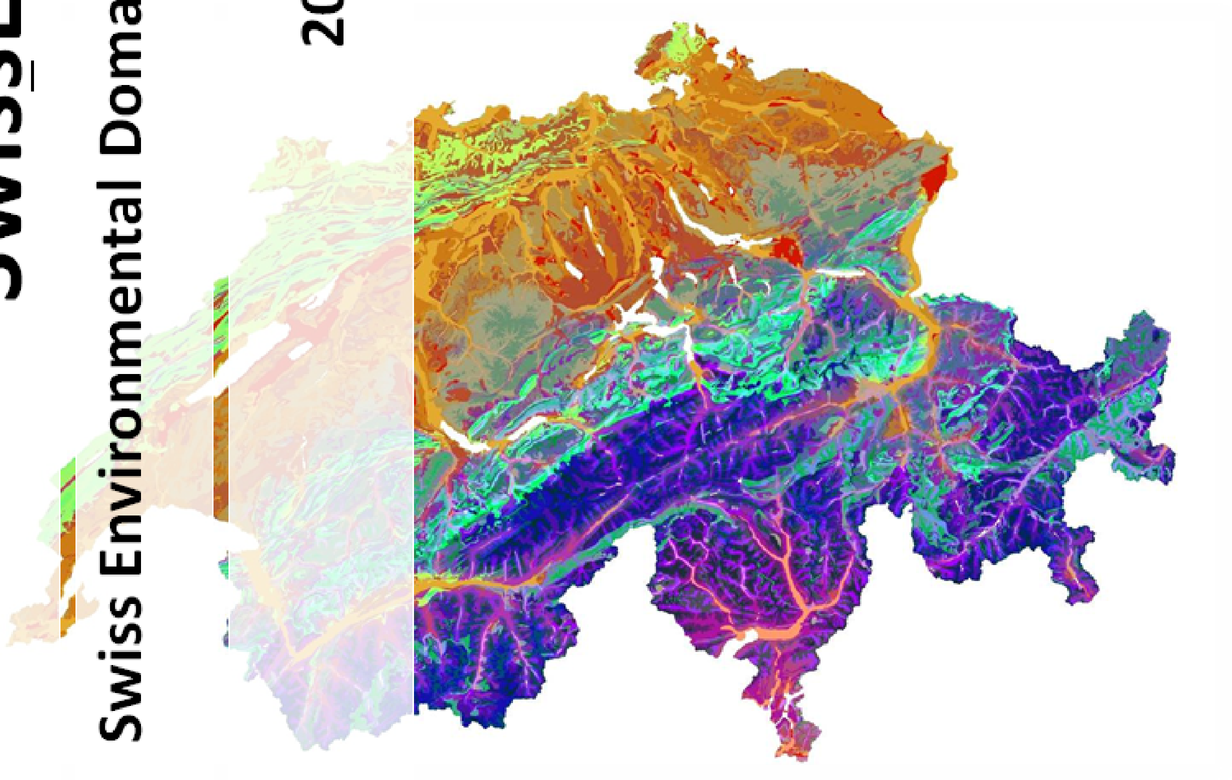
SwissED
Swiss Environmental Domains
2008



TECHNICAL REPORT

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Summary

Swiss Environmental Domains (SwissED) is an environmental classification of key climatic, geologic and topographic variables influencing both natural and anthropogenic processes at various scales. It represents a new spatial framework to analyse data about our environment (e.g. biodiversity, land cover, demography, agriculture, economical activities) that is not replacing existing ones but simply complementing them.

SwissED was inspired from several similar initiatives developed in Australia, New Zealand, USA and Europe. It follows a quantitative and reproducible approach composed of two phases: i) first a non-hierarchical classification to group a sample of pixels representing Switzerland into a 120 domains, ii) second a hierarchical classification of these 120 domains into 100, 50, 25 or 10 domains. These domains can be coloured following the result of a PCA analysis where red corresponds to a gradient of temperature, green a gradient of calcareous content and blue a topography gradient. The first 10 domains were named according to their environmental characteristics: calcareous reliefs, molassic flats and hills, quaternary hills and valleys, crystalline slopes , dry quaternary flats, calcareous midslopes, calcareous upper slopes, crystalline crests, crystalline quaternary slopes and calcareous crests.

SwissED represents the natural potential of the landscapes independently of human activities. It can serve therefore as spatial framework to analyse any environmental statistics according to classes that are defined based on environmental conditions. SwissED would be particularly well suited to represent sustainable development statistics based on the principle that the economy depends on the society, and the society depends itself on the environment. Examples from other countries and regions prove that SwissED can bring a new, complementary and useful spatial framework to underpin environmental research and management in Switzerland at various scales. Possible applications are:

- providing a framework for reporting on the state of the environment;
- identifying the most efficient use of limited financial resources for biodiversity conservation;
- management, including management of protected natural areas and other areas of land with high biodiversity values;
- identifying sites where similar problems are likely to arise in response to human activities, or where similar management activities are likely to have a particular effect;
- identifying the geographic extent over which results from site-specific studies can be reliably extended; and
- designing stratified sampling strategies.

The main conclusions that we can derive from this work are:

- The strong climatic, geologic and topographic gradients found in Switzerland represent the ideal pre-conditions for building environmental domains;
- When compared to traditional spatial frameworks, the maps produced when representing statistics (e.g. land cover) on SwissED return more realistic spatial patterns and surface areas;
- SwissED does not replace previous spatial framework but can bring a valuable complementary tool to represent environmental data;
- SwissED are in line with similar developments made across the world at continental, regional or national levels; and
- SwissED were developed for general purposes analyses without trying to weight the input variables, they could therefore be improved by targeting a specific need (e.g. biodiversity, land cover, agriculture).

Introduction

Swiss Environmental Domains (SwissED) is an environmental classification of key climatic, geologic and topographic variables influencing both natural and anthropogenic processes at various scales. It represents a new spatial framework to analyse data about our environment (e.g. biodiversity, land cover, demography, agriculture, economical activities) that is not replacing existing ones but simply complementing them. SwissED brings a new paradigm in environmental data interpretation that needs to be adequately understood before any possible applications. Swiss Environmental Domains are contiguous groups of pixels that are close together in an environmental space defined by a selection of key variables. Spatial frameworks presently in use (e.g. bio-geographical regions, administrative limits) are defined rather as contiguous groups of pixels that are close together in the geographical space defined by X, Y and Z coordinates.

This study was inspired from a similar work named Land Environment of New Zealand (LENZ: Leathwick et al. 2003) that was achieved by Dr. John Leathwick from Landcare Research. Thanks to an ongoing collaboration, the methods used for LENZ could be transferred entirely and adapted to carry out this study. LENZ was itself inspired from pioneer studies developed in the nineties in Australia (e.g. Kirkpatrick & Brown, 1994) and the United States (Hargrove and Hoffman, 1999, 2005). Altogether these methods share the same goal that is to use modern data-driven techniques to build objective and reproducible classifications of the environment. These classifications create an adapted spatial framework to underpin the management of natural resources and biodiversity. Indeed, the joint development of spatially explicit descriptions of our environment at finer and finer scales, together with the improvement of computer technologies, made it possible to envisage such classifications on larger and larger datasets (e.g. Switzerland at 25m resolution = 64 million pixels).

This work is therefore the fruit of several years of development and experiences made across the world and brought together by John Leathwick in LENZ, and then adapted here for Switzerland. SwissED represents therefore a new and interesting paradigm to look at our environment through a different angle, the angle given by key environment drivers of most natural phenomenon as well as human activities.

Sustainable development framework in Switzerland

Before starting the description of existing classifications of the Swiss territory it is useful to mention the “Swiss landscape concept” (OFEFP 1998) in which several federal offices have prepared a theoretical framework to analyse the national territory from a landscape perspective. The aim was to encourage all national and cantonal offices to integrate general and sectoral objectives into their decision processes in order to better preserve the value of Swiss landscapes in the perspective of their sustainable development. General objectives were split into natural and cultural values, as well as sustainable use and management of resources. Sectoral objectives and measures were developed for 13 political sectors such as construction, energy, leisure, defence, agriculture, aviation, nature, planning, transport, forests, rivers and hydropower. This approach was justified in order to homogenize the different actions taken in various sectors by defining general objectives to preserve Swiss landscapes. However, no quantitative or spatial framework was proposed to companion this concept.

With the Monet indicator system (Altwegg et al. 2004), three federal offices developed together a quantitative framework to measure and monitor Switzerland’s progress in achieving sustainable development. However, once more, no spatial framework was proposed to analyse sustainable development at sub-national levels. Classifications of the Swiss territory into sub-units defined according to specific aims are therefore useful to provide a spatial framework to monitor its sustainable development, as well as to assess its vulnerability to global changes.

Existing Swiss classifications

Before entering the full description of SwissED through this technical report, it is useful to explore the spatial frameworks commonly used in Switzerland, or still under development, to describe the environment either in geographic or environmental space, or defined as landscapes.

Geographic space

Most of the existing spatial frameworks are based on some expert opinion or administrative boundaries such as respectively the biogeographic regions (Gonseth et al. 2001) or the 26 states. These regionalisations have in common the fact they group together elements of the landscape that are close together in the geographical space, resulting in contiguous entities across the geographical space (Figure 1, A&B).

Environmental space

With SwissED, elements of the landscape are grouped together when they are close together and form contiguous groups in the environmental space defined by a selection of variables. When projected back into the geographical space, these groups are not contiguous and form collections of disjoint entities (Figure 1, C&D). This is the strength and weakness of SwissED at the same time. It is strength to be defined in environmental space because the resulting grouping are much more likely to correspond to the patterns of any phenomenon driven by environment conditions, but at the same time it is a weakness being represented by disjoint entities in geographical space that make the usage of these entities more difficult to apprehend by environment practitioners in charge of monitoring the environment and make decisions about its protection.

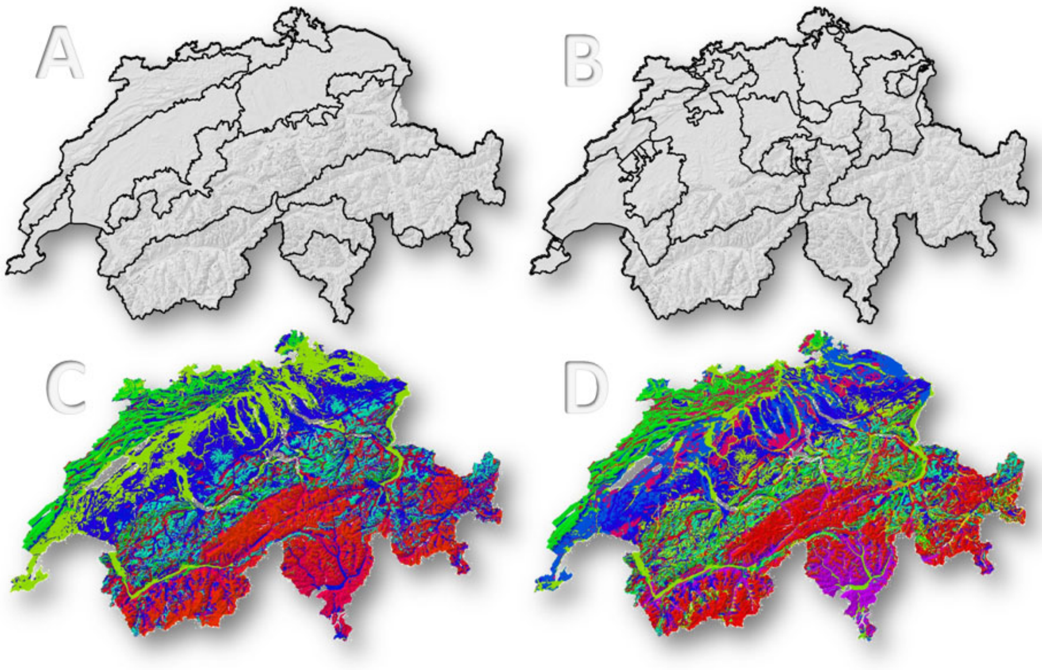


Figure 1. Comparison of existing geographical classifications (A: biogeographical regions, B: states) to environmental domains at different hierarchical levels (C: 10 groups, D: 25 groups).

Table 1 Summary table of main characteristics of classifications in geographic versus environmental space

Expert classification in geographic space	Statistical classification in environmental space
Contiguous in geographic space	Contiguous in environmental space
Generally one level	Hierarchical levels
Essentially expert opinion	Essentially data driven
Reflects biogeography, history, human activity	Reflects pure environmental potential

Landscape classification

A landscape approach was recently followed by different federal offices (ARE, OFEV, BFS; see also Szerencsits et al. 2008) in order to propose a classification of the Swiss territory based on 45 units with a minimum surface of 10km^2. These units were based on an expert process of selection of vector and raster based information available at a national level that were used to split the territory into landscapes according to their similarity along two lines of thought, namely natural stable patterns and unstable land use practices. The central result that is shown in Figure 2 is presently under consultation among various stakeholders.

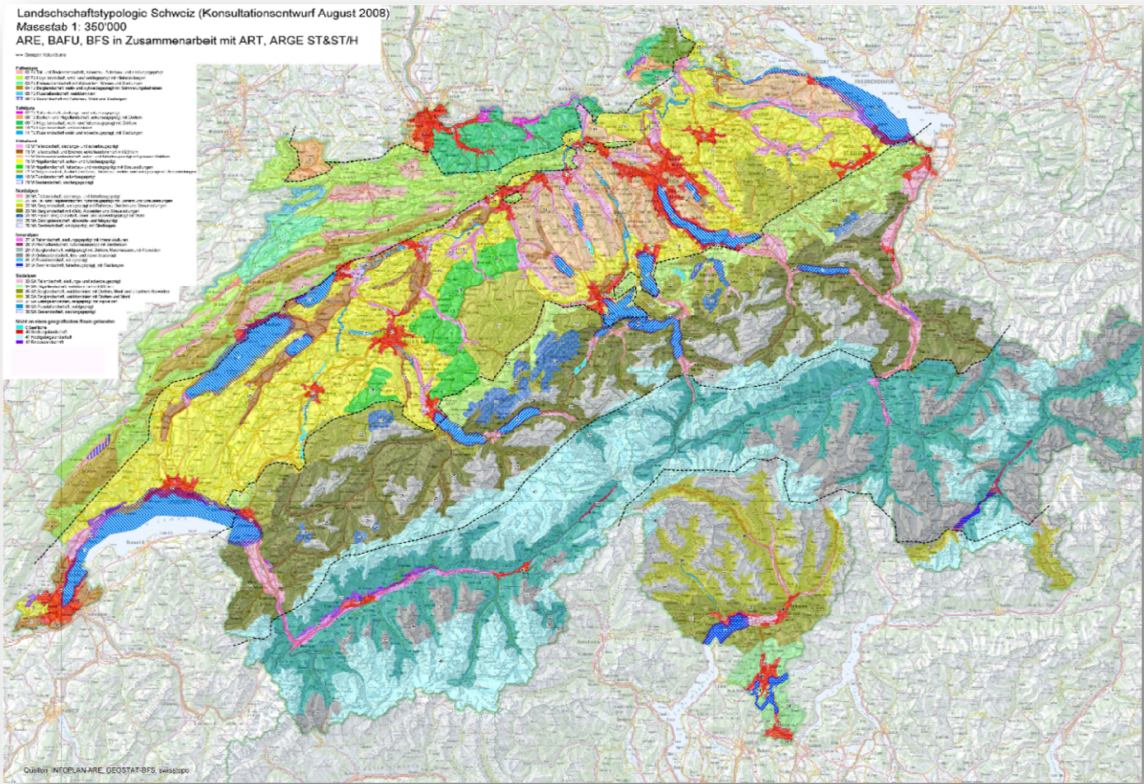


Figure 2. 45 Swiss landscapes defined at a scale of 1:350000 (ARE, BAFU, BFS)

International state-of-the-art

Early attempts

The definition of Environmental Domains takes its root in the ecosystem-based approach of environmental management. The first step of ecosystem-based management is the definition of geographic areas that share similar ecosystem characters (e.g. Bailey 1983) in the search for systematic conservation and biodiversity management (Margules & Pressey, 2000). With the improvements of computer technology in became possible in the early 1990's to classify spatially explicit layers of information into environmental domains. The first scientists that took advantage of the new opportunities brought by multivariate classifications were the Australians (Mackey et al. 1988; Belbin 1987; 1993; Kirkpatrick & Brown 1994; Ferrier and Watson,1997; Faith et al. 2001) followed by the Americans (Bernert et al. 1997; Hargrove & Hoffman 1999).

Australian pioneers

The work of many Australian pioneers is best exemplified in Figure 3 that is presenting the work made by the NSW National Parks and Wildlife Service based on an environmental GIS database for northeast NSW built in the late 1980s. The database contains a wide range of mapped and modelled layers pertaining to topography, climate, substrate, vegetation cover and disturbance, most of which are stored at a 1 ha (100 m × 100 m) grid-cell resolution. These early efforts have allowed them to develop and test many ways of classifying biological and/or environmental data (Ferrier et al. 2002) to underpin conservation planning.

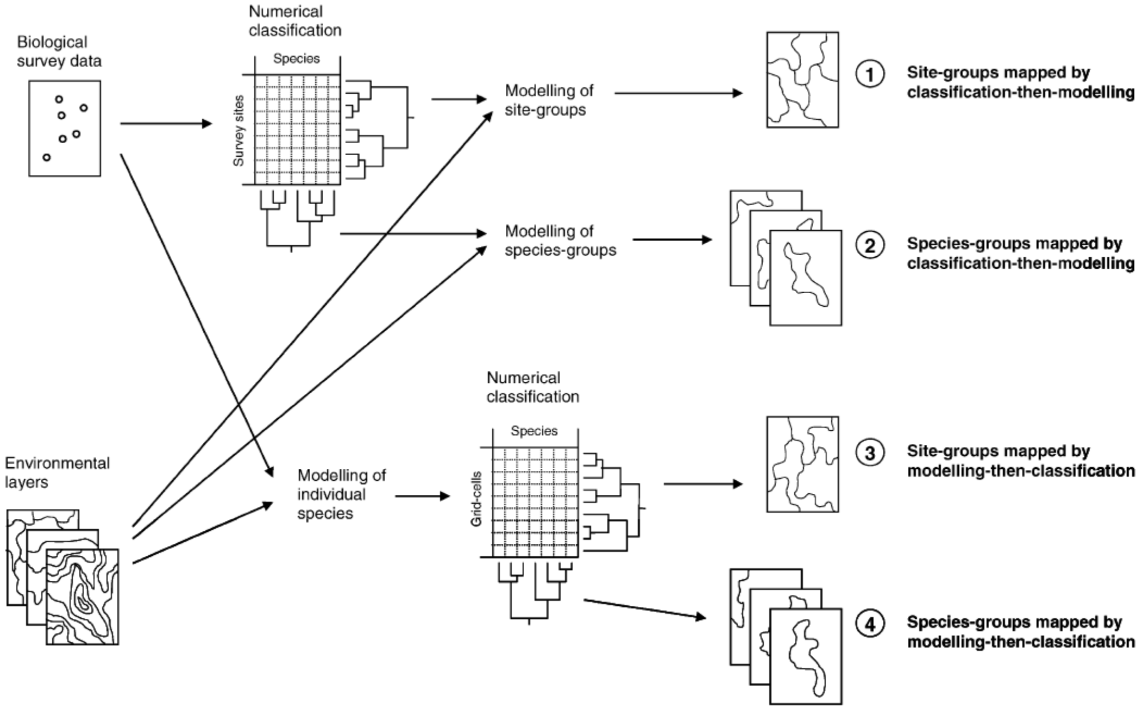


Figure 3 Major strategies for integrating numerical classification and modelling of communities or assemblages (Ferrier et al. 2002).

