Comprehensive analysis of European mountain areas by using GIS techniques

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Prepared for the 18th ESRI European User Conference, Innsbruck, Austria, 8-10 October 2003

Abstract

The paper presents some preliminary results of the European research project entitled "Analysis of mountain areas in the European Union and in the applicant countries" commissioned by the EU-Commission. The aim of the study is to provide an in-depth analysis of the mountain areas in the European Union and the Candidate Countries, as well as Norway and Switzerland. The methodologies applied and some examples of the analysis will be presented.

Particularly, the extensive use of ArcGIS within the project is described in the paper. This includes the GIS-based delimitation of mountain areas by calculating several scenarios with different physical and climate indicators and performed buffering methods in order to find out more about adjacent transition areas. Moreover the structure of the comprehensive GIS-database and the use of several GIS techniques in order to store and derive indicators and perform analyses are covered. Composite assessment indicators were developed with the help of GIS, combining several single indicators. Finally, the results are mapped by using ArcMap.

As a whole, the project illustrates the challenges of characterising a specific physical environment in social and economical terms.

1. Introduction

Since August 2002, an international team is working on the project entitled "Analysis of mountain areas in the European Union and in the applicant countries" commissioned by the EU-Commission. The national governments of Norway and Switzerland financed an extension of the study area to their respective country. The study consequently covers 29 countries, of which 6 (Estonia, Denmark, Latvia, Lithuania, Malta and the Netherlands) do not comprise any mountain areas.

The objectives of the project are:
- to develop a common delimitation of the mountain areas of the European Union, the applicant countries, Norway and Switzerland;
- to compile statistical and geographical information necessary to describe and analyse the situation in these mountain areas (including in relation to national and EU references);

- to create a comprehensive GIS database at municipality level (NUTS 5) on which future analyses and policies may be based and to develop a typology of mountain areas based on the data collected;
- to analyse the measures and policies implemented by the Member States, the applicant countries, and the European Union with regard to mountain areas; to evaluate the impacts of these measures and policies; and to develop proposals for adjustments to make them better suited to the situation of mountain areas, their needs and opportunities.

This paper will rather focus on the first two objectives, for which extensive use of GIS techniques has been made. In order to reach the objectives set by the study, it is necessary to collect, store and analyse a vast amount of quantitative data (i.e. more than 115,000 municipalities are covered in the study area).

2. Delimitation of mountain areas

Trying to delimit and analyse mountain areas, one is confronted with two separate and complementary dimensions. On the one hand, high altitude and rough terrain create an objectively different, and in many cases more difficult, context for human activities. On the other hand, the perception of mountain areas is deeply rooted in each nation's cultural roots and political history. While upland areas are identified as mountains in relation to surrounding lowlands, their landscapes are shaped by the agricultural and economic culture of its inhabitants. A combined qualitative and quantitative approach is therefore necessary in order to encompass these different aspects of European mountains.

2.1. Defining mountain delimitation criteria

Altitude alone is not a sufficient criterion to delimit mountain areas, as illustrated by Scottish or Norwegian mountain areas with fjords plunging directly down to sea level, or coastal dry mountain areas around the Mediterranean Sea. The roughness of the terrain in some cases suffices to characterise an area as mountainous.

While both perceptions of what is to be considered mountainous and actual effects of altitude and roughness on human activities vary greatly from region to region, it was nonetheless necessary to establish a common set of criteria for the whole of Europe in order to obtain an homogenously defined study area. The quantitative thresholds and the types of functions used to delimit mountain areas were progressively adapted so as to fit as well as possible with established national views of what is to be considered as mountains.

16 successive delimitation scenarios were developed and tested using GIS techniques, of which one was finally adopted. This scenario applies increasingly restrictive criteria with regards to local elevation variation as the altitude declines. Furthermore, a climatic constraint indicator based on the proportion of months with an average temperature below 0ºC was created. Areas in which this climatic constraint is higher than in the most exposed mountain peaks (which are to be found in the Central Alps) were assimilated to mountain areas. This implies that a relatively large proportion of northern Sweden and Finland was assimilated to a mountain area.

