terrestrial, airborne missions. The HRSC-A sensor (Tab. 1) is a multispectral stereo scanner containing 9 bands: blue, green, red (tending to near infrared), near infrared and 5 panchromatic bands covering the green and red spectrum. Each band has another viewing angle so that a DEM can be produced using different bands.

	HRSC-A
Focal length [mm]	175
Numbers of CCD lines	9
Numbers of sensors per line	5184
Sensor size [µm]	7
Radiometric resolution[bit]	8
Multispectral viewing angle [°]	15.9 (R) 3.3 (B) -3.3 (G) -15.9 (nIR)
Stereo viewing angle [°]	± 18.9 ± 12.8 0
Field of view [°]	± 11.8
Flight altitude for 50 cm geometrical resolution [m]	~ 3000
Spectral resolution [nm]	
Blue	395-485
Green	485-575
Red	730-770
Near Infrared	925-1015
Nadir (panchromatic)	585-765
Stereo forward/backward (panchromatic)	585-765
Photometry forward/ backward (panchromatic)	585-765
Maximum line frequence per band [Lines/s]	450
Platform	stabilised Zeiss T-AS-Plattform
Data recording	SONY high speed data recorder
Weights: camera [kg]	~32
adapter [kg]	~40

(According to Neukum and HRSC-Team 2001).

Table 1: Technical information about the HRSC-A sensor.

In September 2001 the entire Turtmann valley has been recorded. The spatial resolution is 50cm for the image and 1 m for the DEM data. Multispectral data tend to be slightly blurred in flight direction due to their – compared to the more panchromatic filters of the stereo bands – smaller filter bandwidth (see Tab. 1) which results in longer exposure times. Nevertheless, sharpening can be achieved by using HSI transformation with the very sharp Nadir band as the intensity component.

There have been only few research projects applying the terrestrial HRSC data so far. Most of them investigated vegetation by mapping biotopes or classifying land cover at small scales. Ehlers et al. (2003), Leser (2003) and Bock et al. (2005) for instance developed a (semi-)automated analysis of HRSC data for biotope type and habitat mapping. Lehmann et al. (1998) fused data of the very high geometrical resoluted HRSC with the very high spectral resoluted HyMap sensor to automatically extract trees in urban areas. Otto (in prep.), Nyenhuis (2005) and Roer et al. (2005) e.g. used the HRSC DEM to map rock glaciers, sediment storage landforms or to calculate rock glacier movements.

Besides the remote sensing data, vegetation information is needed. In order to set up the diversity model exactly, vegetation parameters were mapped in a field campaign in 2005 and 2006. The 109 test plots were chosen randomly taken into consideration exposition, height, slope and curvature. They were localised in the field using a differential GPS and mapped using two scales: 2m x 2m and 10m x 10m.

4. Methods

All vegetation plots from the field campaign 2005 and 2006 were analysed and categorised into plant communities following the key of Oberdorfer (1992) and Delarze et al. (2002).

In a second step, particularly topographic parameters and indices were derived from the HRSC DEM data (see Tab. 2).

Topographic Parameters (15x15, 9x9, 5x5 m^2)	**Indices (1, 10, 25 m)**
Height	Solar Radiation
Exposition	Duration of Insolation
Slope	Topographic Wetness
Longitudinal curvature	
Cross-sectional curvature	
2D-Distance to ridge	
2D-Distance to river	
Toposcale	

Table 2: Survey of parameters derived by remote sensing data.

According to Wood (1996) the topographic parameters height, exposition, slope, cross-sectional curvature and longitudinal curvature are calculated on the 1m DEM using three different moving window sizes: 15x15m^2, 9x9m^2 and 5x5m^2 to receive three different scales. The longitudinal curvature intersects with the plane of the slope normal and aspect direction and cross-sectional curvature intersects with the plane of the slope normal and perpendicular aspect direction. For all five topographic parameters the maximum, minimum and mean value of a plot as well as its standard deviation is extracted and added as a separate variable.

Additionally, the shortest 2D-distance to a ridge as well as the shortest 2D-distance to a stream are calculated for each plot and added as two of the topographic parameters describing specific habitat conditions depending on the distance extreme locations (ridges or streams). A more complex topographic parameter is the toposcale (see Zimmermann and Kienast (1999)). It is based on relative differences between actual pixel elevation and mean local elevation at different spatial scales. Three different scales are calculated: the first level comprises the elevations between 3 and 15m, the second compares the elevations between 10 and 50m and the third consists of elevations between 20 and 100m. The relative position in a terrain can explain habitat and therfore diversity patterns.

To achieve complex abiotic parameters describing certain habitat conditions the following indices were derived by the DEM in three different scales: (1) 1m, (2) resampled to 10m and (3) resampled to 25m. The solar radiation index describes the potential incoming solar radiation per pixel per day in kWh/m², the duration of insolation index contains the hours of insolation for each pixel per day (Wilson and Gallant 2000). A topographic wetness value for each pixel was estimated combining slope and catchment areas (Moore et al. 1991).

