# Relatedness and scale dependency in very high resolution digital elevation models derivatives


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**KEYWORDS :** Very High Resolution (VHR), Digital Elevation Model (DEM), Environmental variables, Multiscale, SAGA GIS, Rochers-de-Naye (Swiss prealps)

## Introduction

In the field of landscape genetics, environmental variables are needed to assess the influence of the environment on the spatial distribution of the genetic information of animals or plants [1]. However, measuring variables (e.g. temperature, precipitation) at locations of each sampled individuals is time consuming. Landscape geneticists therefore often use variables from remote sensors such as existing satellite imagery and digital elevation models (DEMs). From these DEMs, many variables related to morphology, solar radiation or hydrology can be computed. However, their spatial resolution is not high enough when studying the local adaptation of organisms to their local environment. Indeed climatic variables available for our study site in Switzerland offer a resolution that is coarser than 25m [2] and the same issue is encountered for the globally available DEMs which have a spatial resolution of 30 (ASTER) and 90m (SRTM) with a low accuracy (+- 15m) [3, 4]. An additional difficulty comes as many indices have been created in the last 20 years to approximate wetness, erosion, soil type distribution, stream power, etc. These indices are often highly mutually correlated and the impact of spatial resolution on their computation is unknown. Also, the user faces the choice of the software, which are numerous and are able to provide different variables computed with different methods.

In this paper we use the software SAGA GIS, which has the advantages to be both free and open source, but remains rarely used in landscape genetics. SAGA is a raster GIS and is able to produce variables that are not proposed by other software, making it one of the most complete to analyze DEMs. These variables are described in papers informing on the context and their relatedness to environmental processes. In addition, SAGA GIS can be accessed through R. It is thus possible to script once the computation of all variables for a model instead of computing them "by hand" in the software. We computed 17 environmental variables (see Table 1) using SAGA software for three DEMs of different spatial resolution (0.25, 0.5, 2m) acquired over the region of "les Rochers de Naye" where we study the adaptation of the alpine plant Biscutella Laevigata L. (Brassicaceae) to its environment. We compared these 51 variables in order to: I) assess their mutual correlation, II) analyze the influence of the spatial resolution on their computation, III) assess whether a DEM obtained from stereophotogrammetry is accurate enough to compute these variables.

## Material and Methods

*Study site*

"Les Rochers-de-Naye" study area is located in the Swiss Prealps (N46°26'00", E6°58'50"). Altitude ranges between 1805 and 2030m. The site is characterized by a steep South-East-facing ridge covered mostly by grass. We showed in a recent paper that the use of variables related to hydrology, topography and solar radiation computed from DEMs is relevant to identify genomic regions possibly involved in the adaptation process of Biscutella laevigata to its local environment [5].

*Digital Elevation Models*

SwissAlti3D (ST2m) is a 2m spatial resolution model acquired by swisstopo using a LIDAR sensor mounted on a plane. Such VHR model is rarely available in other countries. Elevation accuracy is expected to be ±0.5m up to 2'000 meters. (http://www.swisstopo.admin.ch/internet/swisstopo/en/home/products/height/swissALTI3D.html).

Rpod0.5m was acquired by the Rpod team using a drone and the SenseFly technology. Images were used to produce a DEM by means of stereophotogrammetry (http://www.r-pod.ch/; http://www.sensefly.com/). The spatial resolution is 0.5m and the accurateness in elevation is often lower than a LIDAR based model.
Finally, Heli0.25m was acquired by Helimap using a LIDAR sensor mounted on a helicopter (http://www.helimap.ch/). After filtering the laser point cloud, the spatial resolution was set to 0.25m.

*Derivated variables*

In SAGA GIS, we computed the 17 variables shown in table 1 for each of the 3 DEMs. Some of these are of interest for ecology and landscape genetics studies.The dataset used to calculate the correlations is defined by 1000 points randomly distributed over the study area. Values of all variables were extracted for each of these points using the nearest neighbor method.

Hypothesis of independence between variables as well as correlations coefficients were calculated in R [12] for each pair of variable. Only significant correlations ($p < 0.01$ for a Spearman's rank correlation test) are discussed. In addition, for each trio of a variable (i.e. the same variable computed for each DEM), box percentile plots were created in R and correlation coefficients compared.

## Results and discussion

Curvature, slope length and catchment area show few significant correlations, unlike solar radiation variables that are correlated to almost all variables. In fact, excepted for Direct-to-diffuse ratio, all variables related to insolation are mutually highly correlated (0.70 – 0.97). Consequently, considering only one of the three variables (i.e. Direct insolation, Duration of insolation or Total insolation) for one period during the year is enough to approximate a relative insolation at our study site. However, for direct-to-diffuse ratio computed for December 21 and June 21, the correlations with other insolation variables can be low (several ≈0.5). While this may be meaningful for plants, it is difficult to analyze the pertinence of such variable since diffuse insolation is computed on the basis of a uniform reflection of the surface, which may be inaccurate as, for example, snow is present until May on our study site. Another example of redundancy exists between MPI and sky view factor, with a strong negative correlation at all scales (-0.79 – -0.93). In addition correlation coefficients are similar between the different spatial resolutions for sky view factor (0.82 – 0.92) and for MPI (0.83 – 0.94). Consequently, the computation of one of these variables from one DEM is sufficient to represent the heterogeneity of the landscape.