American Quantitative Ecoregions

Multivariate clustering was used to classify maps of elevation, temperature, precipitation, soil characteristics, and solar inputs to produce a spectrum of quantitative ecoregions (Hargrove and Hoffman, 1999; 2005). The coarse ecoregions capture intuitively-understood regional environmental differences, whereas the finer divisions highlight local conditions, ecotones, and clines. These data-driven ecoregions can be produced from different sets of input variables corresponding to different set of problems. These ecoregions are thought to be more objective by removing the limitations of human subjectivity and opening the way to a new array of useful derivative products.

A RGB colour scheme based on Principal Components Analysis allows visualizing the main gradients at stake. Multiple geographic areas can be classified into a single common set of quantitative ecoregions to provide a basis for comparison, or maps of a single area through time can be classified to portray climatic or environmental changes geographically in terms of current conditions (Figure 4).

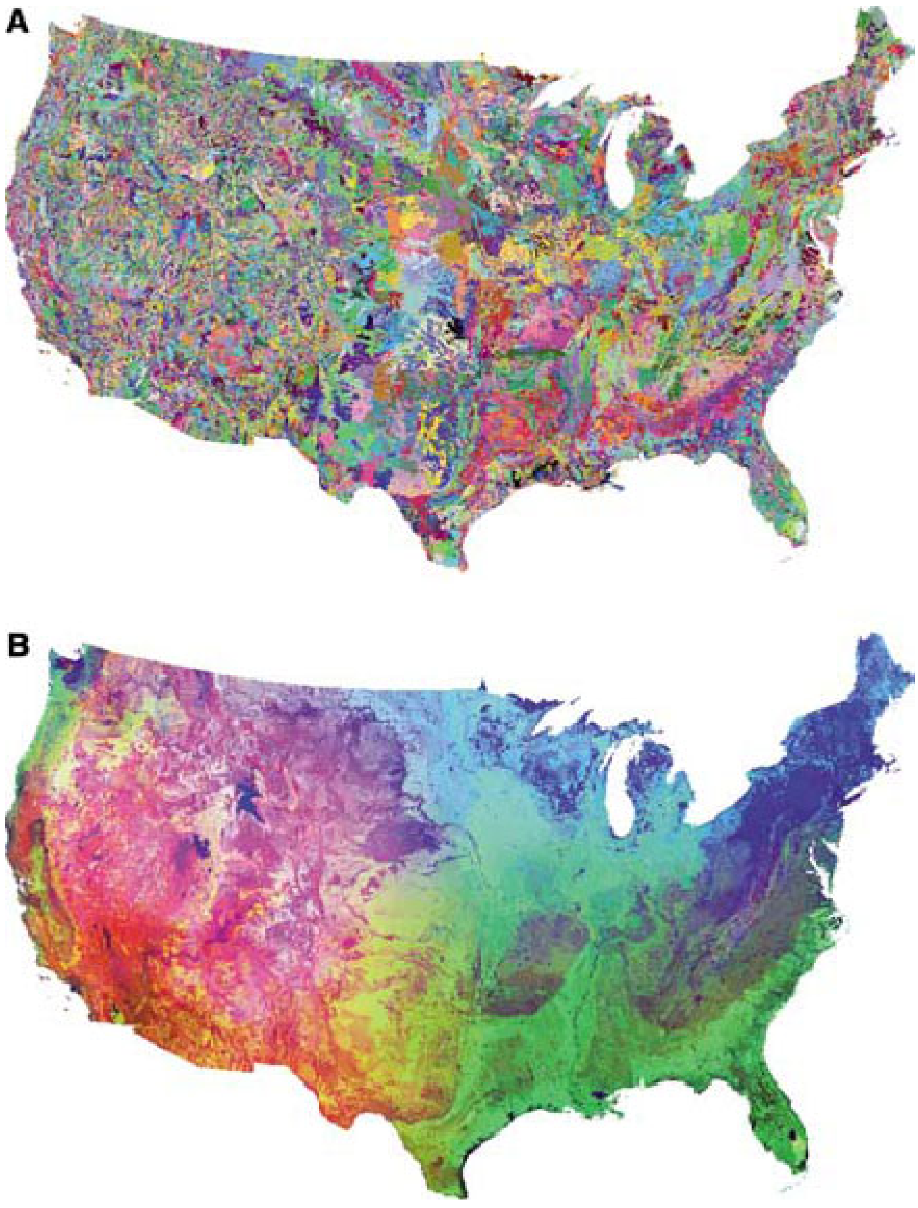


Figure 4 American Quantitative Ecoregions (Hargrove and Hoffman, 2004)

Land Environments of New Zealand (LENZ)

LENZ (Land Environments of New Zealand) is an environmental classification that was built to underpin conservation and resource management issues (Leathwick et al. 2002; 2003; 2004) (Figure 5). LENZ was based on the natural relationship between the environment and species distributions. Indeed, species tend to occur in areas having similar environmental conditions. As a consequence, similar environments tend to support similar groups of plants and animals, provided they have not been substantially modifed by human activity.

LENZ exploit the species-environment relationships by identifying climatic, geologic and topographic variables that can influence the distribution of species. LENZ uses these factors to group together sites that have similar environmental conditions. Such a classification can then be used to identify sites that might have similar potential ecosystem characters, therefore similar groups of species and biological interactions and processes.

One of the objectives is to map the potential character of different sites instead of its true realisation through the present land cover mapping, allowing to explore what should be the natural ecosystems where it has been modified by human activities.

Even though LENZ was developed for biodiversity and conservation planning it can be applied in many more types of applications because the environmental factors used to define LENZ are the same factors that guide human activities such as agriculture, tourism or forestry. LENZ are the central part of the information pyramids system developed in New Zealand and that can be exported in any other country (Overton et al. 2002).

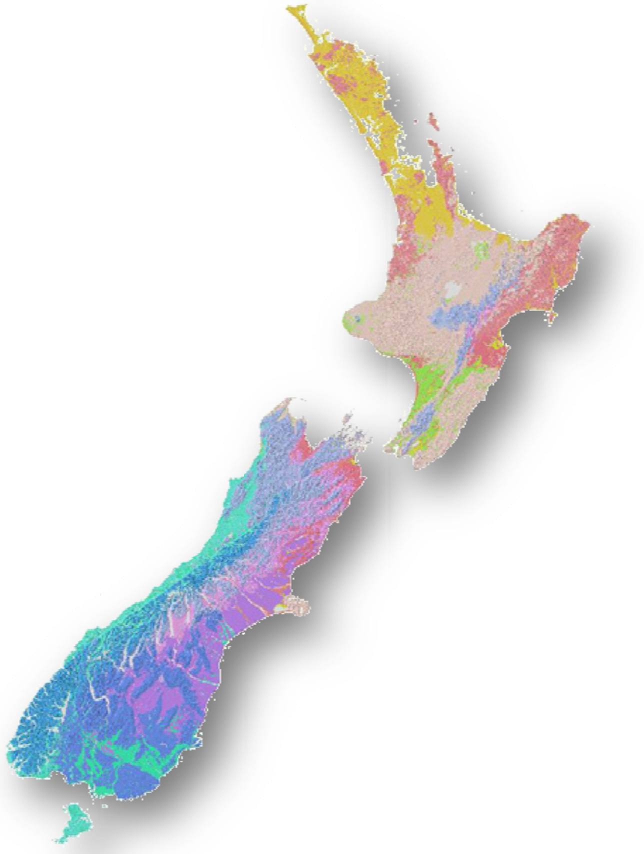


Figure 5 Land Environments of New Zealand level 1 (20 groups) (Leathwick et al. 2002; 2003; 2004) LENZ: www.landcareresearch.co.nz/databases/LENZ/about.asp)

Landscapes of Europe (LANMAP2)

LANMAP2 is the product of decisions made at European level in 1995 by the ministers for the Environment who decided on the Pan-European Biological and Landscape Diversity and Strategy (PEBLDS) to enhance the importance of nature and landscapes (Council of Europe, UNEP and ECNC).

The PEBLDS strategy enclosed the establishment of a Pan-European Landscape Map, development of landscape assessment criteria and a SWOT analysis of European landscapes. Therefore an initiative was started by Alterra in 2002 to produce a Pan-European landscape classification, giving the fact that existing approaches fall short of using state-of-the-art technology. The new LANMAP2 classification should provide a practical and easy tool for European policy implementation (Mücher et al., 2003; Metzger et al., 2005) (Figure 6). Important applications are integrated environmental assessment, monitoring and reporting, and especially indicator-based approaches such as now being used in various projects.

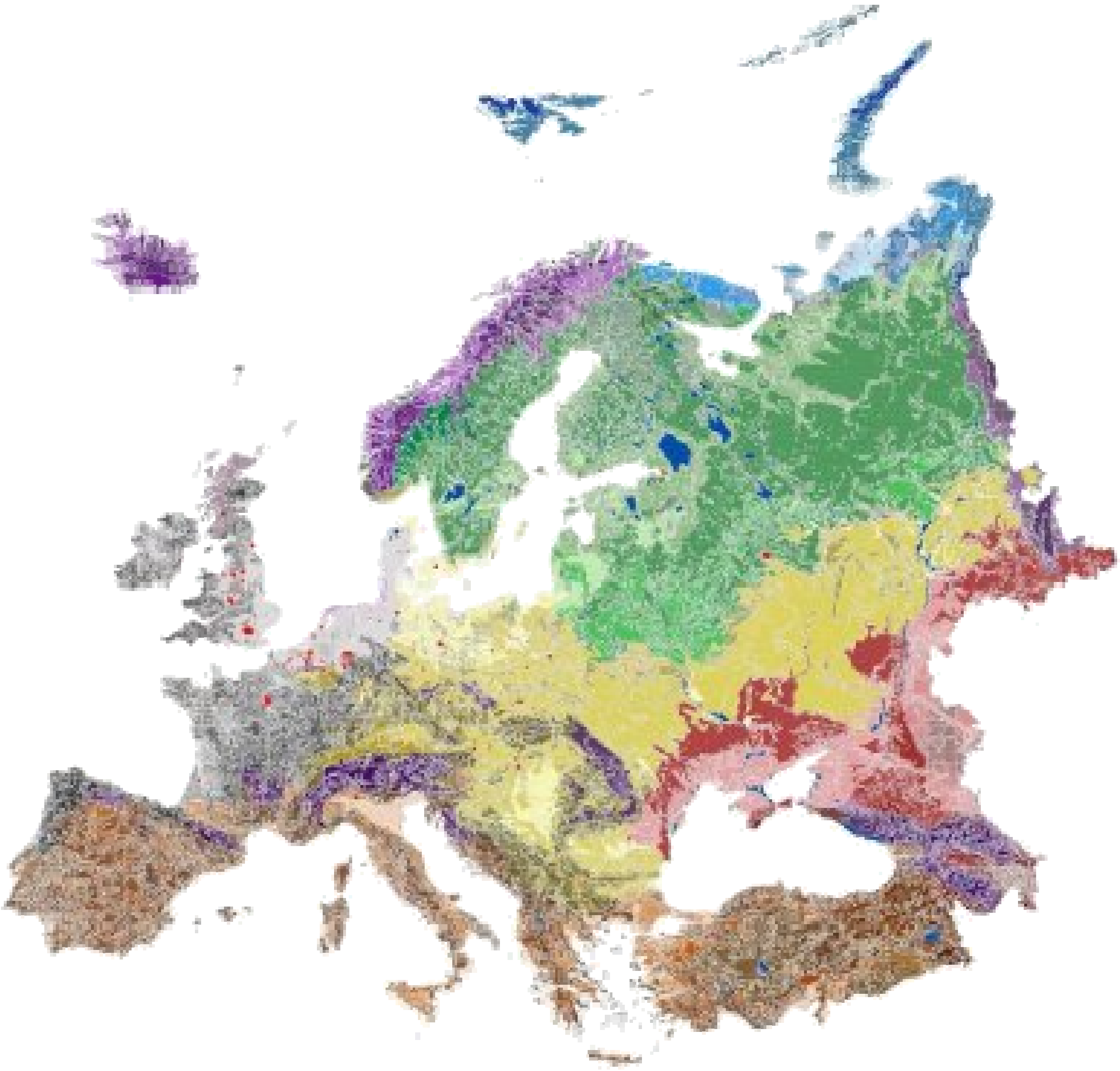


Figure 6 Landscapes of Europe level I (LANMAP2) (www.alterra.wur.nl/UK/research/Specialisation+Geo-Information/Projects/LANMAP2)

Selection of variables, transformation and weighting in New Zealand

New Zealand legislation invokes ecosystem-based management by requiring the management of resources according to "the life supporting capacity'" of the environment. For instance, the management of water resources is carried out at the regional level by regional councils. Regional councils can develop regional water plans to establish objectives and criteria for water management. Regional water planning has been problematic, and their objectives have been criticized as too broad and not sufficiently quantified. The lack of ecologically relevant management units has prevented regional water plans from fulfilling their intended function. The River Environment Classification was introduced as a means of defining units for assessment and management to support regional water management planning (Figure 7).

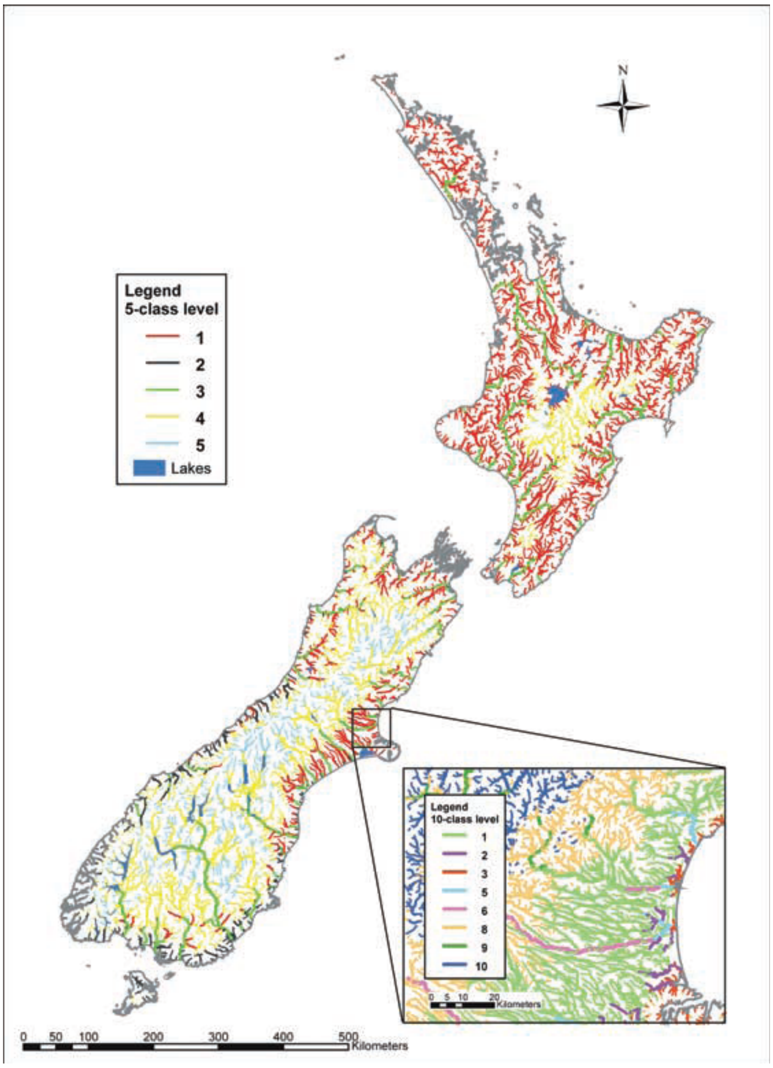


Figure 7 Classification with Selection of variables, Transformations, and Weightings (SWT) at the 5-class and 10-class (smaller region) levels.

Multivariate classifications of environmental variables are now increasingly used as frameworks for environment management. The choice of input variables has been subjective in most previous studies. In New Zealand, Mantel tests were used on a limited set of sites for which biological data were available to appropriately transform and weight environmental variables in order to maximize the correlation with the same sites described in a biological space (Snelder et al. 2007). The procedure was used to select input variables for a classification of New Zealand’s rivers that discriminates variation in fish communities for biodiversity management. A similar approach was used to define the Marine Ecological Classification for the New Zealand economic zone (Snelder et al. 2006) (Figure 8).

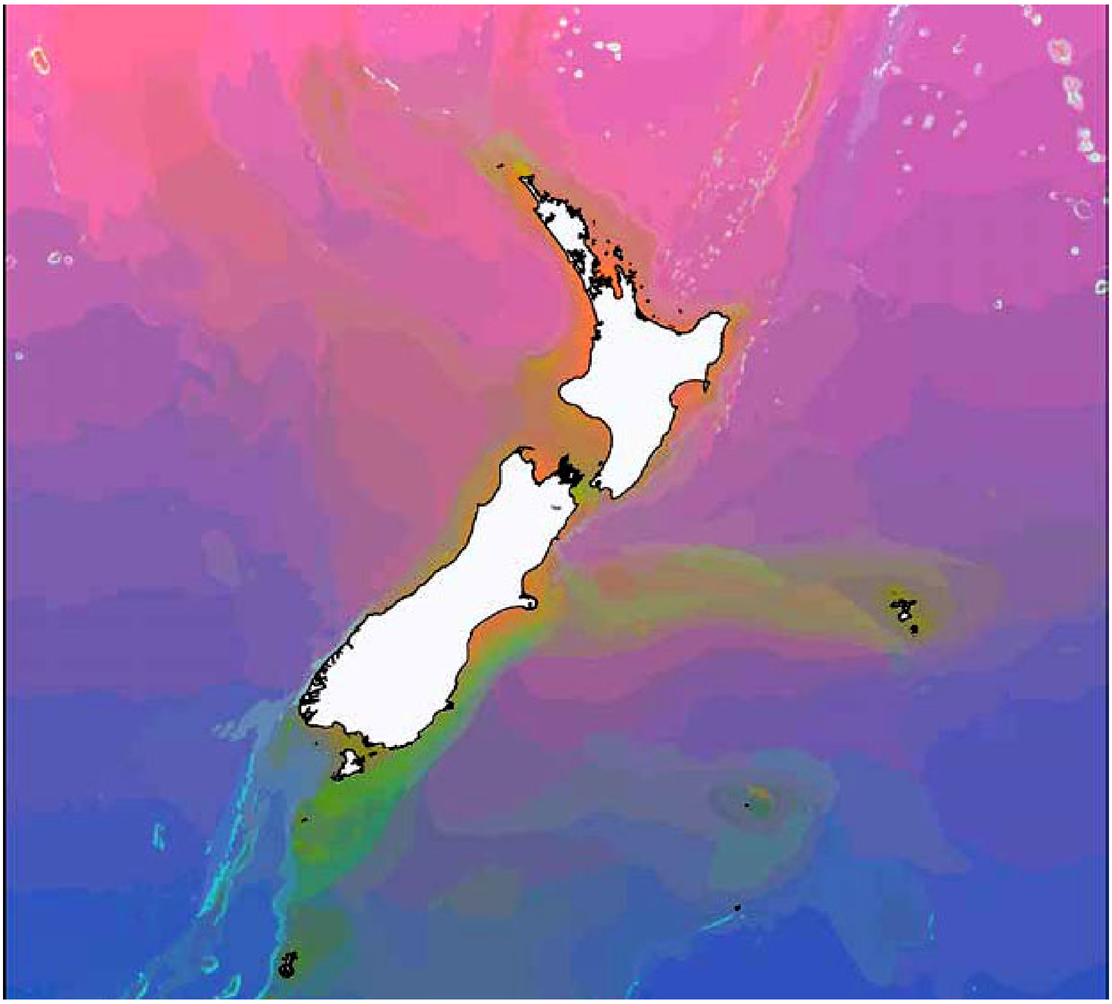


Figure 8 Map of the most detailed level (290 classes) of the Marine Ecological Classification for the New Zealand region using a continuous color scheme (Snelder 2007).