All calculated parameters and indices were linked to the vegetation parameters mentioned above in order to find single correlations and complex relations. So far, multivariate linear correlations, especially stepwise linear regressions and non linear regression, in this case the partial least square regression (PLS), have been applied to reduce the large number of parameters only to the best correlated ones.

5. First results

First statistical correlations between diversity and calculated parameters are generally weak. The best univariate correlations resulted from height, 2D-distance to ridges, 2D-distance to rivers and topographic-wetness-index with the number of species. Following the elevation gradient from the sub-alpine to the nival zone the number of species decreases (-0.56 R^2). For the same reason towards ridges and near peaks species richness decreases (0.5 R^2), while it increases closer to streams (-0.32 R^2). Wet locations showed slightly more species richness than drier habitats (0.31 R^2).

Species richness and landform parameters or indices correlate moderately in a stepwise multiple linear regression. Tab. 3 shows the statistics of the stepwise linear regressions with the predictors listed under the tables to forecast the number of species. Chosen predictors in the stepwise regression are height from the 1 m DEM, the Wetness-Index of the 10 m DEM and the toposcale calculated from 20 m to 100 m. The adjusted R^2 of 0.45 proves moderate correlations and fair regression models. According to Chin (1998) results from the nonlinear partial least square regression show average correlations between the number of species and landform parameters with R^2 of 0.35. The summary of the PLS statistics is shown in table 4. Main predictors going in the PLS model are the Solar-Radiation-Index of the 25 m DEM, curvatures of the 15, 9 and 5 kernel and the Duration-Of-Insolation-Index of the 10 m DEM.

Model Summary	R	R Square	Adjusted R Square	Std. Error of the Estimate
	0.69	**0.47**	**0.45**	**11.69**
	Dependent variable:	number of species per plot		
	Predictors:	height (1m), wetness (10m), toposcale (20-100m)		

Table 3: Model summary of the multiple stepwise linear regression predicting number of species.

Model Summary	R Square	
	0.35	
	Dependent variable:	number of species per plot
	5 best Predictors:	solar-radiation (25m), curvature (15x15, 9x9, 5x5), duration-of-insolation (10m)

Table 4: Model summary of the partial least square (PLS) regression predicting the number of species.

Summarising the first analyses, the best correlations turned out to be between number of species and height, distance to ridges or streams, respectively, wetness, toposcale, curvature and solar radiation so far.

6. Discussion and Outlook

Analysing the univariate correlations, the strongest relation was found between elevation and species richness being reflected in all three parameters: height, 2D-distance to ridges/streams and the Wetness-Index.

Ascending towards ridges and peaks habitats become drier and climatic conditions are more extreme causing species richness to decrease towards the nival zone where vegetation lacks at all. A clear causal statistically proven relation is only found between a decreasing number of species and elevation or ridge proximity where R^2 exceeds 0,5.

Elevation and wetness are also important predictors in the linear regression model. Additionally, the toposcale(-index), calculated from elevation and relative local positions, is a main input variable to model species richness. The most important relation in this case again is the decreasing number of species with increasing elevation.

Different predictors are chosen in the PLS. Species richness also increases with increasing solar radiation and duration of insolation. Solar radiation usually increases towards ridges. However, apparently species richness decreases with ridge proximity but also rises with increasing solar radiation. This divergence will be investigated in the future. Curvature parameters are important predictors for the PLS but don‘t show a similar tendency of correlation with the number of species. Using the 15 and 9 kernel, species richness is higher in concave (pit) than in convex places (peak) whereas with the 5 kernel the inverse situation is observed. Convex regions are normally more elevated and soil wetness is less. Decreasing species richness in convex places would hence correspond to the relations found in the univariate analysis. A reason for the op posing correlation observed with the 5x5 kernel data could be the small plot size. This again requires further investigation.

Linear regression in general showed better R^2, but as input parameters are statistically not independent, the PLS regression creates formally more correct models. As input parameters are transformed to statistically independent components (comparable to a principle component analysis) before generating the PLS model, over assessment is avoided.

Testing the most related scales to the 10m x 10 m plots didn‘t afford definite results. In all statistical analysis landform parameters derived by the 1 m, 10 m or 25 m DEM as well as the by all three different moving window sizes were used as predictors without a clear tendency to a certain scale.

Summarizing the analysis and results so far, the correlation between species richness and landform is low and previously models can’t find a satisfying relation of both ecological elements. There are two possibilities for the weak results: either only landform parameters cannot express the distribution of diversity adequately and additional parameters are necessary for modeling phyto-diversity or the sampling size isn’t large enough and hence isn’t representative. Hence, further investigations will be undertaken following the mentioned explanations.

Aimed at improving the results at the same scale, additional remote sensing data was recorded in summer 2006. Quickbird as well as SPOT data recorded in July 2006 will provide spectral data. Textures measures derived by the spectral data will be used to improve the regression models.

Enlarging the sampling will be tested to see if the 109 sampling plots at present are representative for the study area. As each vegetation type has its certain range of numbers of species, a mean number of species can be applied to each pixel of the existing vegetation map according to its vegetation type. The sampling is than enlarged and can be applied to the regression modeling.

Further investigations will as well focus on a larger scale to model the variety of vegetation types.

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