High correlation values are calculated between the same variables at different resolutions. First, as expected, the correlation between altitude models is very high (>0.99); however this does not imply a strong correlation between all variables calculated from these DEMs, as explained for example in [13]. For the first order derivatives, aspect and slope show high correlations between resolutions (0.90 – 0.96; 0.84 – 0.90 respectively) while second order derivatives (Plan and profile curvature) vary a lot with resolution (no significant correlation). This observation on simple terrain attributes is coherent with the literature over other areas [13, 14].

MPI correlation between different resolutions is high as mentioned above. As this index is based on the highest and lowest angle found over a defined radius, it depends more on the altitude precision than on the resolution of the DEM. However, an interesting observation is that the range of values for this index is much wider in the Rpod0.5m than in the two LIDAR models . This remark is also valid for the TRI despite showing more variation among the different spatial resolutions (0.61 – 0.75). The most likely explanation of the higher correlation between LIDAR DEMs than between LIDAR DEMs and Rpod DEM would be due to the technique used (stereophotogrammetry) and to the filter applied. In fact, the additional noise due to its lower accuracy influences these indices that depend on the heterogeneity of the landscape.

**TABLE 1**

| | Variable | Unit |
|---|---|---|
| **Variables related to morphology** | Slope | 0-90 Degrees |
| | Aspect | 0 (Nord) -360 degrees |
| | Plan Curvature | °/100LU |
| | Profile Curvature | °/100LU |
| | Terrain Ruggedness Index (TRI) | |
| | Morphometric Protection Index (MPI) | no unit 0-1 |
| | Sky view factor | no unit 0-1 |
| **Solar radiation variables** | Direct insolation | kwh/m² |
| | Total insolation | kwh/m² |
| | Direct-to-diffuse ratio | no unit |
| | Duration of insolation | hours |
| **Variables related to hydrology** | Modified catchment area | m² |
| | Catchment slope | degrees |
| | Slope length | m |
| | Stream power index | no unit |
| | LS factor | no unit |
| | Wetness index | no unit |

| Parameters | Comment | Reference |
|---|---|---|
| Method= Fit 2.Degree polynom | | [6] |
| | | |
| | LU is the length unit | |
| | LU is the length unit | |
| Radius = 2meters | Quantifies the heterogeneity of the topography | [7] |
| | Degree of dominance or enclosure of a point on an irregular surface. Evaluates the protection of a point from the surrounding relief over a defined distance | [8] |
| Distance = 20 meters | Ratio of the sky area over the obstructed area | [9] |
| Parameters: Atmospheric effects=lumped atmospheric transmittance, Latitude = 46°, time resolution = 0.5(h); period= 21 December and 21 June | | [9] |
| | | |
| | | |
| | | |
| | Discharge contributing upslope area of each grid cell | [10] |
| | Average slope over the catchment | [10] |
| | Mean length of flow paths to a point in the catchment | |
| $SPI = 0.2\,(Specific\ catchment\ area \times plan\ curvature\ \times\ \tan(slope))^{0.25}$ | | [11] |
| $LS = 1.4 * \left(\frac{Catchment\ Area}{22.13}\right)^{0.4} \times \left(\frac{\sin(slope)}{0.0896}\right)^{1.3}$ | effect of slope length on erosion | [11] |
| $WI = \ln\left(\frac{\text{Specific catchment Area}}{Slope}\right)$ | | [10] |

Hydrology and insolation variables were both expected to show an effect of fine scale heterogeneity. This was not observed for the latter ones and it could be explained by the terrain attributes they depend on. Indeed, insolation variables depend on orientation, slope and shadow of surrounding relief, which are not varying much with resolution, as mentioned above. Quite the reverse, hydrology variables are based on curvature, for which scale variability is high. The fine scale structure of Rpod0.5m and Heli0.25m may allow representing these small variations that alter the local flow and the consequence being that SPI, WI, LS factor, slope length and Modified catchment area have smaller values on average for these two DEMs. As regards catchment slope, this variable does not vary as it is a based on the average upslope.

Our results also demonstrate that the Rpod DEM is showing similar results like the ST2m and the Heli025m for most variables while being much less expensive and easier to acquire. We show with these high correlations that the method based on stereophotogrammetry, which is usually less accurate, should be considered in the landscape genetics domain to produce new high resolution environmental variables. Indeed, for most regions in the world, freely available DEMs have a low resolution and a low accuracy (ASTER and SRTM model mentioned in introduction). Therefore acquiring a DEM using a drone can be of great interest for research purposes in order to acquire variables at a fine scale.

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