Australian dissimilarities (GDM)

The most evolved approach to environmental classification is probably the Generalized Dissimilarity Modelling (GDM) that is a statistical technique for analysing and predicting spatial patterns of community composition across large regions (Figure 9). The approach is designed to accommodate nonlinearities commonly found in large-scaled ecological data sets. GDM can also accommodate information on phylogenetic relationships between species and information on barriers to dispersal between geographical locations. The approach is able to serve various applications such as the description of spatial patterns in community composition, environmental classification, distributional modelling of species or community types, survey gap analysis, conservation assessment, and climate-change impact assessment (Ferrier et al. 2007).

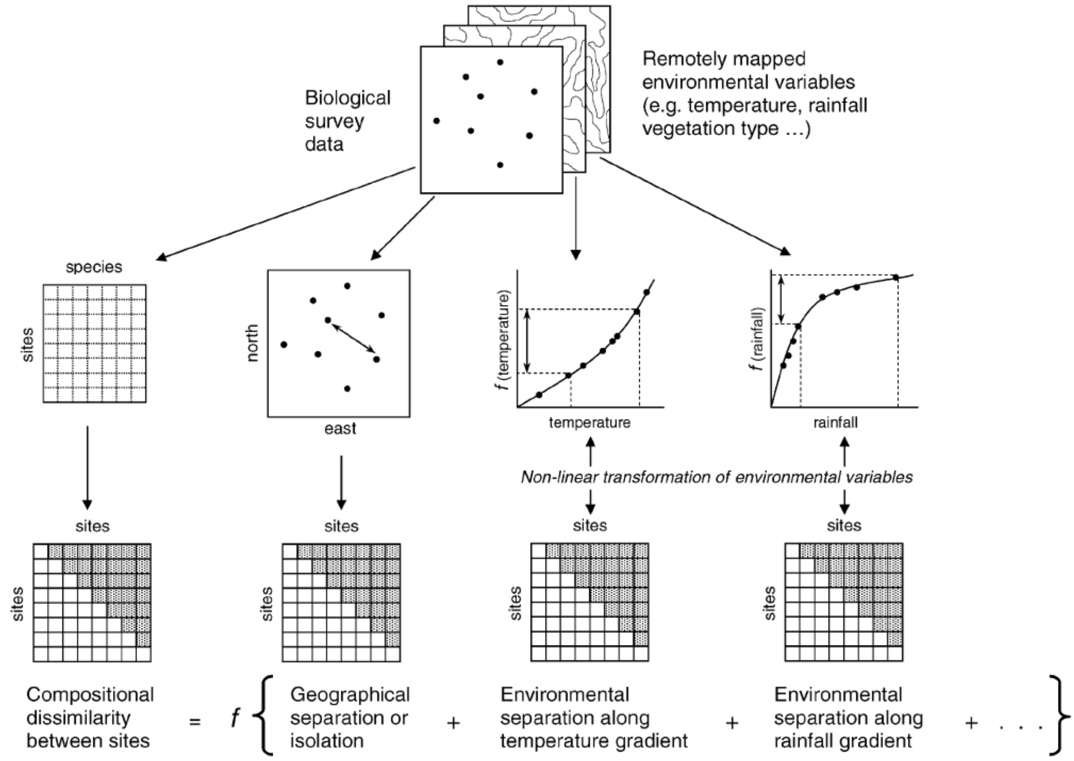


Figure 9 A diagrammatic illustration of the GDM approach to modelling compositional dissimilarity (Ferrier et al. 2002, 2007)

Project objectives

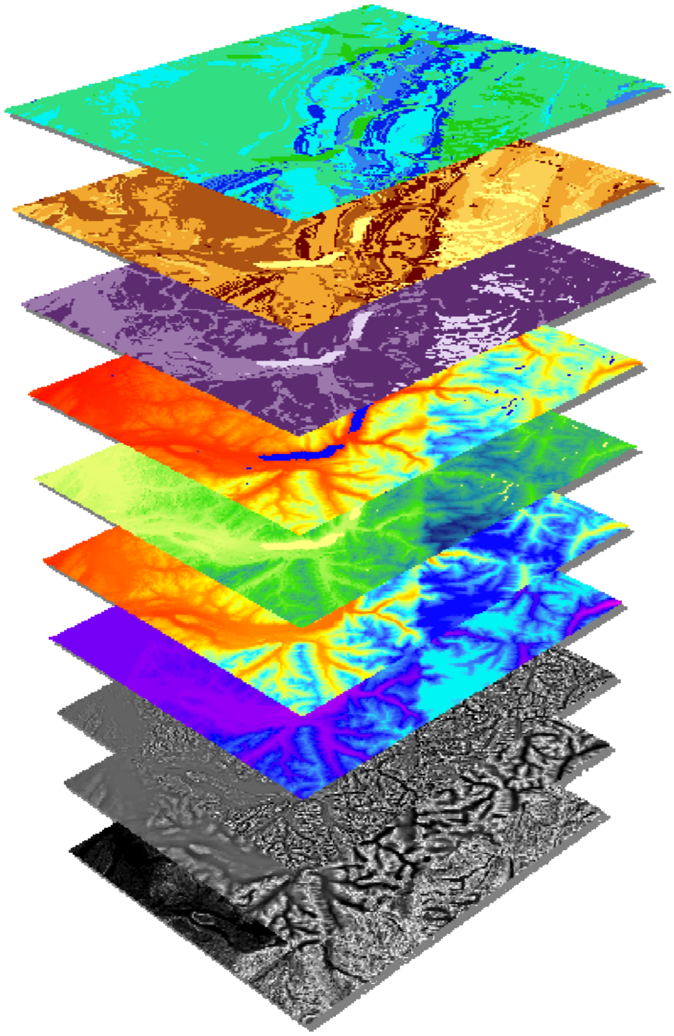
The state-of-the-art presented above show a clear evolution in building environmental classifications that has followed several steps and progresses:

1. Simple classifications of environmental variables;
2. Classification of spatial predictions of biological data;
3. Classification of transformed and weighted variables according to targeted biological data;
4. Modelisation of species dissimilarity according to dissimilarities in various environmental spaces.

In the context of the previous efforts that were developed in different countries and across continents, the present study is following a simple classification of environmental variables by adapting it to the Swiss context in order to:

- create a Swiss Environmental Domains classification (SwissED) at four different levels (10, 25, 50 and 100 groups) at a 25m resolution;
- explore the use of SwissED to represent land cover statistics.

Definition of the environmental space



Swiss environmental domains were defined on the base of nine carefully selected environmental variables that can be grouped in three categories: climate, geology and topography variables.

Together, these nine variables define the environmental space in which the Swiss domains were classified in order to group together pixels that share similar environmental conditions and are therefore situated close to one another in the environmental space. Swiss Environmental Domains can be defined as unique combinations of key parameters describing the environment.

The parameters were prepared in raster format at a resolution of 25m. Each parameter was equally weighted in the classification. This choice was made in order not to favour any particular interpretation of the domains and rather to define a "universal" classification.

Climate estimates are derived from mathematical surfaces fitted to long-run average climatic data (Zimmermann et al. 1999).

Inspired by the previous work done by Jacques Ayer (University of Neuchâtel), lithologies have been extracted from the geotechnical map of Switzerland (provided by the "Schweizerische Geotechnische Kommission SGTK" and reclassified into CaCO3 and permeability gradients with the help of Prof. Mario Sartori at University of Geneva.

Slopes and Topographic Position Index are calculated from the Digital Elevation Model at 25m resolution provided by Swisstopo. A useful extension developed for Arcview 3.2 provided by Jenness Enterprises (www.jennessent.com) calculates Topographic Position Index (TPI) grids from Digital Elevation Models.

Finally, nine 25m-resolution grids were selected to develop a general purpose classification adapted to Switzerland:

- 3 climate variables: Mean Annual Temperature, Minimum Annual Temperature, Mean Growing season Moisture Index,
- 3 geology variables: CaCO3 gradient, Permeability gradient, Age, and
- 3 topographic variables: Slope, Topographic Position Index at small scale (500m), Topographic Position Index at large scale (2000m).

Climate variables

Mean Annual Temperature

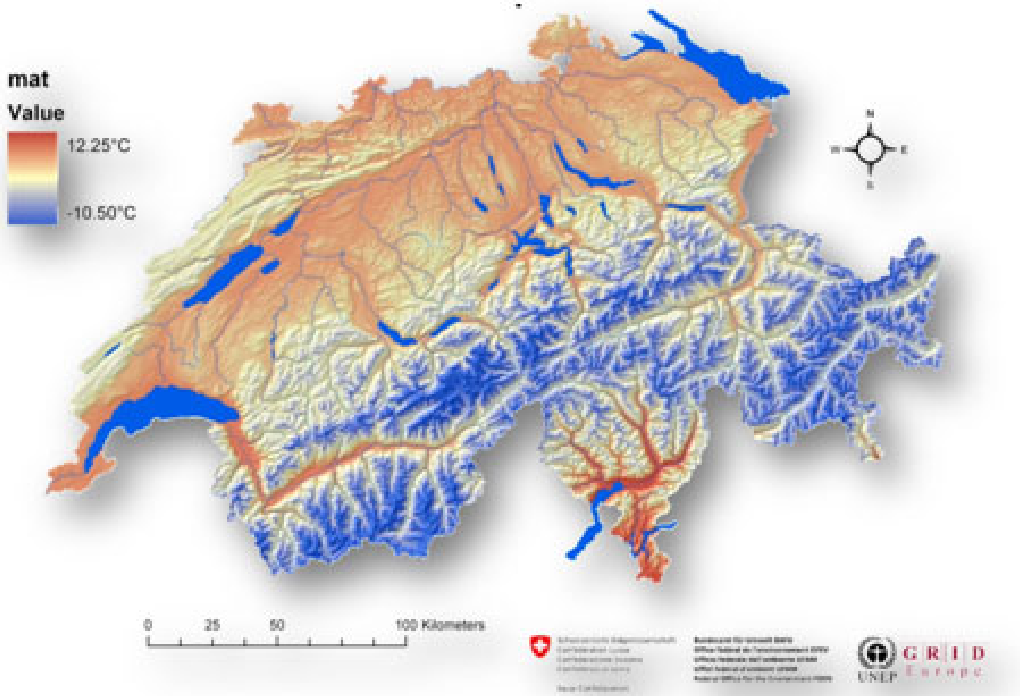


Figure 10 Mean Annual Temperature

Climate maps were generated by using data from meteorological recordings and a digital terrain model to spatially interpolate the climate data (Zimmermann et al. 1999).

Meteorological data were derived from the national network with recording stations at different altitudes. Long-term monthly means for average temperature (°C) for the period 1961-1990. For temperature 158 were used for interpolation.

Source: WSL, Resolution:25m

Period: 1961-1990, Method: interpolation

Minimum Annual Temperature

Figure 11 Minimum Annual Temperature

Climate maps were generated by using data from meteorological recordings and a digital terrain model to spatially interpolate the climate data (Zimmermann et al. 1999).

Meteorological data were derived from the national network with recording stations at different altitudes. Long-term monthly minimum of temperature for the period 1961-1990 observed in 158 stations were used for interpolation.

Source: WSL, Resolution: 25m

Period: 1961-1990, Method: interpolation

Mean Growing season Moisture Index

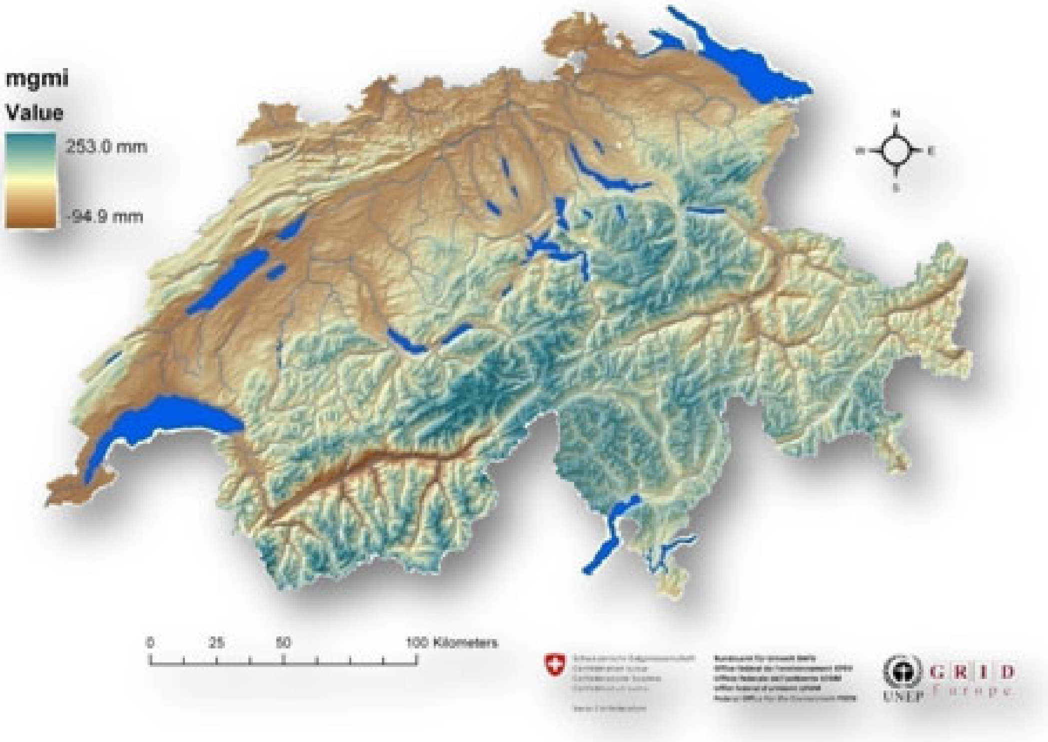


Figure 12 Mean Growing season Moisture Index

Climate maps were generated by using data from meteorological recordings and a digital terrain model to spatially interpolate the climate data (Zimmermann et al. 1999).

Long-term monthly means for precipitation and temperature were obtained for the period 1961-1990. For precipitation 365 stations were available, and 158 for average temperature. Moisture index was then calculated as the difference between precipitation and evapotranspiration on a monthly basis within the growing season from March to October.

Source: WSL, Resolution: 25m

Period: 1961-1990, Method: interpolation

Geology variables

Calcareous content

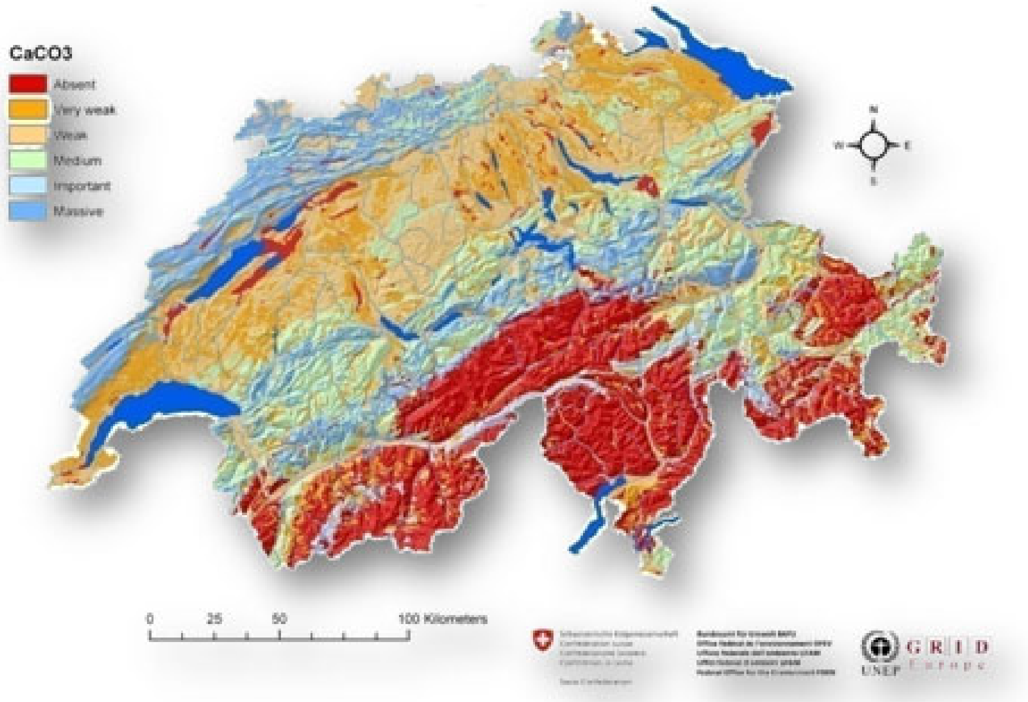


Figure 13 Calcareous content

Inspired by the previous work done by Jacques Ayer (University of Neuchâtel), lithologies have been extracted from the geotechnical map of Switzerland (provided by the "Schweizerische Geotechnische Kommission SGTK" and reclassified into CaCO3 gradient with the help of Prof. Mario Sartori at University of Geneva.

Polygon features were then rasterized at 25m resolution

Source: SGTK, Resolution: 25m

Original scale: 1:500000, date: 2000 Version 1 (V1/00)

Method: expert classification

"Digitale Geotechnische Karte (V1/00) © SGTK"

Permeability Index

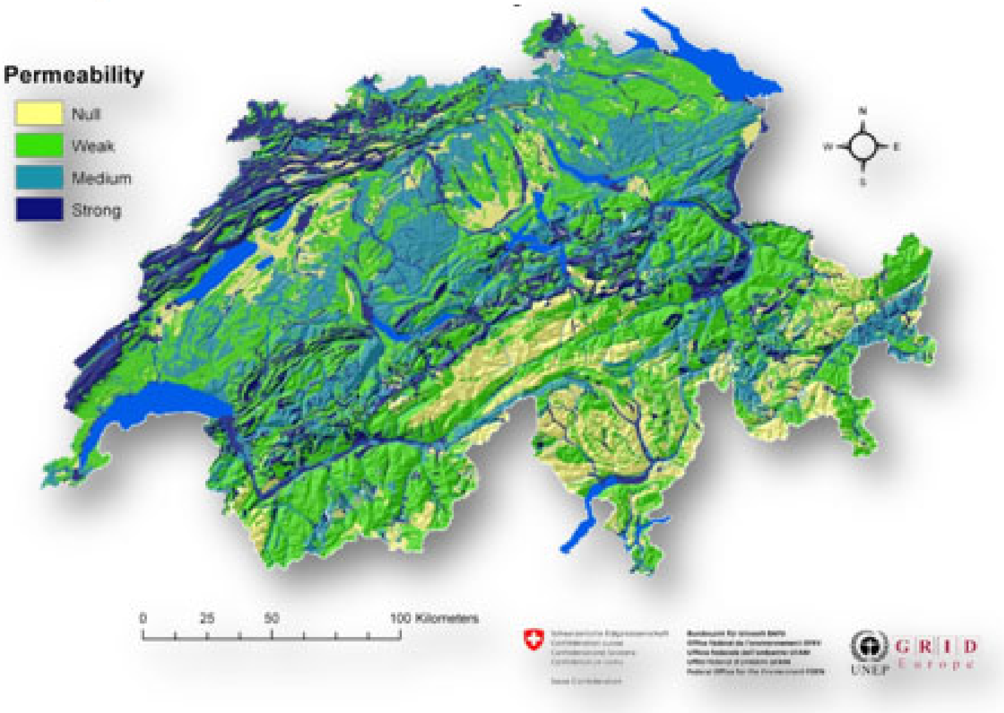


Figure 14 Permeability index

Inspired by the previous work done by Jacques Ayer (University of Neuchâtel), lithologies have been extracted from the geotechnical map of Switzerland (provided by the "Schweizerische Geotechnische Kommission SGTK" and reclassified into permeability gradient with the help of Prof. Mario Sartori at University of Geneva.

Polygon features were thenrasterized at 25m resolution

Source: SGTK, Resolution: 25m

Original scale: 1:500000, date: 2000 Version 1 (V1/00)

Method: expert classification

"Digitale Geotechnische Karte (V1/00) © SGTK"

Quaternary formation

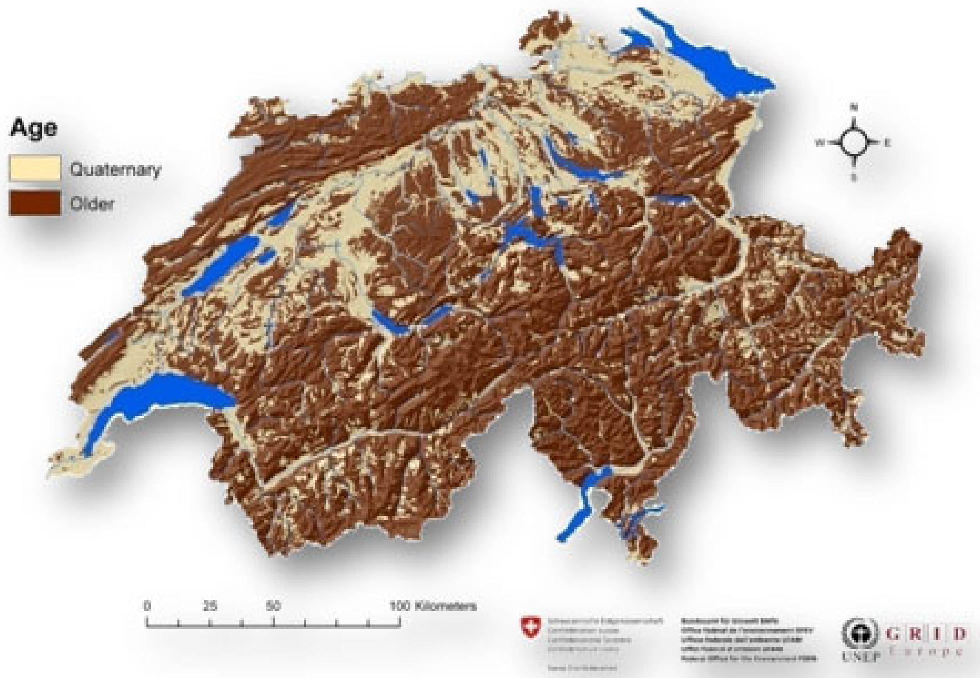


Figure 15 Quaternary formation

Age layer has been previously extracted from the geological map (GeoKarten500) provided by FOEN.

Similar but not identical polygons will introduce unnecessary complexity into the system.

Polygon features were then rasterized at 25m resolution

Age: GeoKarten 500 (GK500_v1_1)

Polygons: SGTK, Resolution:25m

Original scale:1:500000, date: 2000 Version 1 (V1/00)

Method: expert classification

"Digitale Geotechnische Karte (V1/00) © SGTK"

"GK500_V1_1 © swisstopo"

Topography variables

Slope

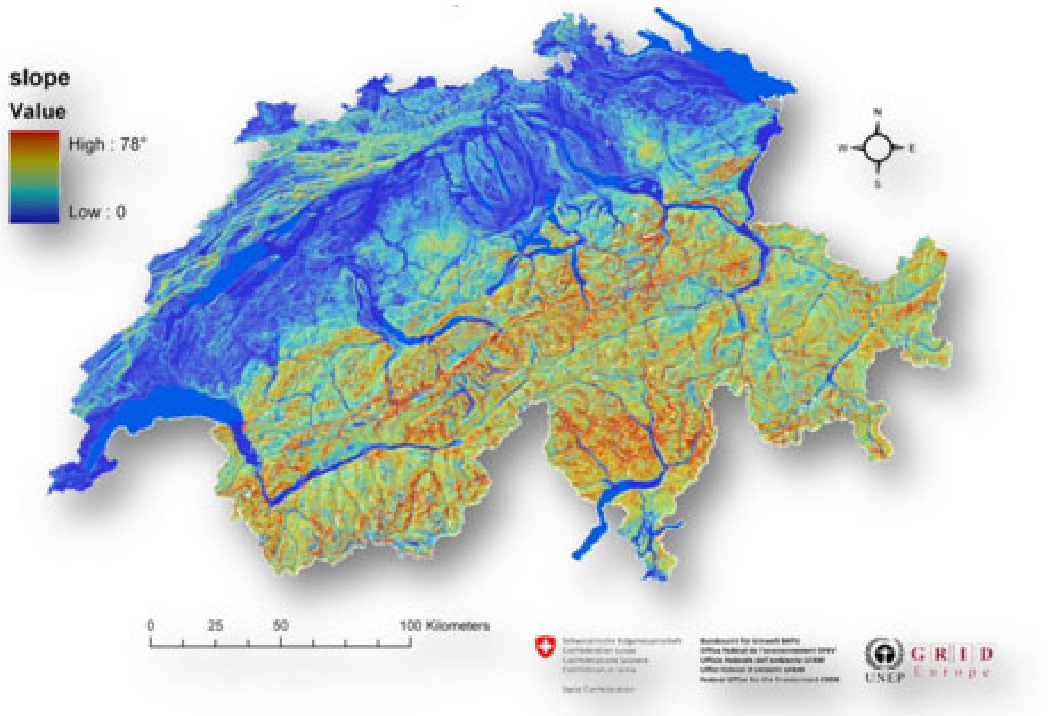


Figure 16 Slope

Slope has been derived using the extension Spatial Analyst Tools in ArcGis from the smoothed DEM.

Then a slope correction has been applied for value < 2 degree (=0) and smoothed again, as we did for the DEM.

Source: Swisstopo, Resolution: 25m

date: 2001 (last update)

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Topographic Position Index at 500m (TPI500)

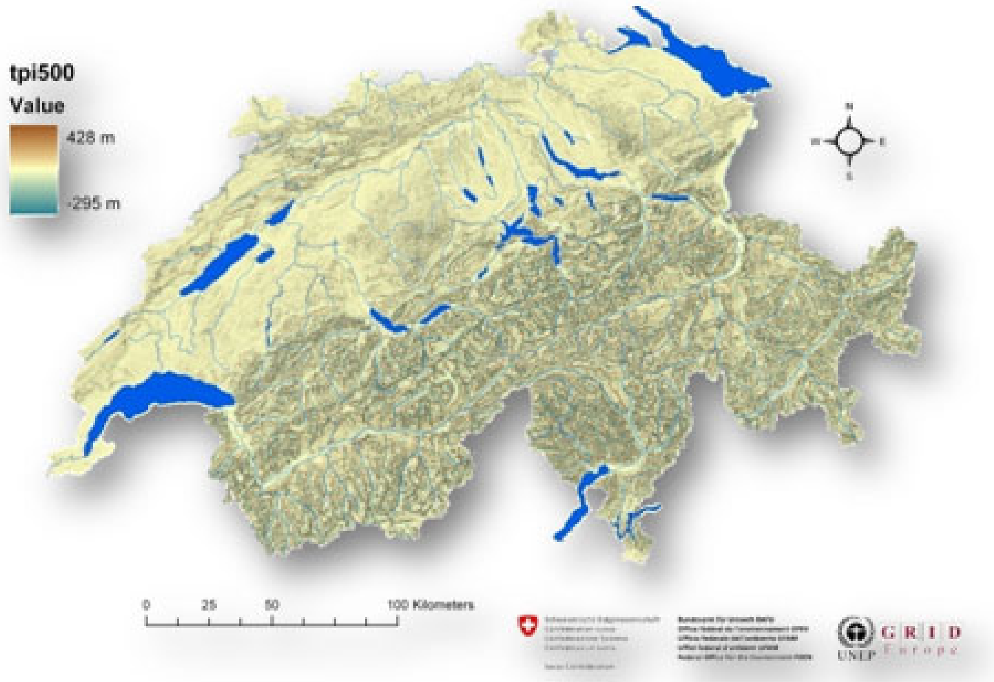

Figure 17 Topographic Position Index at 500m (TPI500)

A useful extension developed for arcview 3.2 provided by Jenness Enterprises (www.jennessent.com) calculates Topographic Position Index (TPI) grids from Digital Elevation Models.

TPI500m is the difference between the elevation of each cell of the DEM and the mean elevation of a 500m radius around that cell.

Positive values represent higher location than its surrounding (ridges) while negative values mean it is lower (valleys). Near zero value are either flat areas or areas of constant slope.

As we did for the DEM and the slope, we smoothed also the TPI grids.

Source: UNEP/GRID, Resolution:25m

date: 2001 (last update)

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Topographic Position Index at 2000m (TPI2000)

Figure 18 Topographic Position Index at 2000m (TPI2000)

A useful extension developed for Arcview 3.2 provided by Jenness Enterprises (www.jennessent.com) calculates Topographic Position Index (TPI) grids from Digital Elevation Models.

TPI2000m is the difference between the elevation of each cell of the DEM and the mean elevation of a 2000m radius around that cell.

Positive values represent higher location than its surrounding (ridges) while negative values mean it is lower (valleys). Near zero value are either flat areas or areas of constant slope.

As we did for the DEM and the slope, we smoothed also the TPI grids.

Source: UNEP/GRID, Resolution:25m

date: 2001 (last update)

"MNT25 © swisstopo (DV002234.1)"

Classification of environmental domains

The size of the input dataset covering Switzerland at a 25m resolution corresponds to 64 million pixels multiplied by 9 selected variables. This huge matrix cannot be processed by any existing statistical package to build directly a hierarchical classification from the first group composed of all pixels to 64 million unique groups composed of only one pixel. This is why the LENZ project (Leathwick et al. 2002) developed an approach in several steps:

- Pre-processing of variables
- Sampling of 500'000 random pixels
- Non-hierarchical classification of the 500'000 pixels into 120 domains
- Hierarchical classification of 120 domains centroids
- Assigning each of the 64 million pixels to the closest domain
- Principal Component Analysis of the nine variables to build RGB coloration scheme

Pre-processing

Nibbling

Different sources of data introduce some disparity between the layers such as dissimilar contour of lakes, missing values in the DEM (into the South), missing values on TPI grids (limited by the extension of the DEM). We used therefore the nibbling techniques in ArcGIS to fill the missing values with the values of the nearest neighbours according to Euclidean distance.

Masking

In order to avoid missing data on some of the nine variables, we applied the same mask to all layers to delineate the contour of Switzerland and exclude the largest lakes (Figure 10).

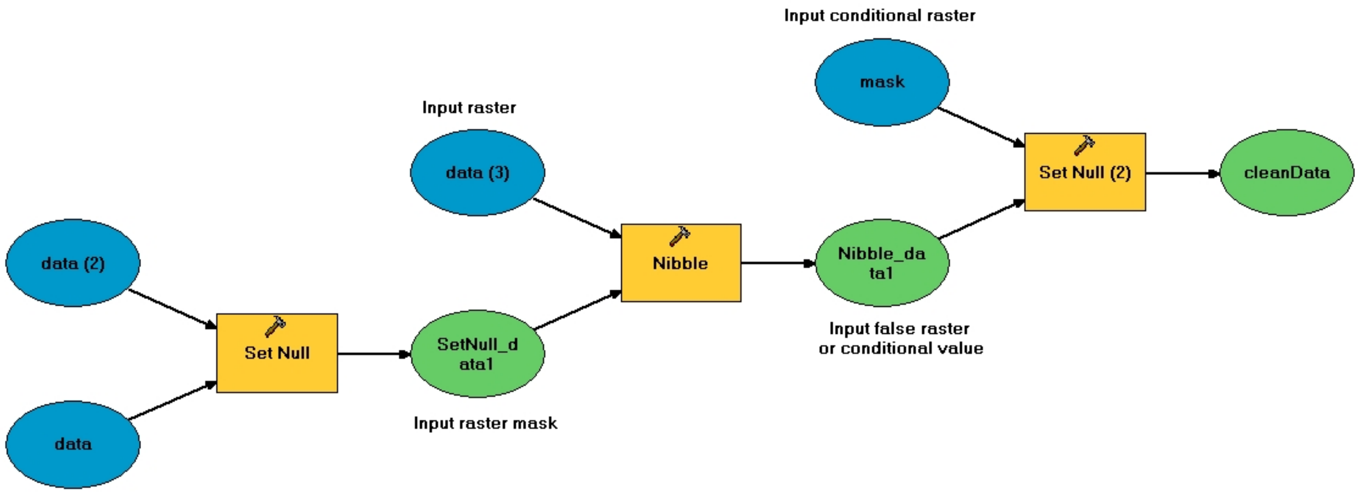


Figure 10 Cleaning model applied to all layers

Projection

The projection applied to all layer is CH1903. Projected coordinate system name: Bessel_1841_Hotine_Oblique_Mercator_Azimuth_Natural_Origin

Random sampling

As the number of pixels at a 25 m resolution is too large (64 million) to be classified at once, the classification was run on a sample of 500'000 pixels randomly selected across Switzerland and avoiding lakes and glaciers (Figure 11). The extension Hawth's Analysis Tools for ArcGIS (http://www.spatialecology.com/htools) was used to create the random sample and to extract the values of the 9 environmental raster layers under each point.

Figure 11 Map showing the distribution and density of some of the 500000 random points sampled to build the non-hierarchical and hierarchical classification.

Non-hierarchical classification

The sampled pixels are grouped into different "domains" (120 groups) calculating their similarity "distance" in the environmental space (non-hierarchical classification). This classification is performed in the PATN software (http://www.patn.com.au) that is specialized to analyze large datasets (Belbin 2001).

As recommended for larger datasets, we applied a non-hierarchical classification using Gower Metric association measures. We decided to give an equal weight and therefore an equal influence to all variables in the analysis (Figure 12). Non-hierarchical classification or clustering methods in pattern analysis are simple in concept. While hierarchical methods require all pair-wise association between objects to pre-exist, non-hierarchical methods only calculate association values on the fly between objects and group centroids. This makes non-hierarchical methods faster, and more accurate as the dataset gets larger (more objects).

PATN uses a non-hierarchical clustering method called ALOC (Belbin, 1987). It has proven to be very robust, even for millions of objects. The algorithm is simple:

1. Select the first object in the Data Table to represent one group

2. Seek through all objects looking for objects that are ‘far enough’ away (in terms of the association measure). When found, create another group. Repeat until k objects have been found. These will temporarily represent k groups
3. Allocate all objects to the closest group / object
4. Calculate the group centroids as the average of the object variables in each group
5. Remove in turn each object from its group, calculate the distances between the object and all group centroids, and place it in the closest group.
6. Repeat 5 until no object changes groups or the maximum number of iterations is exceeded.

From the PATN user manual (Belbin 2001) we find also that “the Gower Metric is most useful when equal differences between values should have the same influence on association, regardless of the absolute size of the values. For example, a two point difference high on the value scale is treated the same as a two point difference low of the scale of the variable. Gower metric is also best applied to ‘physical’ rather than biological variables. The Gower Metric has in-built range standardization; in determining the association between objects, variables will be range standardized (given equal weight) by default.”

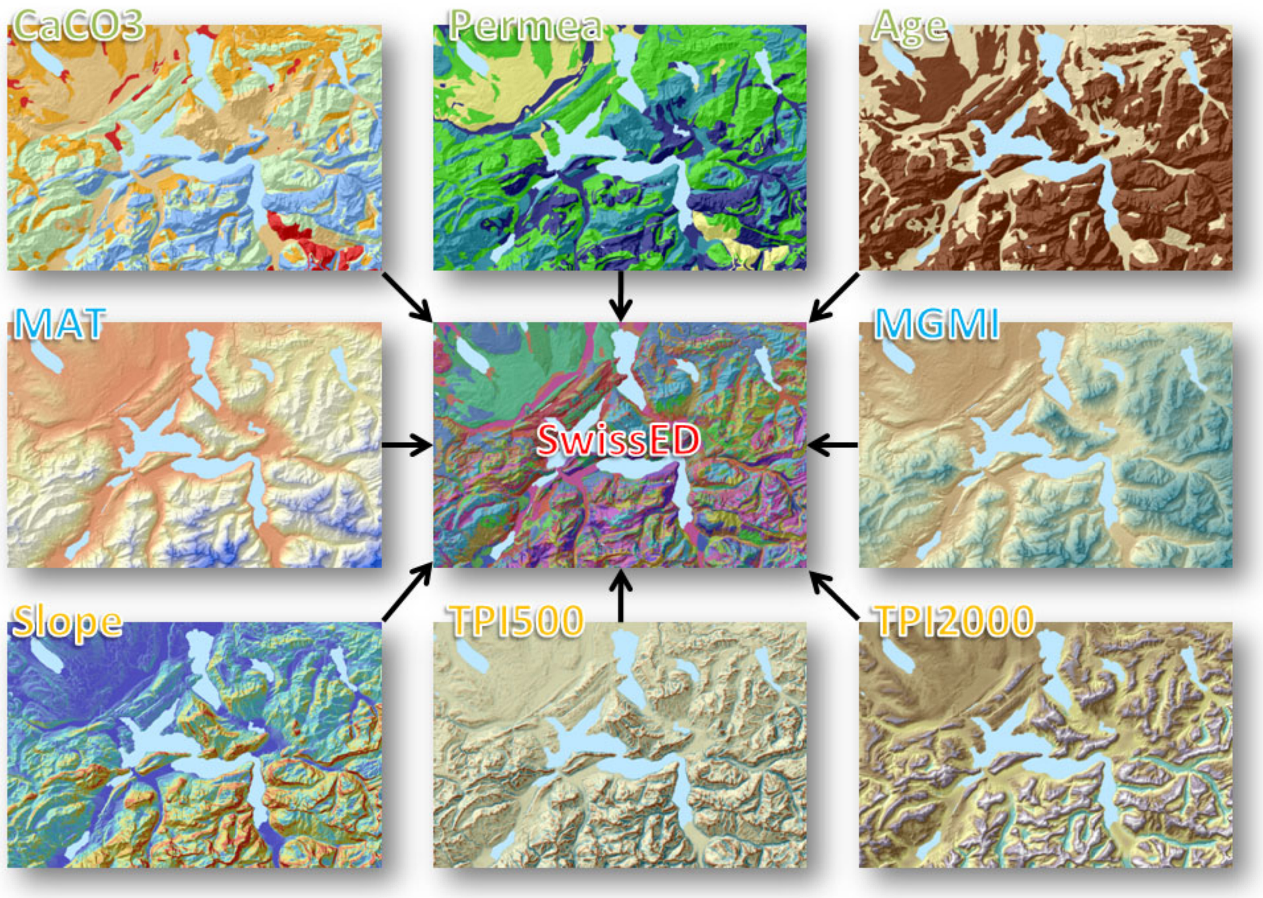


Figure 12 Each of the environmental layers contribute equally to calculate the environmental distances of each point to each domain centroid.

Hierarchical classification

Once the non-hierarchical classification has produced a reduced number of groups (here 120), it becomes possible to use an agglomerative hierarchical classification based on the centroids of these groups. Flexible UPGMA (Un-weighted Pair Group Using Arithmetic Averaging) was used in PATN to perform this classification. This class of method iterates through the following process (Figure 13):

1. Find the pair of objects with the smallest association value (from the stored lower symmetric association matrix)
2. Fuse those two objects into a group
3. Re-calculate the associated between this new group and all other objects (or groups)
4. Repeat from 1 until all objects are in one group.

Flexible UPGMA require a beta value. Beta is a type of weighting that is used in step (3). Beta is used to control what happens to the perceived association values as the agglomeration proceeds. Beta values operate like this:

- Beta = -0.3 strongly dilates the space
- Beta = -0.1 slightly dilates the space
- Beta = 0.0 ‘conserves’ the space
- Beta = 0.1 slightly contracts the space
- Beta = 0.3 strongly contracts the space

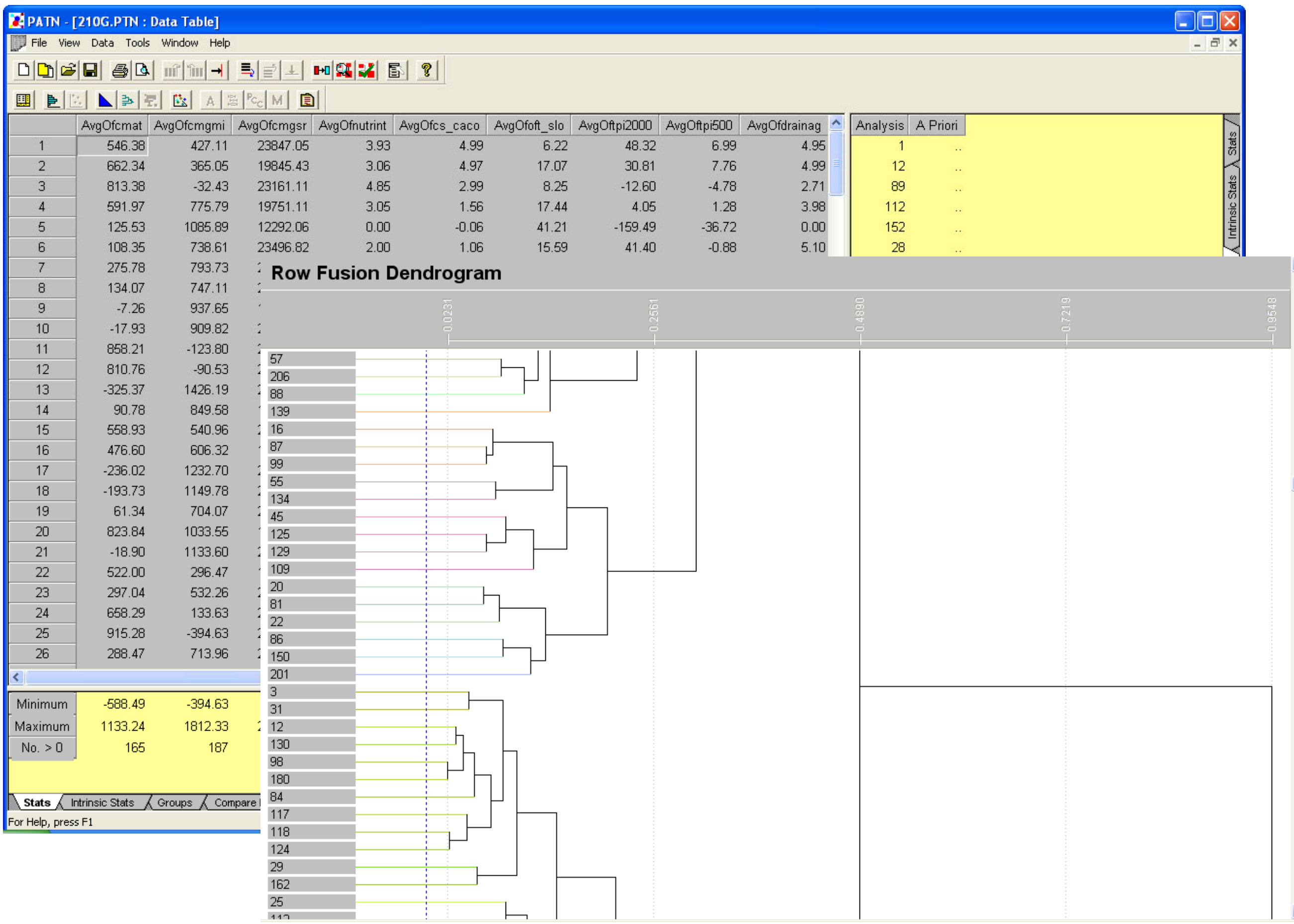
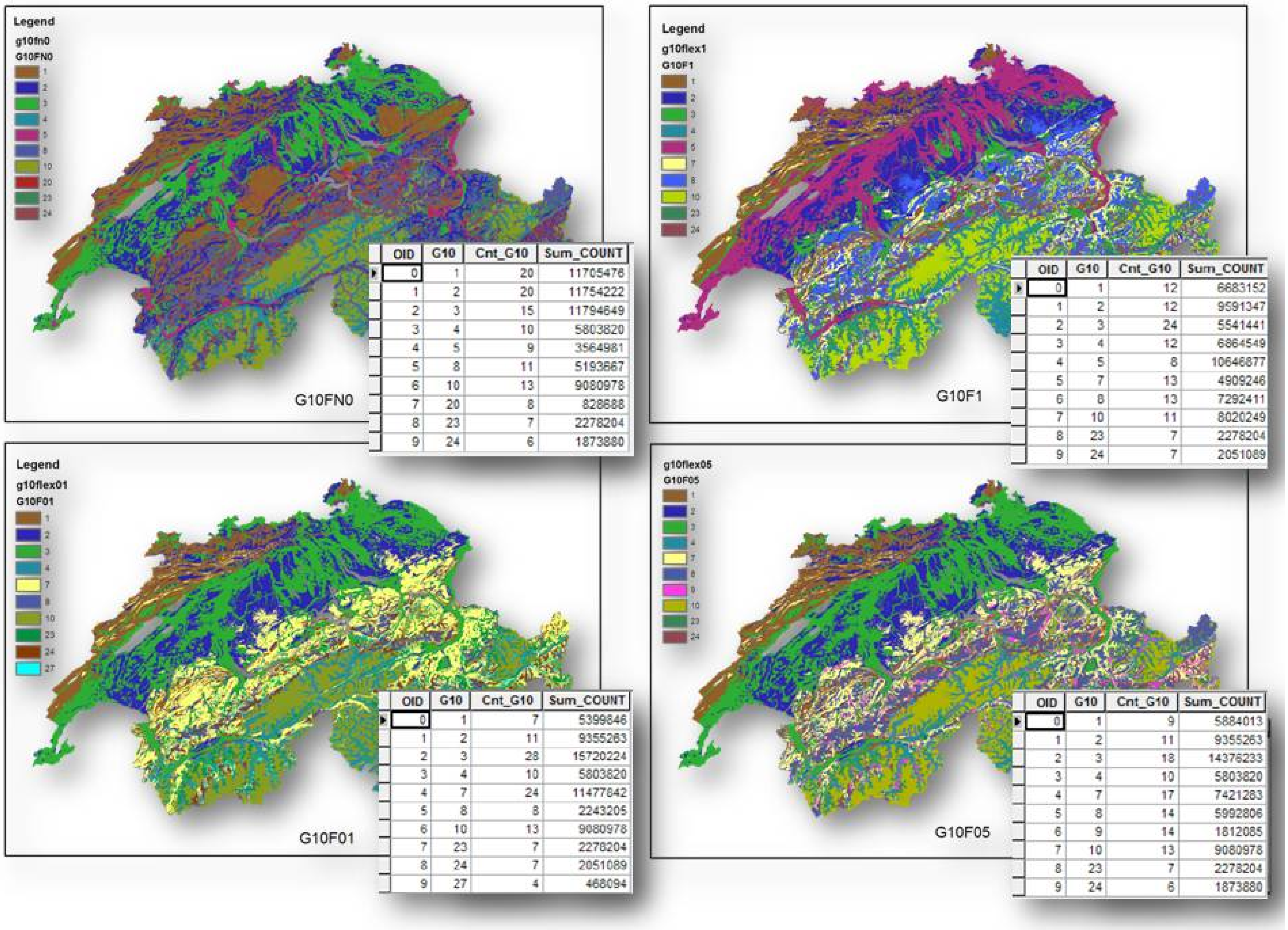


Figure 13 Example of outputs of hierarchical classification in PATN

We tested different beta values to explore what was their effect on the size of the domains. In order to obtain domain with similar sizes (number of pixels) we finally decided to use a beta value of -1 (G10F1) that was giving the most satisfactory results (Figure 14). While the default setting -0.1 (G10F01) ends up with the smallest group having approximately 468’000 pixels and the biggest 15’720’000 pixels, the chosen setting (G10F1) results in a narrower range between 2’050’000 and 10’640’000 pixels.



G10FN0

OID	G10	Cnt_G10	Sum_COUNT
0	1	20	11705476
1	2	20	11754222
2	3	15	11794649
3	4	10	5803820
4	5	9	3564981
5	8	11	5193667
6	10	13	9080978
7	20	8	828688
8	23	7	2278204
9	24	6	1873880

G10F1

OID	G10	Cnt_G10	Sum_COUNT
0	1	12	6683152
1	2	12	9591347
2	3	24	5541441
3	4	12	6864549
4	5	8	10646877
5	7	13	4909246
6	8	13	7292411
7	10	11	8020249
8	23	7	2278204
9	24	7	2051089

G10F01

OID	G10	Cnt_G10	Sum_COUNT
0	1	7	5399846
1	2	11	9355263
2	3	28	15720224
3	4	10	5803820
4	7	24	11477842
5	8	8	2243205
6	10	13	9080978
7	23	7	2278204
8	24	7	2051089
9	27	4	468094

G10F05

OID	G10	Cnt_G10	Sum_COUNT
0	1	9	5884013
1	2	11	9355263
2	3	18	14376233
3	4	10	5803820
4	7	17	7421283
5	8	14	5992806
6	9	14	1812085
7	10	13	9080978
8	23	7	2278204
9	24	6	1873880

Figure 14 Four different methods are used to test domain size :
G10FN0 = Further Neighbor; G10F01 = Beta -0.1; G10F05 = Beta -0.5; ; G10F1 = Beta -1

RGB coloring

An ingenious way to map the domains (non-continuous geographic distribution) is to create a RGB colour scheme from a Principal Components Analysis (PCA) on environmental variables where the first three axes will correspond to Red, Green and Blue bands in the resulting image.

From the results of the PCA (Figure 15), we can see that Red-Cyan axis corresponds to a temperature-moisture gradient; Green-Magenta axis corresponds to a geological gradient and Blue-Yellow axis to a topographic gradient.

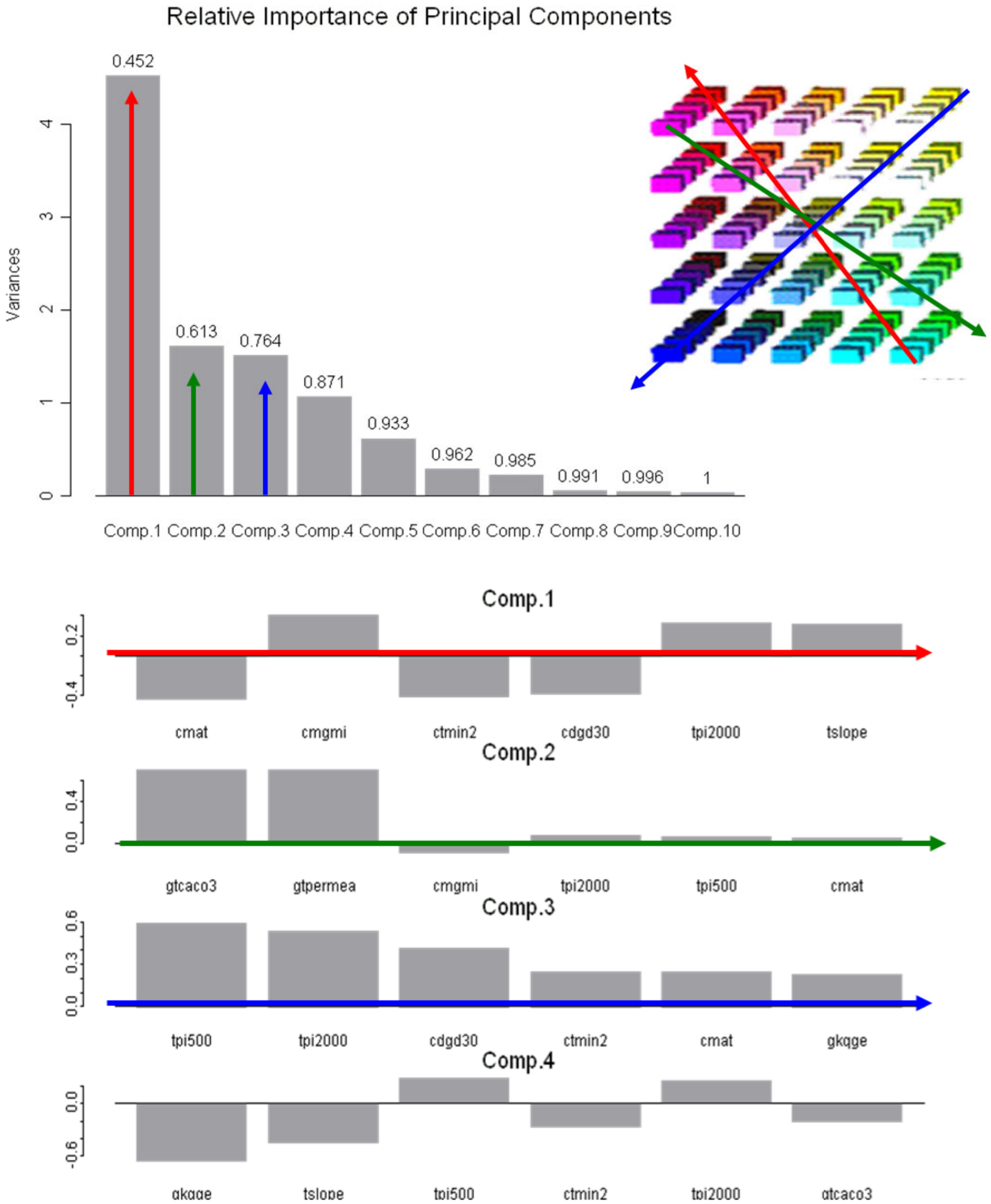


Figure 15 Results of PCA analysis on 120 domain centroids and the association of the three first axes with a color band

Reassigning domains to all pixels

A C++ code written by Landcare Research and adapted to our study was used to reassign each of the original 64 million pixels to the closest of the 120 obtained domains defined in the environmental space (

Figure 16).

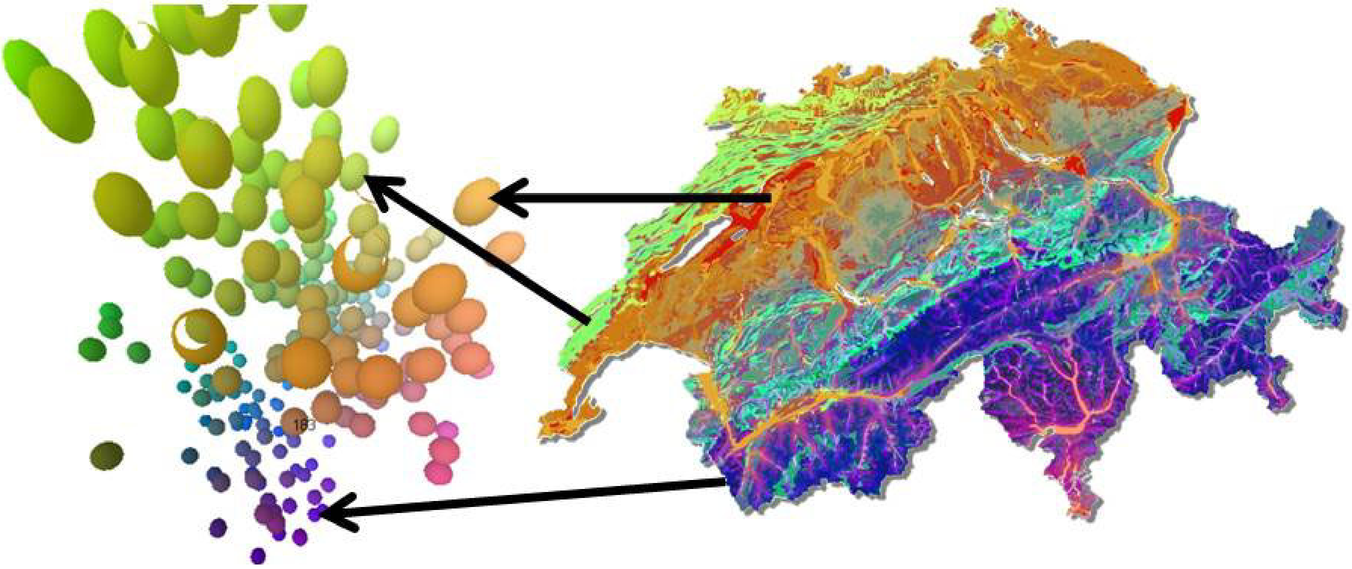


Figure 16 Reassignment of each pixel to one of the 120 domains

Levels and scales

With its hierarchical classification, SwissED was developed at four different levels (

Figure 18) that in practice correspond to different scales for which they are better suited:

- Level IV : 100 groups: 1:100’000
- Level III : 50 groups: 1: 250’000
- Level II : 25 groups: 1: 500’000
- Level I : 10 groups: 1: 2’000’000

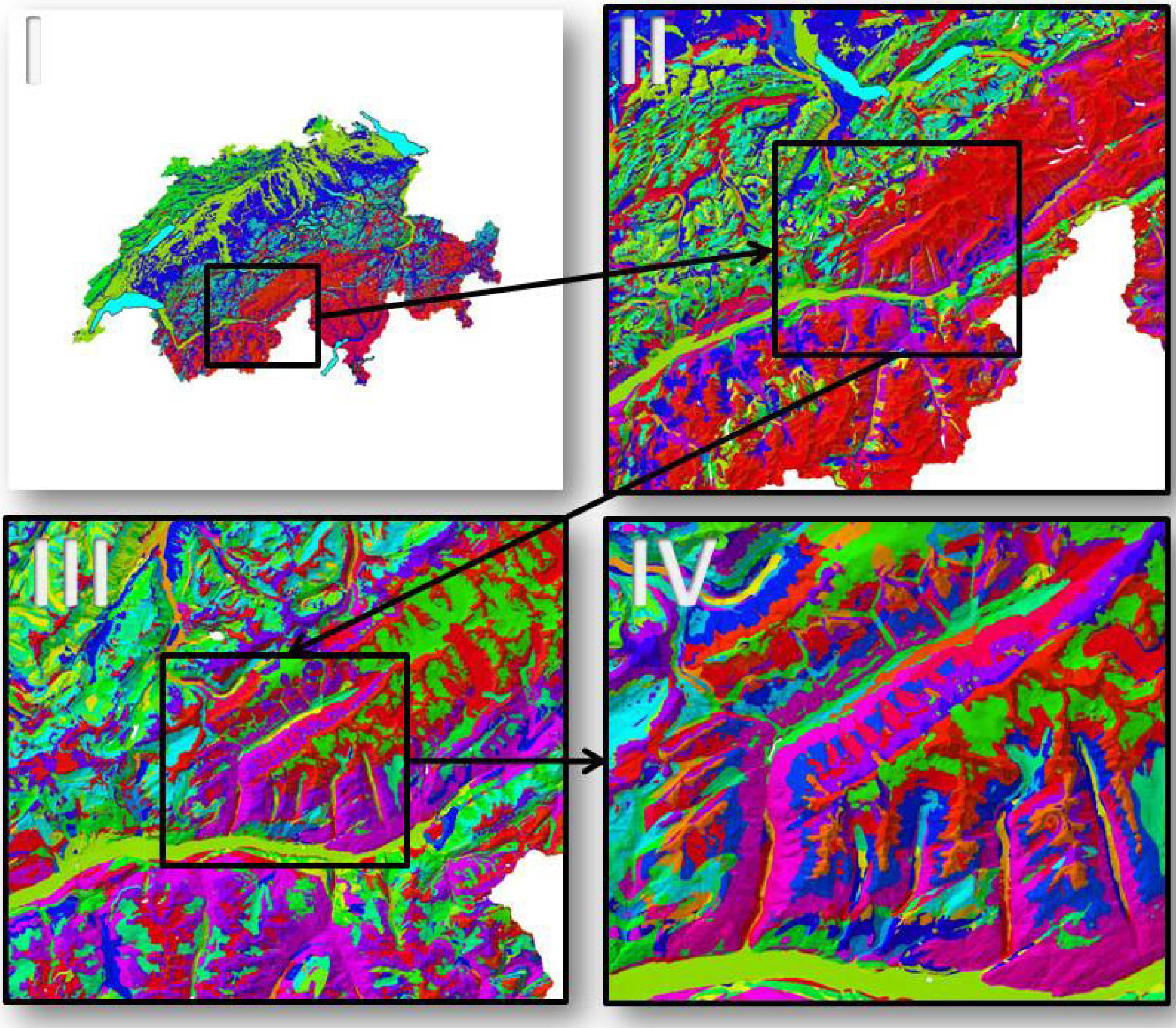


Figure 17 Relative scales at which SwissED are thought to be used from level I (1:2’000’000) to level IV (1:100’000)

If we zoom on a given region (Figure 18), we can assess the quantity of details provided by each level.

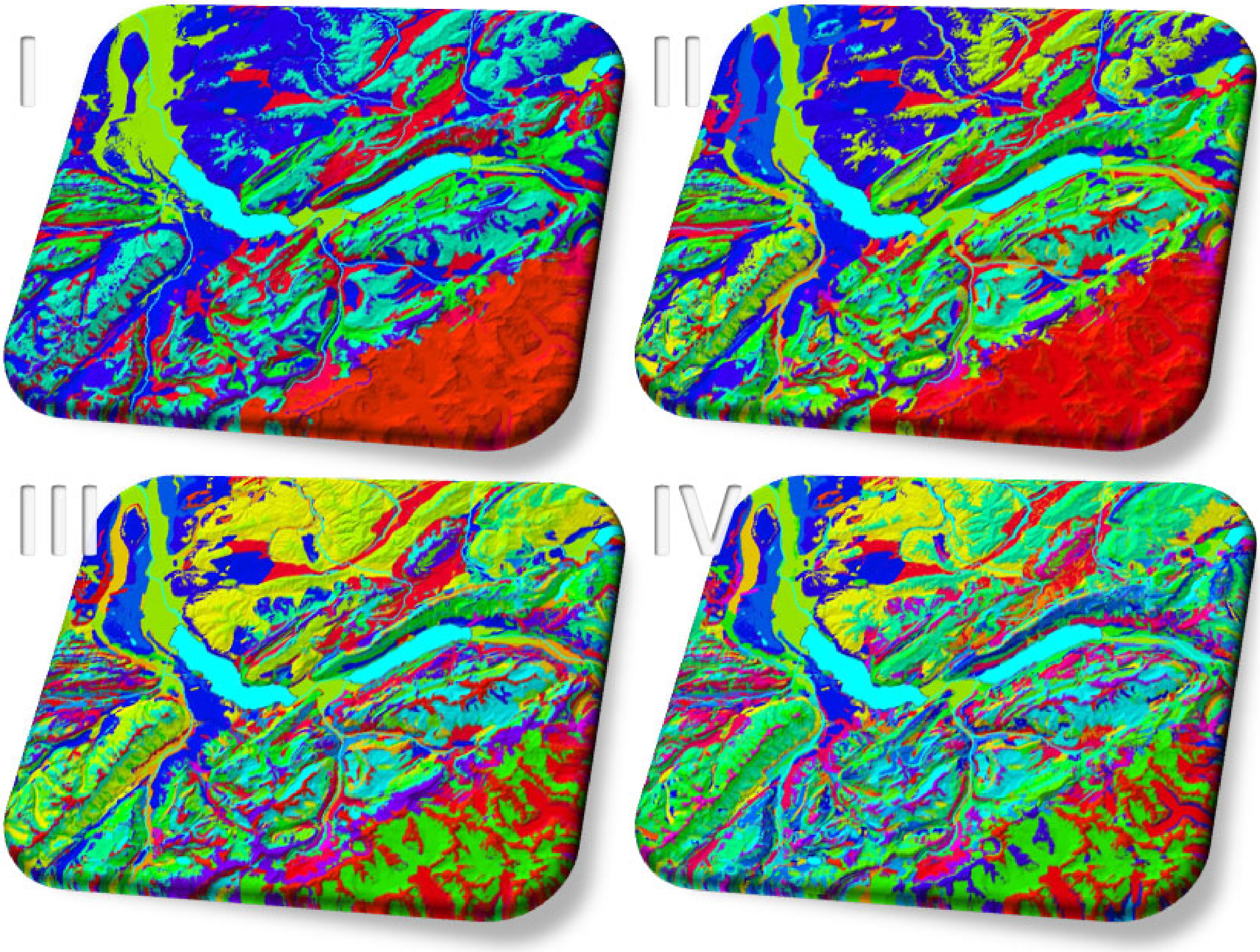


Figure 18 Zoom on the Interlaken region to visualize the amount of details provided by the 4 different levels of SwissED randomly colored.

Resulting Environmental Domains

In the following figures (19 to 22), SwissED are represented at the four different levels in order to represent first the level of details (random colors) and second the environment gradients underpinning them (RGB).

Level I: 10 groups

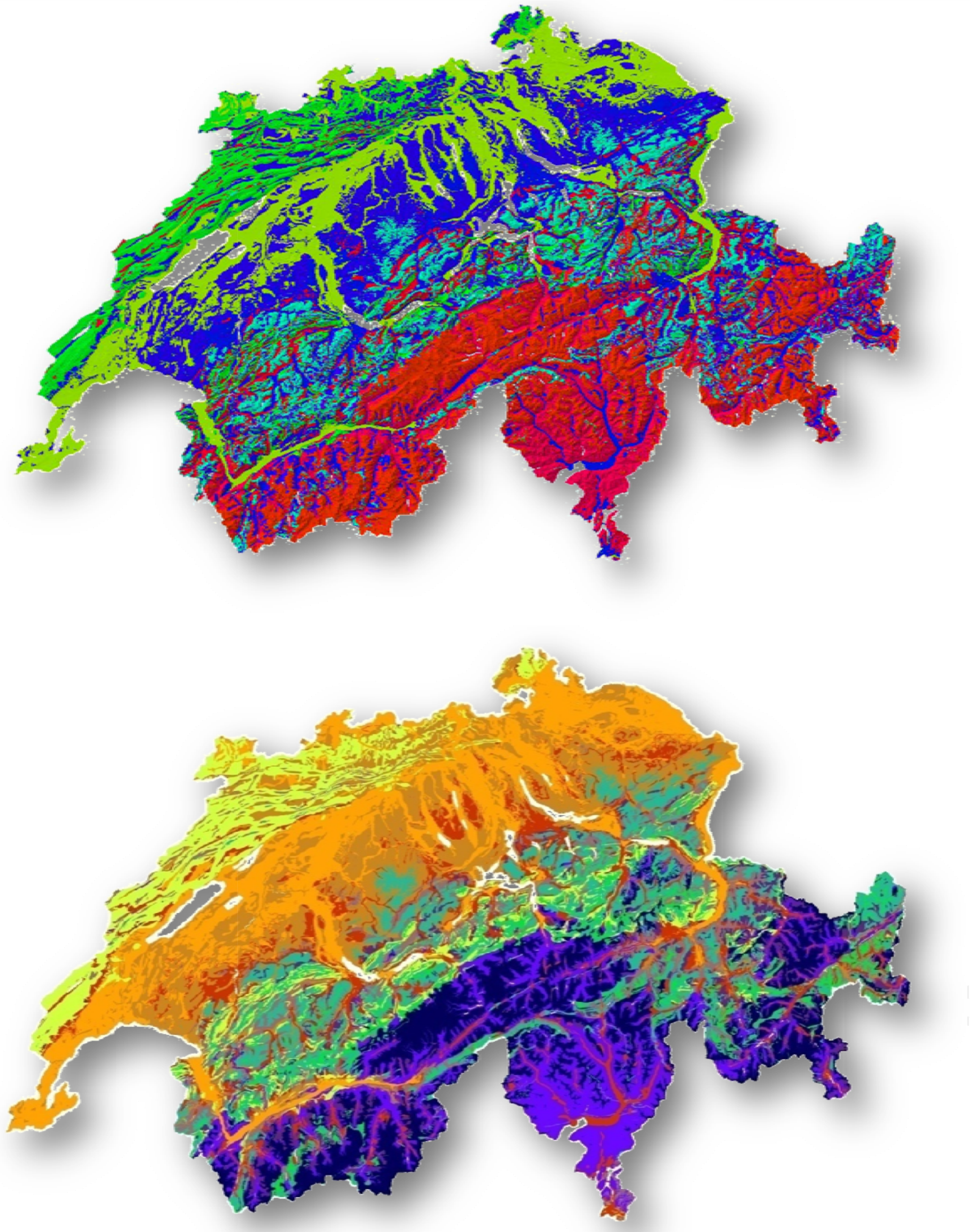


Figure 19 Randomly and RGB colored Swiss Environmental Domains at level I (10 groups)

Level II: 25 groups

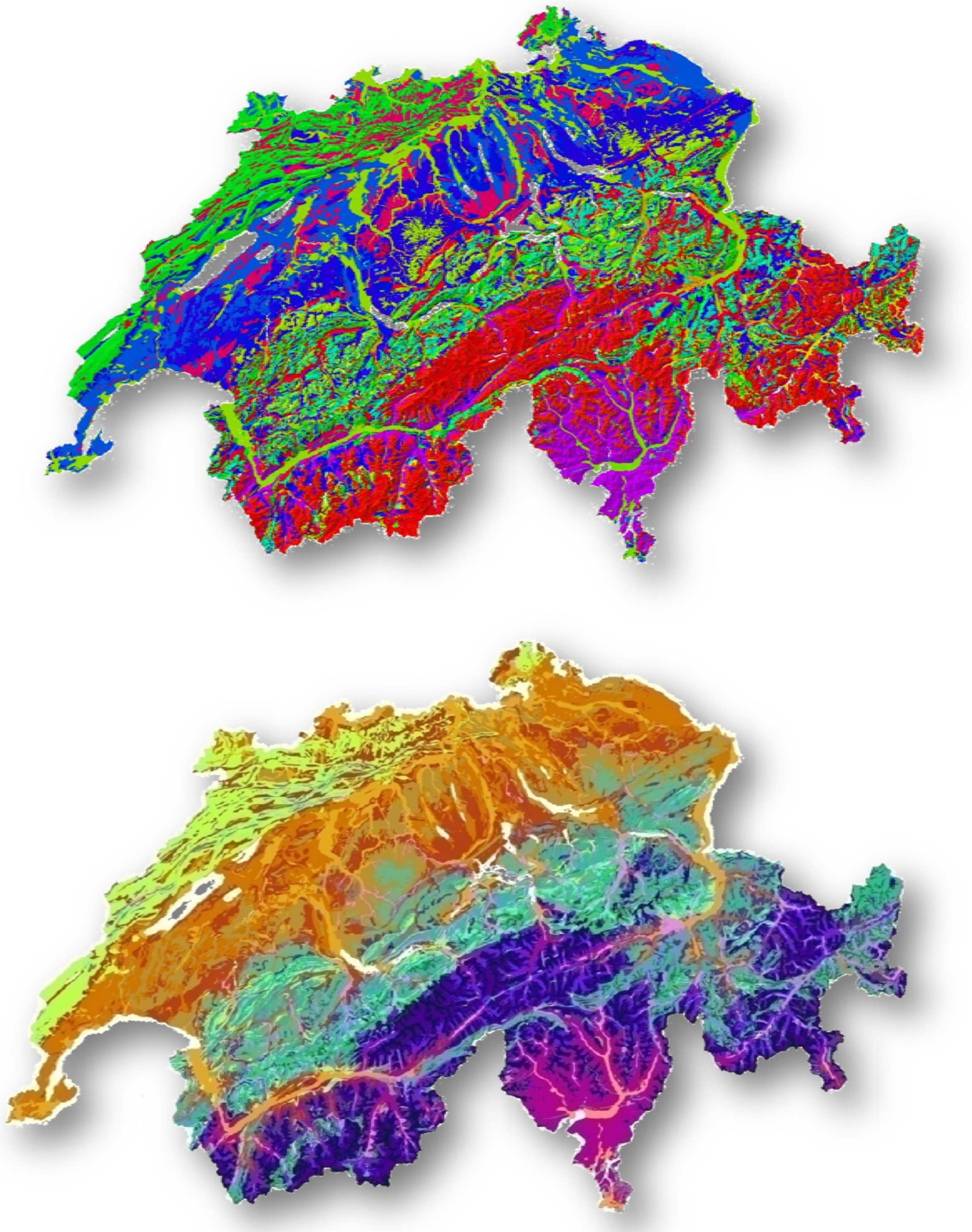


Figure 20 Randomly and RGB colored Swiss Environmental Domains at level II (25 groups)

Level III: 50 groups

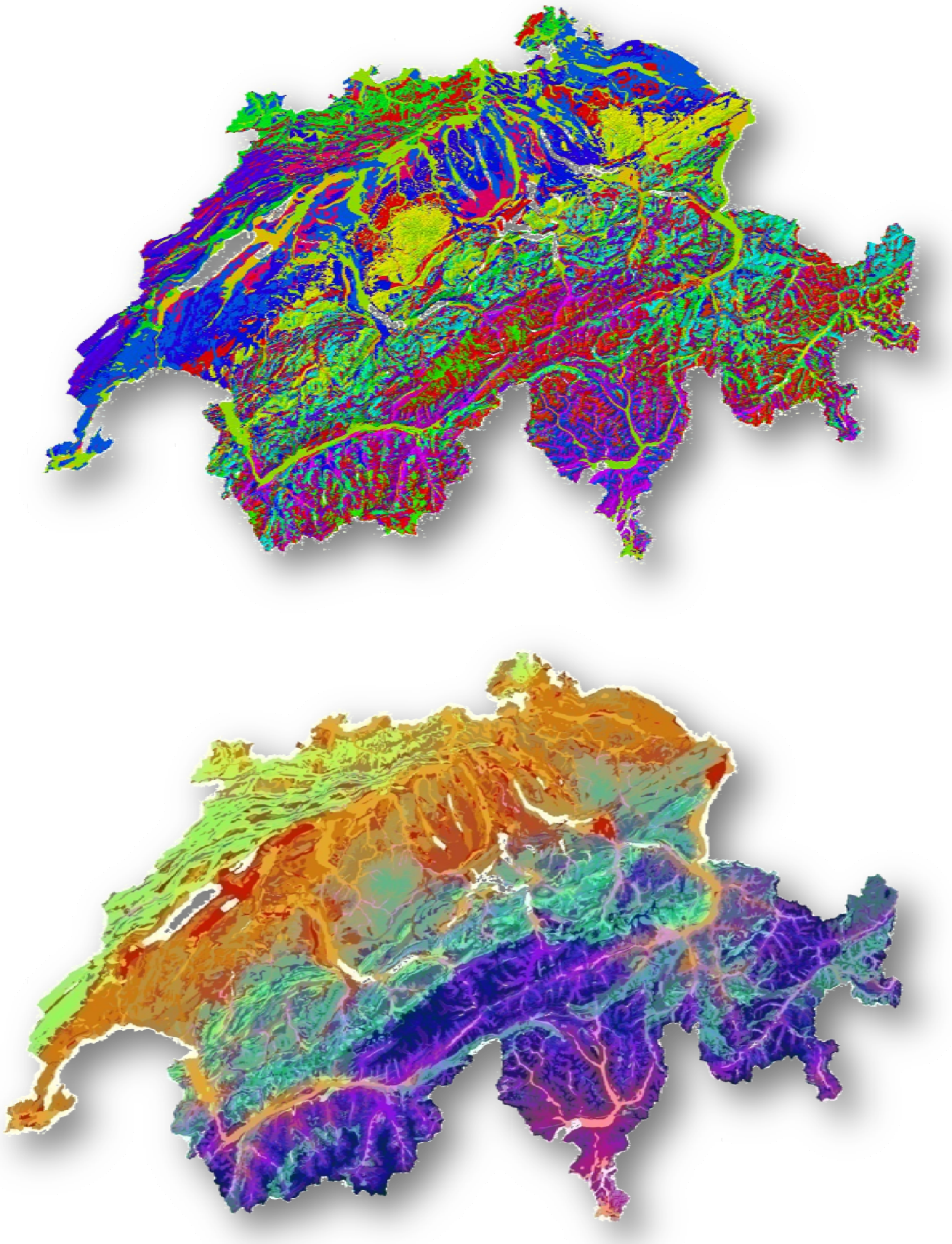


Figure 21 Randomly and RGB colored Swiss Environmental Domains at level III (50 groups)

Level IV: 100 groups

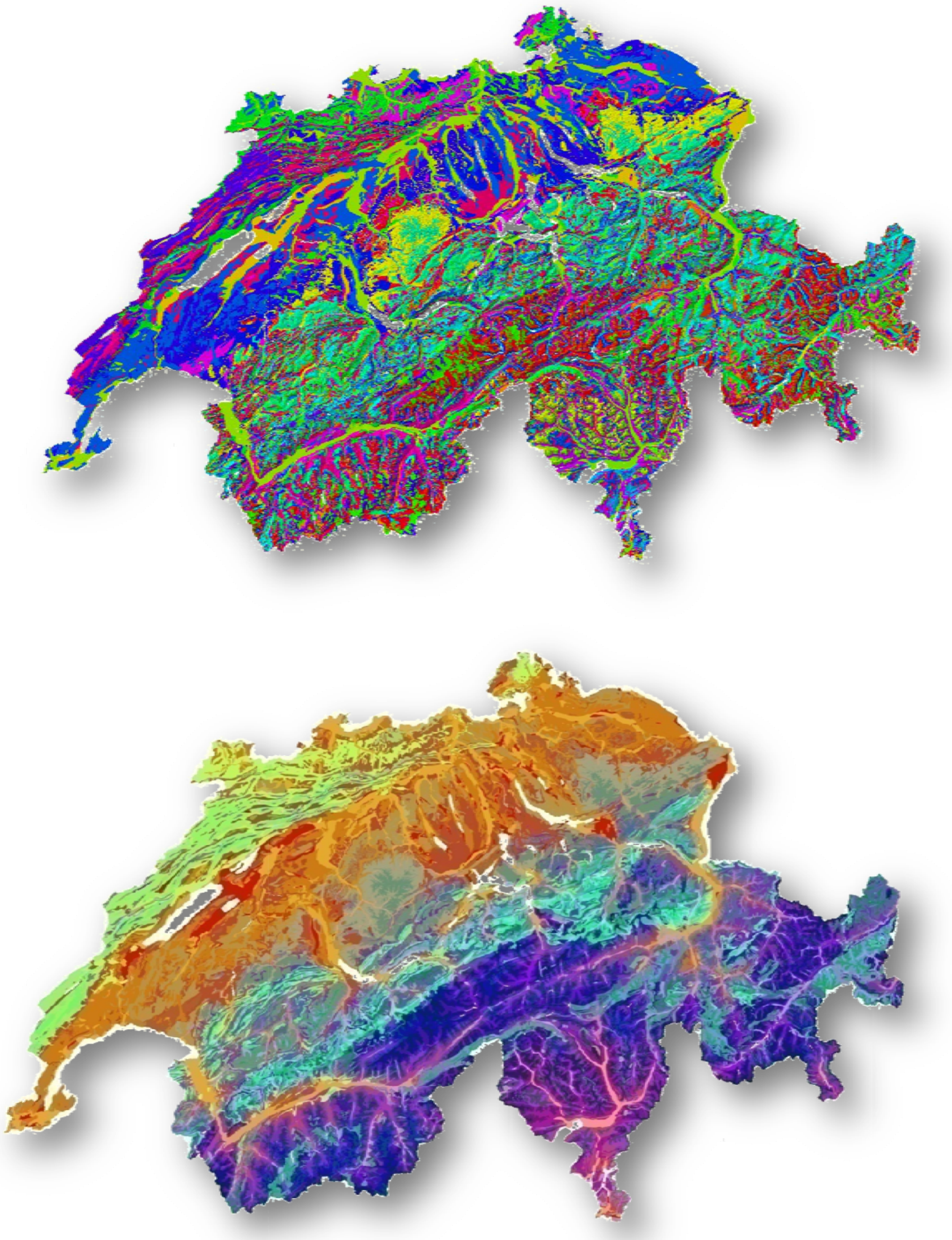


Figure 22 Randomly and RGB colored Swiss Environmental Domains at level IV (100 groups)

Environmental domains description at level 1 (10 groups)

In this section, we describe the 10 groups obtained at level I of SwissED in more details, attempting also to provide a descriptive name for each of them (Tables 2 and 3, Figure 23).

Table 2 Average values of environmental variables for levels I grouping

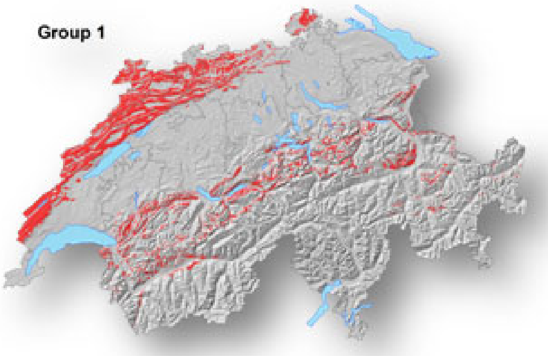
Groups	MAT °C	Tmin °C	MGMI mm	TPI500 m	TPI2000 m	Slope °	CaCO3 index	Permeability index	Age index
1	5.9	-24	35	-1.5	5	18	Massive	Strong	older
2	7.6	-22	9	-2	-13	10	Medium	Medium	older
3	6.5	-22	29	-12	-93	13	Weak	Medium	quaternary
4	4.3	-23	70	-12	-94	30	Absent	Very weak	older
5	8.6	-21	-16	-1.5	-21	3	Weak	Medium	quaternary
7	4.7	-24	51	-15	-71	26	Important	Medium	older
8	2.4	-27	84	6	66	24	Important	Medium	older
10	-1.3	-31	114	22	140	27	Absent	Very weak	older
23	2.6	-27	59	-4	-30	21	Very weak	Weak	quaternary
24	-1	-32	113	57	272	34	Massive	Medium	older

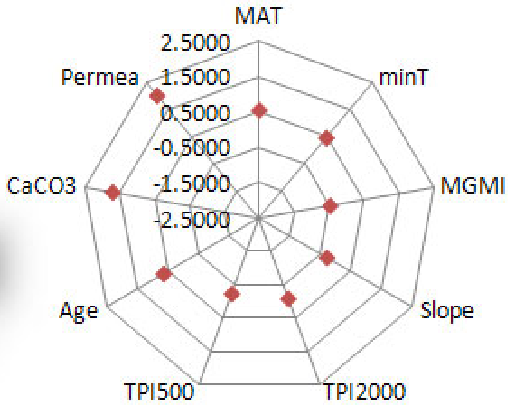
Table 3 Proposed names and description of Level I grouping

Group	Code	Short name	Description	Size (nb of pixels)	Distribution
1	A	CALCAREOUS RELIEFS	Limestone reliefs with very high permeability and calcareous content	6’883	Jura and Northern Alps
2	B	MOLASSIC FLATS & HILLS	Molassic plains and hills	9’591	Mainly Plateau and Jura
3	C	QUATERNARY HILLS & VALLEYS	Quaternary hills and valleys	5’541	Distributed everywhere
4	D	CRYSTALLINE SLOPES	Slope of crystalline domain	6’864	Northern and Southern Alps
5	E	DRY QUATERNARY FLATS	Dry quaternary flats	10’646	Plateau
7	F	CALCAREOUS MIDSLOPES	Midslopes with high calcareous content	4’909	Jura, Northern and Southern Alps
8	G	CALCAREOUS UPPER SLOPES	Upper slopes with high calcareous content	7’292	Mainly Alps
10	H	CRISTALLINE CRESTS	Crests of crystalline domain	8’020	Alps
23	I	CRYSTALLINE QUATERNARY SLOPES	Quaternary in crystalline domain	2’278	Mainly Alps
24	J	CALCAREOUS CRESTS	Crests of limestone domain	2’051	Alps

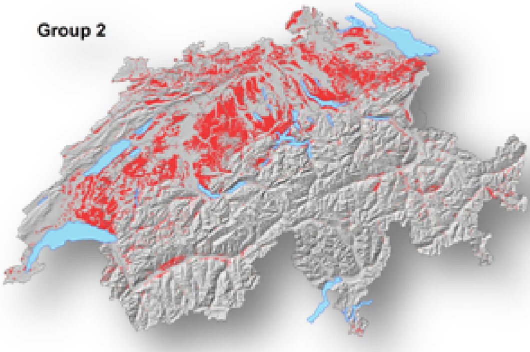
Figure 23 (below) Detailed maps and signatures of Level I SwissED. Star graphs represent standardized values of the nine variables composing SwissED.

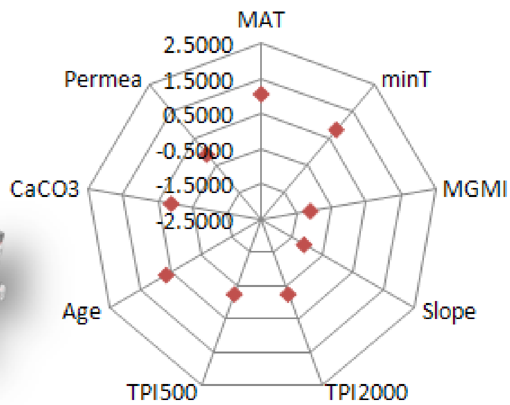
GR1 : A) CALCAREOUS RELIEFS



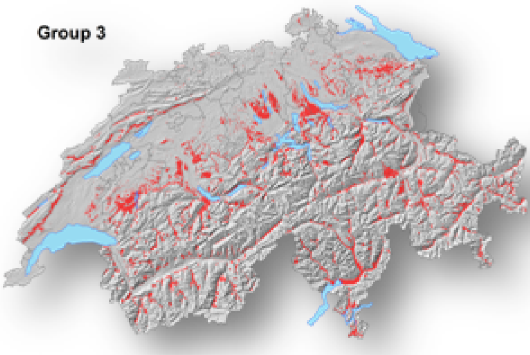


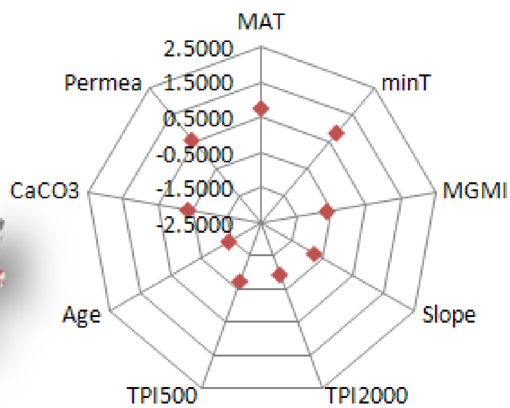
GR2 : B) MOLASSIC FLATS & HILLS



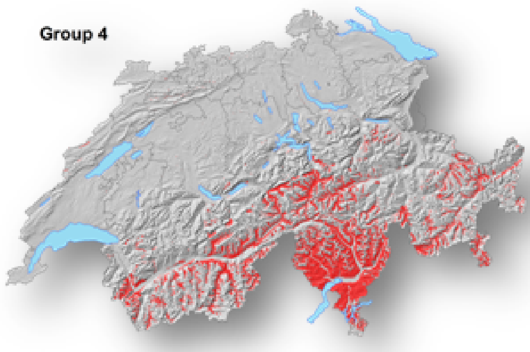


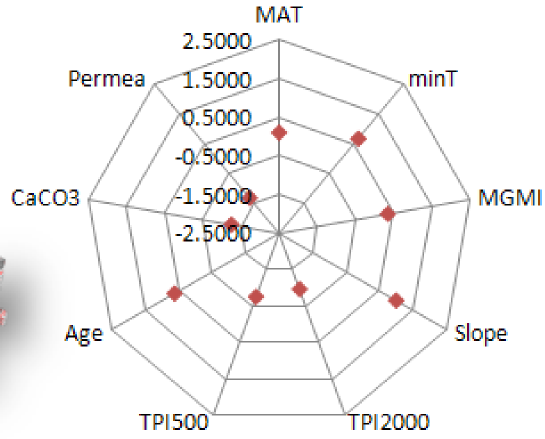
GR3 : C) QUATERNARY HILLS & VALLEYS



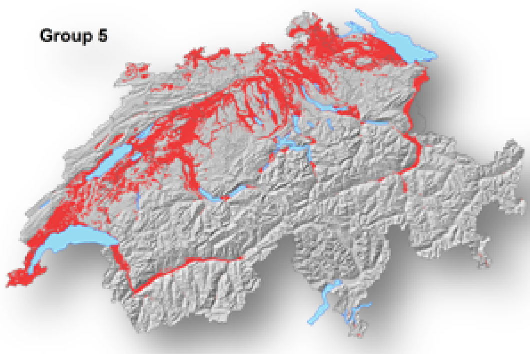


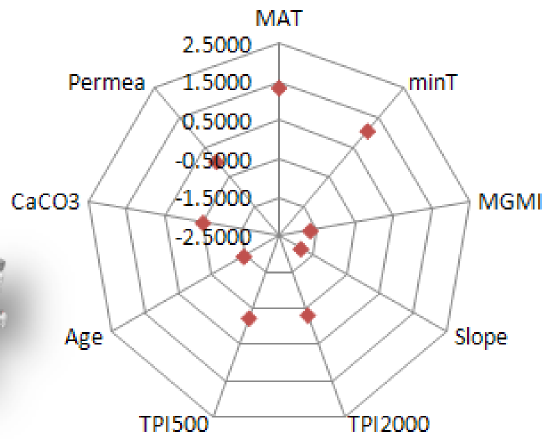
GR 4: D) CRYSTALLINE SLOPES



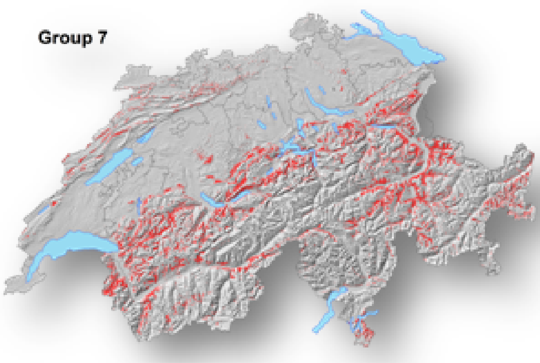


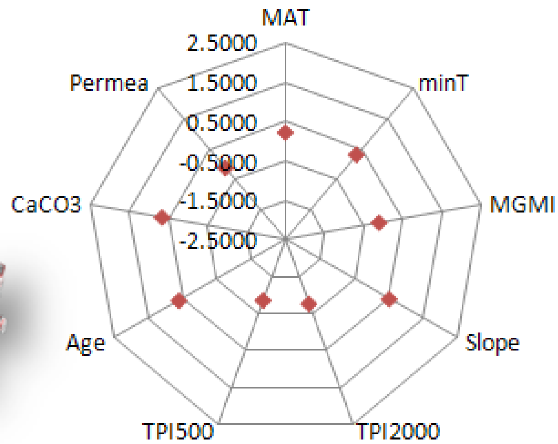
GR 5: E) DRY QUATERNARY FLATS



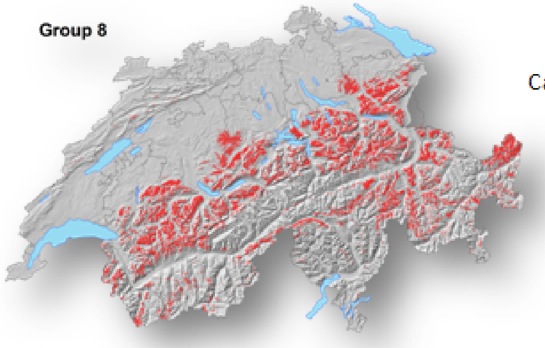


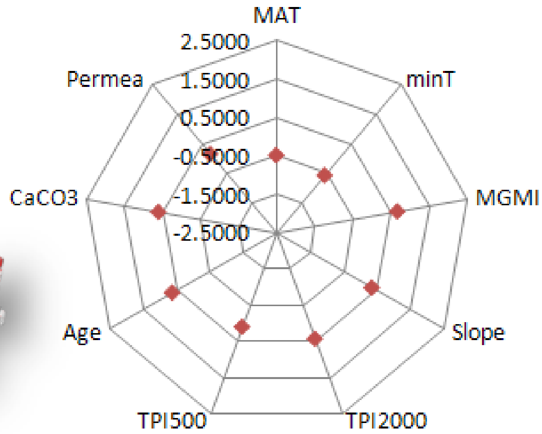
GR 7: F) CALCAREOUS MIDSLOPES



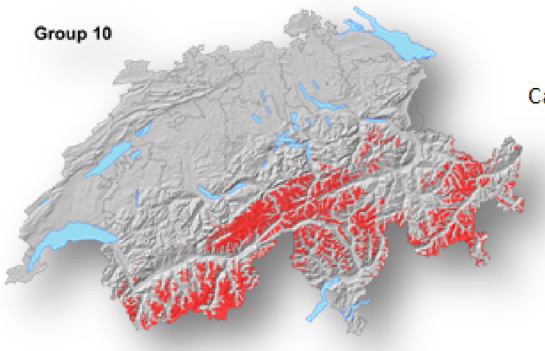


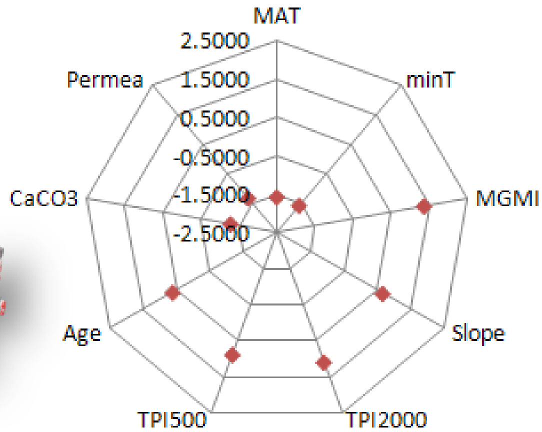
GR 8: G) CALCAREOUS UPPER SLOPES



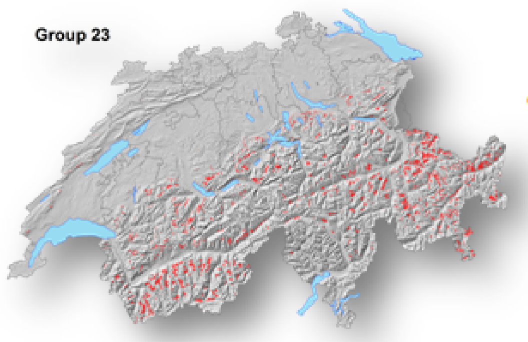


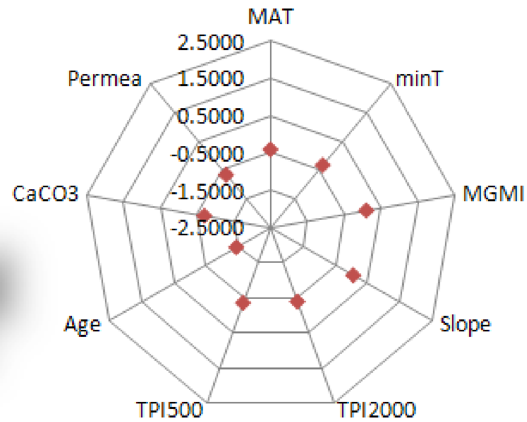
GR 10: H) WET CRISTALLINE CRESTS



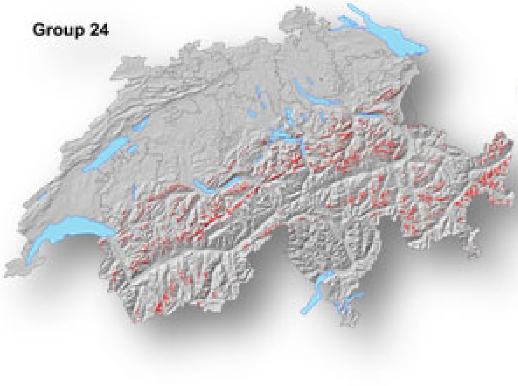


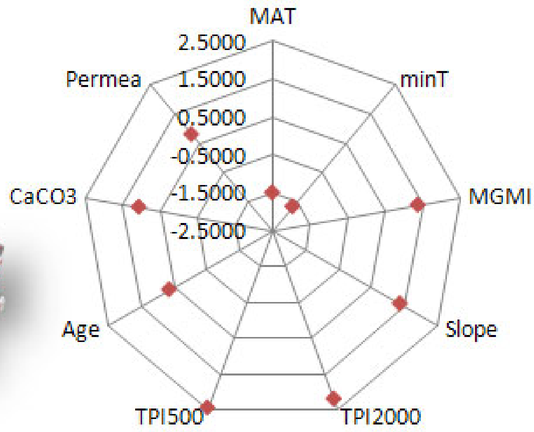
GR 23: I) CRISTALLINE QUATERNARY SLOPES





GR 24: J) CALCAREOUS CRESTS





Hierarchical organisation and naming of SwissED

Table 4 Hierarchy and names of SwissED at level I, II, III and IV

I	II	III	IV	G100
A	A1	A1.1	A1.1a	1
A	A1	A1.1	A1.1b	68
A	A1	A1.2	A1.2a	108
A	A1	A1.2	A1.2b	118
A	A2	A2.1	A2.1a	17
A	A2	A2.2	A2.2a	67
A	A2	A2.2	A2.2b	81
A	A2	A2.3	A2.3a	80
A	A2	A2.3	A2.3b	87
B	B1	B1.1	B1.1a	2
B	B1	B1.2	B1.2a	41
B	B1	B1.2	B1.2b	113
B	B1	B1.3	B1.3a	47
B	B2	B2.1	B2.1a	6
B	B2	B2.2	B2.2a	15
B	B2	B2.2	B2.2b	28
C	C1	C1.1	C1.1a	3
C	C1	C1.1	C1.1b	77
C	C2	C2.1	C2.1a	9
C	C2	C2.1	C2.1b	86
C	C2	C2.1	C2.1c	88
C	C2	C2.2	C2.2a	51
C	C2	C2.2	C2.2b	102
C	C3	C3.1	C3.1a	14
C	C3	C3.1	C3.1b	117
C	C3	C3.2	C3.2a	74
C	C3	C3.2	C3.2b	114
C	C4	C4.1	C4.1a	20
C	C4	C4.1	C4.1b	53
C	C4	C4.2	C4.2a	89
C	C4	C4.3	C4.3a	105
C	C5	C5.1	C5.1a	27
C	C5	C5.1	C5.1b	38
C	C5	C5.1	C5.1b	78
C	C5	C5.1	C5.1c	64
C	C6	C6.1	C6.1a	49
C	C6	C6.1	C6.1b	69

I	II	III	IV	G100
D	D1	D1.1	D1.1a	4
D	D1	D1.1	D1.1b	72
D	D1	D1.2	D1.2a	26
D	D1	D1.2	D1.2b	106
D	D2	D2.1	D2.1a	21
D	D2	D2.1	D2.1b	85
D	D2	D2.2	D2.2a	32
D	D2	D2.2	D2.2b	92
D	D2	D2.3	D2.3a	33
D	D2	D2.3	D2.3b	48
D	D2	D2.3	D2.3c	58
D	D2	D2.3	D2.3d	90
E	E1	E1.1	E1.1a	5
E	E1	E1.1	E1.1b	45
E	E2	E2.1	E2.1a	12
E	E2	E2.2	E2.2a	25
E	E2	E2.2	E2.2b	76
F	F1	F1.1	F1.1a	7
F	F1	F1.1	F1.1b	107
F	F1	F1.2	F1.2a	50
F	F1	F1.2	F1.2b	56
F	F2	F2.1	F2.1a	29
F	F2	F2.1	F2.1b	111
F	F2	F2.1	F2.1c	112
F	F3	F3.1	F3.1a	30
F	F3	F3.1	F3.1b	35
F	F3	F3.1	F3.1c	75
F	F3	F3.1	F3.1d	95
G	G1	G1.1	G1.1a	8
G	G1	G1.1	G1.1b	18
G	G1	G1.2	G1.2a	46
G	G1	G1.2	G1.2a	101
G	G1	G1.2	G1.2b	61
G	G1	G1.3	G1.3a	73
G	G1	G1.3	G1.3b	119
G	G2	G2.1	G2.1a	52
G	G2	G2.1	G2.1b	54
G	G2	G2.1	G2.1c	116
G	G2	G2.2	G2.2a	59
G	G2	G2.2	G2.2b	103
G	G2	G2.2	G2.2c	109

I	II	III	IV	G100
H	H1	H1.1	H1.1a	10
H	H1	H1.1	H1.1b	40
H	H1	H1.2	H1.2a	43
H	H1	H1.2	H1.2b	55
H	H1	H1.2	H1.2c	60
H	H2	H2.1	H2.1a	13
H	H2	H2.2	H2.2a	39
H	H3	H3.1	H3.1a	22
H	H3	H3.1	H3.1b	71
I	I1	I1.1	I1.1a	23
I	I1	I1.1	I1.1b	42
I	I1	I1.1	I1.1c	57
I	I1	I1.2	I1.2a	62
I	I1	I1.3	I1.3a	93
I	I1	I1.3	I1.3b	120
J	J1	J1.1	J1.1a	24
J	J1	J1.1	J1.1b	37
J	J1	J1.2	J1.2a	84
J	J1	J1.2	J1.2b	115
J	J2	J2.1	J2.1a	34
J	J2	J2.1	J2.1b	65
J	J2	J2.1	J2.1c	91

Possible applications

The examples from other countries and regions prove that SwissED can bring a new, complementary and useful spatial framework to underpin environmental research and management in Switzerland at various scales.

Future applications could be:

- providing a framework for regulatory activities and reporting on the state of the environment (see Figures 24 and 25);
- identifying the most efficient use of limited financial resources for biodiversity;
- management, including management of protected natural areas and other areas of land with high biodiversity values;
- identifying sites where similar problems are likely to arise in response to human activities, or where similar management activities are likely to have a particular effect;
- identifying the geographic extent over which results from site-specific studies can be reliably extended; and
- designing stratified sampling strategies.

Example of maps derived from land cover statistics

See next pages

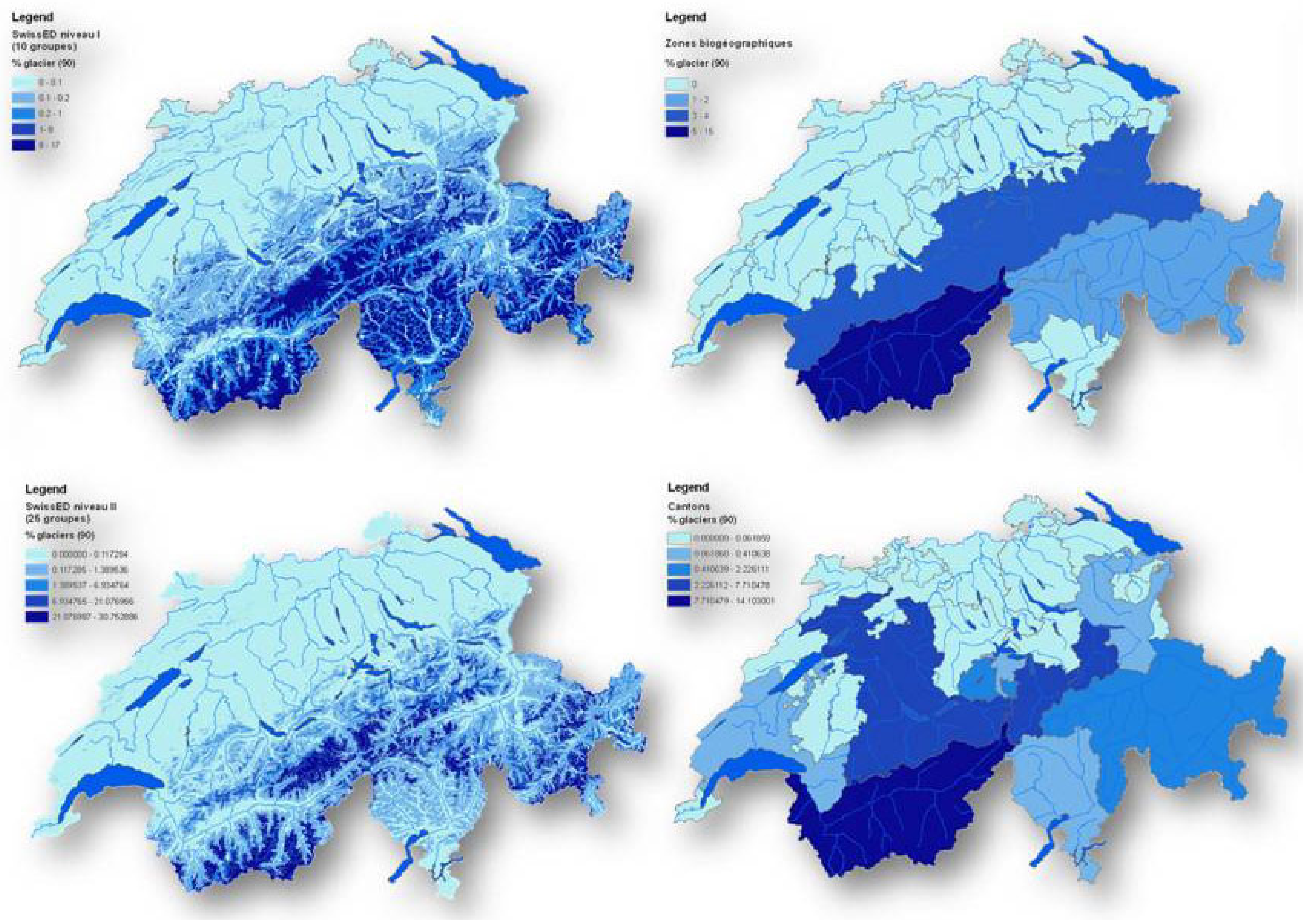


Figure 24 Percentage of glaciers represented according to 4 different spatial frameworks

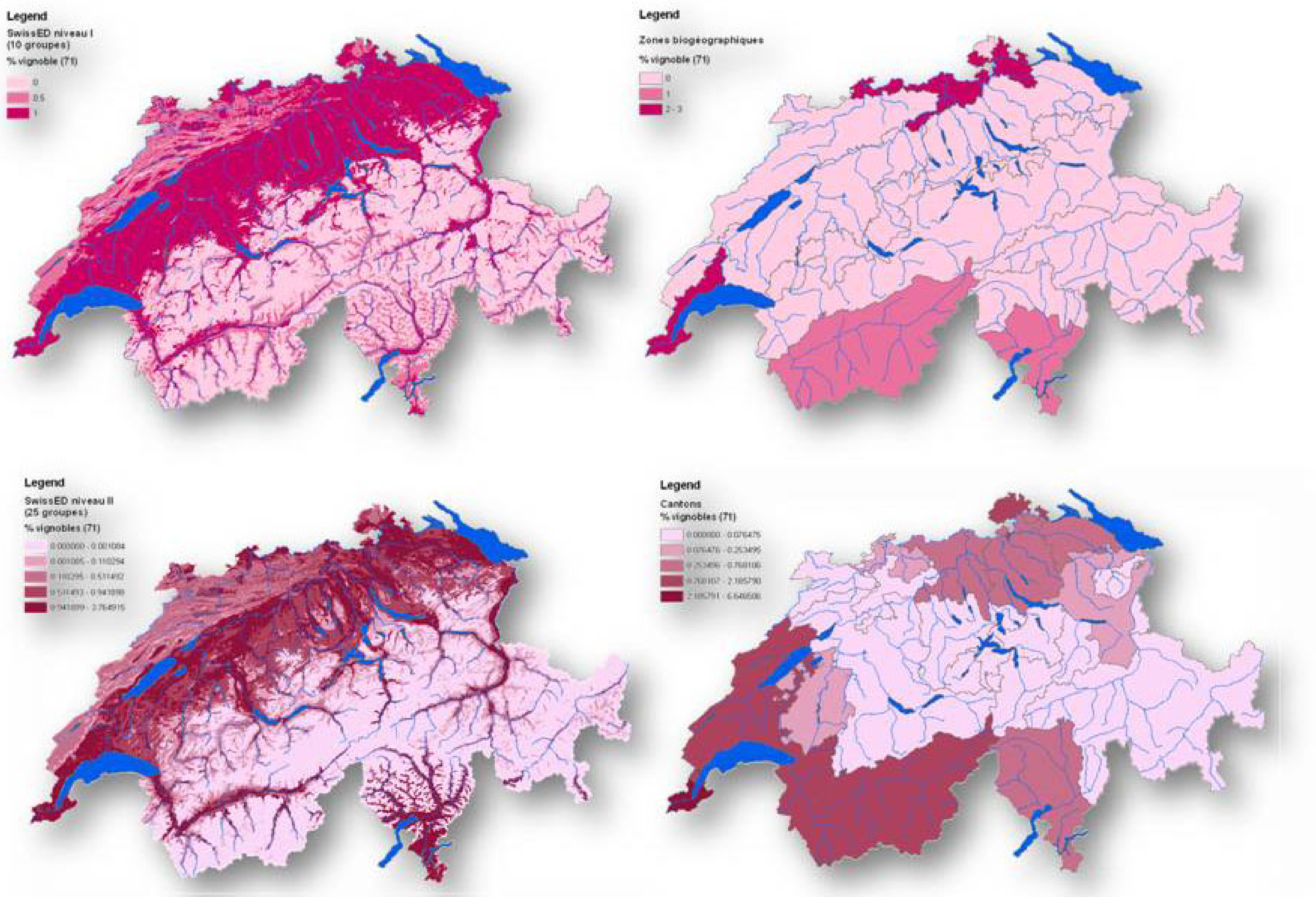


Figure 25 Percentage of vignards represented according to 4 different spatial frameworks

Discussion

SwissED was derived from state-of-the-art techniques developed in the Land Environment of New Zealand (LENZ) to classify environment variables on large datasets (Leathwick et al. 2003). This approach aims at producing a general classification that is representing the absolute potential of purely environmental variables, independently of human activities. This general classification should perform well in many types of applications, however more advanced techniques have been developed recently to produce classifications that best summarize specific target responses (Snelder et al. 2007). Future developments of SwissED should target specific needs (e.g. biodiversity, land cover, demography), and be calibrated accordingly, by selecting, transforming and weighting variables.

Environmental classifications can be exploited in other type of ecosystems (e.g. river, marine) as demonstrated by Snelder et al. (2006; 2007) in New Zealand. If the terrestrial approach was adopted by practitioners in Switzerland, the next logical step would be to develop a similar approach for rivers. In order to accomplish this, a spatial framework of environmental descriptors of river segments still needs to be developed. A first attempt was made in Switzerland (Lehmann et al. In prep.), but much work is still needed to create a comprehensive and useful environmental description of Swiss rivers.

The RGB coloration brings an attractive view of the territory corresponding to the main environmental gradients at stake. This colouring was used in many similar project (e.g. Ferrier et al. 2002; Leathwick et al.2004; Hargrove and Hoffman, 2005; Mücher et al. 2006). However, the RGB coloration is somehow masking the true purpose of SwissED, which is to build groups of similar environmental conditions that can be used as a spatial framework to represent the spatial distribution of other environmental statistics (e.g. land cover, reserves, species richness). We recommend to present the comparison of calculating such statistics on environmental domains instead of other existing spatial framework (e.g. administrative boundaries) when explaining the environmental domains to new potential users.

The purpose of this report is to present how SwissED were built in details. The potential main application is demonstrated at the end by showing how this framework can be used to produce interesting maps of land cover statistics representing their potential distribution across the country. In the literature we can find other existing or potential applications such as the assessment of existing reserve network in New Zealand (Walker et al. 2005), the distribution of environmental conditions according to past or future climate conditions in the USA (Hargrove & Hoffman, 2005) or statistics of sustainable development in Switzerland (Jaeger et al. 2008).

One possible use of SwissED is its combination with existing land cover information in order to produce environmental classifications within each type of main land covers. A simple overlay of polygons derived from SwissED at a given level with the polygons from Vector 25 "Primary Surfaces" should produce the expected result. This small development can allow the SwissED framework to move from its general purpose into a tool useful for the management different type of land cover (forests, agriculture, grasslands).

As demonstrated here and elsewhere, environmental domains can become useful frameworks for different applications. However, one should not overestimate its potential use and it should be clearly stated that SwissED can be useful only at some adapted scales to simplify complex approach and represent environmental statistics in an adapted framework. SwissED does not represent a simple solution for all problems; specific methods exist for species or habitat distribution modelling (Lehmann et al. 2002; Maggini et al. 2006), reserve selections

(Margules and Pressey, 2000), invasive and rare species assessment (Guisan and Thuiller, 2007), or climate change predictions (Thuiller 2005).

Conclusions

The main conclusions that we can derive from this work are:

- The strong climatic, geologic and topographic gradients found in Switzerland represent the ideal pre-conditions for building environmental domains;
- The methodology imported from the Land Environment of New Zealand could be reused appropriately in the Swiss context with only few new developments;
- SwissED bring a new spatial framework for analyzing and reporting on all sorts of data in Switzerland;
- When compared to more traditional spatial frameworks, the maps produced when representing statistics (e.g. land cover) on SwissED return more realistic spatial patterns and surface areas;
- SwissED does not replace previous spatial framework but can bring a valuable complementary tool to represent environmental data;
- SwissED are in line with similar developments made across the world at continental, regional or national levels;
- SwissED were developed for general purposes analyses without trying to weight the input variables, they could therefore be improved by targeting a specific need (e.g. biodiversity, land cover, agriculture);

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Finally, we wish to thank the participants of the SwissED workshops for their appreciated feedbacks:

Workshop 1 was organized on May 26. 2008 at FOEN with:

- FOEN: Sarah Pearson, Gilbert Thélin, Juerg Schenker, Markus Wuest, Jean-Michel Gardaz
- BFS: Laurent Zecha
- ARE: Marco Kellenberger
- Agroscope: Felix Herzog
- Vogelwarte: Peter Knaus, Ramona Maggini Lehmann
- CSCF: Fabien Fivaz
- WLS: Niklaus Zimmermann

Workshop 2 was organized on May 5. 2009 at FOEN with:

- FOEN: Jean-Michel Gardaz, Karin Fink, Tom Klingl, Chantal Donze, Marika Schaffner, Hugo Aschwanden, Christian Schlatter
- BFS: Laurent Zecha
- ARE: Reto Camenzind
- Agroscope: Gabriela Hofer
- Vogelwarte: Ramona Maggini Lehmann
- WLS: Charlotte Steinmeier

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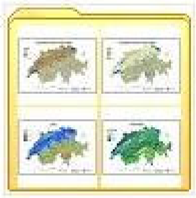
Annex 1: DVD content

1. Factsheet

Fiche_swissed.pdf

2. Variables



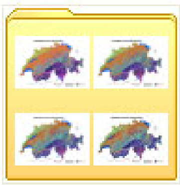
ArcGis 9.2 map

EVariables.mxd

Illustrations

Maps in jpeg and pdf formats of variables

3. Results



ArcGis 9.2 map

SwissED.mxd

Illustrations

Maps in jpeg and pdf formats of SwissED

4. Presentation

Power Point presentation

SwissED08.ppt

SwissED08.pdf

6. Report

Technical report (pdf) (this report)

7. References

Some interesting references

8. Geodatabase

SwissED08lyr
SwissED08.gdb

ArcGis 9.2 Geodatatbase
Raster and vector data, Legends (LYR)

Annex 2 : Topographic position index

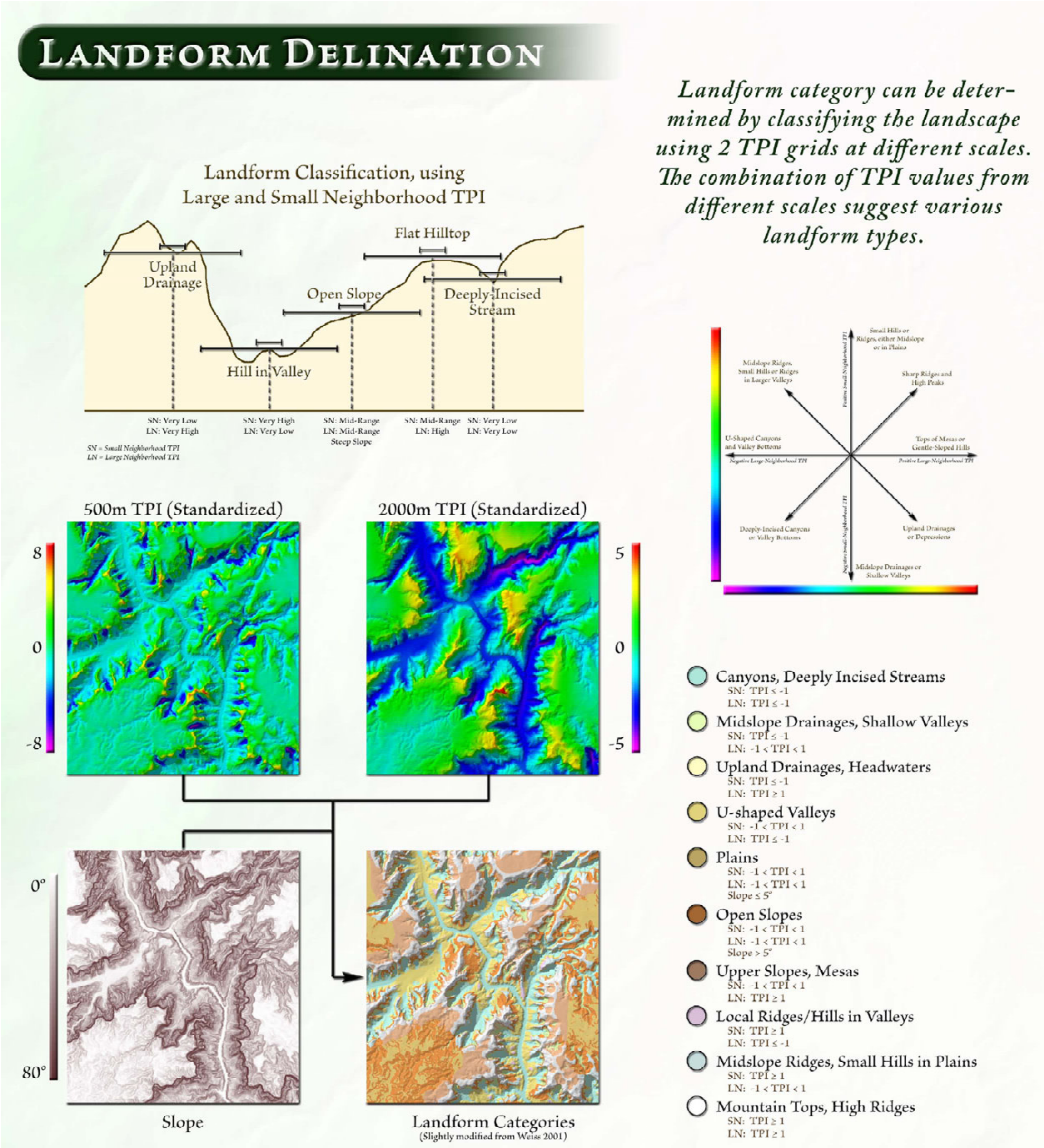


Figure 26 Illustration of Landform Categories obtained by the combination of 2 TPI at different scale and the slope. TPI Poster, Jeff Jenness