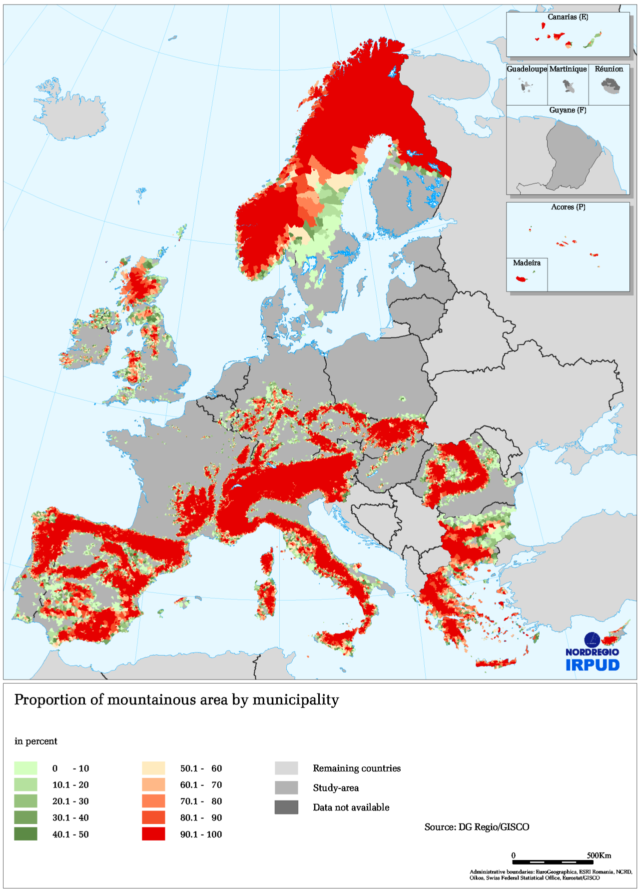

Figure 1. Proportion of mountainous area by municipality.

In order to be characterised statistically, and in order to gain policy relevance, the delimitation had to be approximated to municipal boundaries. This first implied that a municipality boundary layer of the whole study area had to be compiled. For most countries, Eurogeographics[1] have compiled a seamless municipal boundary map called SABE. At the time of the launch of the study, only the 1997 version of this database was available. It has since been updated with a 2001 version. It however did not include boundaries for Romania and Bulgaria. These were obtained from separate sources. Furthermore, it proved necessary to introduce alternative boundary layers for Switzerland, Slovenia and Slovakia.

Overlaying this municipal layer with the above mentioned mountain delimitation, a new administrative delimitation was obtained by identifying all municipalities with at least 50% mountainous terrain (see Figure 1).

Table 1 shows the proportion of country area covered by mountains. It becomes obvious that the figures differ significantly across the study area.

Table 1. National area covered by mountains: 1,000 km^2 and %

Country	Country area (1,000 km^2)	Mountain area (1,000 km^2)	% Mountain area as proportion of total country area	Country	Country area (1,000 km^2)	Mountain area (1,000 km^2)	% Mountain area as proportion of total country area
Study area	4,671.42	1,893.71	40.5				
Austria	83.85	61.51	73.4	Bulgaria	101.74	54.18	53.3
Belgium	30.62	1.29	4.2	Cyprus	9.23	4.40	47.6
Denmark	43.10	0.00	0.0	Czech Republic	78.79	25.41	32.3
Finland	326.76	166.08	50.8	Estonia	45.23	0.00	0.0
France *	548.64	138.64	25.3	Hungary	92.48	4.37	4.7
Germany	356.77	52.59	14.7	Lithuania	65.30	0.00	0.0
Greece	132.22	102.98	77.9	Latvia	64.59	0.00	0.0
Ireland	70.14	7.44	10.6	Malta	0.22	0.00	0.0
Italy	300.59	180.78	60.1	Poland	311.44	16.18	5.2
Luxembourg	2.59	0.11	4.4	Romania	238.40	90.24	37.9
The Netherlands	41.20	0.00	0.0	Slovenia	20.27	15.81	78.0
Portugal	92.36	36.14	39.1	Slovakia	48.99	30.37	62.0
Spain	505.21	281.61	55.7	Norway	323.90	295.86	91.3
Sweden	450.00	227.70	50.6	Switzerland	41.30	37.46	90.7
UK	245.49	62.56	25.5				

** Excluding Overseas Territories*

[1] www.eurogeographics.org

2.2. Delimitation mountain ranges or *massifs*

Based on this mountain delimitation approximated to municipality boundaries, a number of *massifs* (mountain ranges) were defined, based on advice from national experts. These delimitations were founded on social and cultural criteria rather than geological ones, using commonly accepted entities used in school textbooks or meteorological reports as a first basis. Administrative regions are in most cases of little help, as their borders usually cut through mountain ranges.

There are numerous justifications for such an ex-ante aggregation of mountainous municipalities. First, applying a statistical classification method on the 33,000 identified mountain municipalities would not produce regionally coherent groups. It would at the contrary be likely to reflect the internal diversity of each mountain area, grouping mountain cities together, depopulation rural areas, etc. Second, social actors generally do not relate to “mountains” as a category, but to specific regions or areas identified as being mountainous. Whether they are homogenous or not, functionally integrated or not, characterising these ‘generally perceived mountain areas’, or ‘massifs’, is an important task as such. The delimitation of massifs does not depart from the presumption that the areas are homogenous, as the statistical analysis can also focus on the level of internal diversity. Massif delimitation is therefore a way of taking into account the social and cultural embeddedness of mountains as a social category.

The methodology used for massif delimitation is a qualitative one, and is primarily based on advice from national experts. The output is therefore highly subjective, but nonetheless provides useful insight into how each country perceives the partition of its mountain areas. The delimitation were coordinated trans-nationally, in order to identify both European-wide and national mountain ranges. At the European level, 39 mountain ranges were identified, as well as a number of isolated mountain areas.

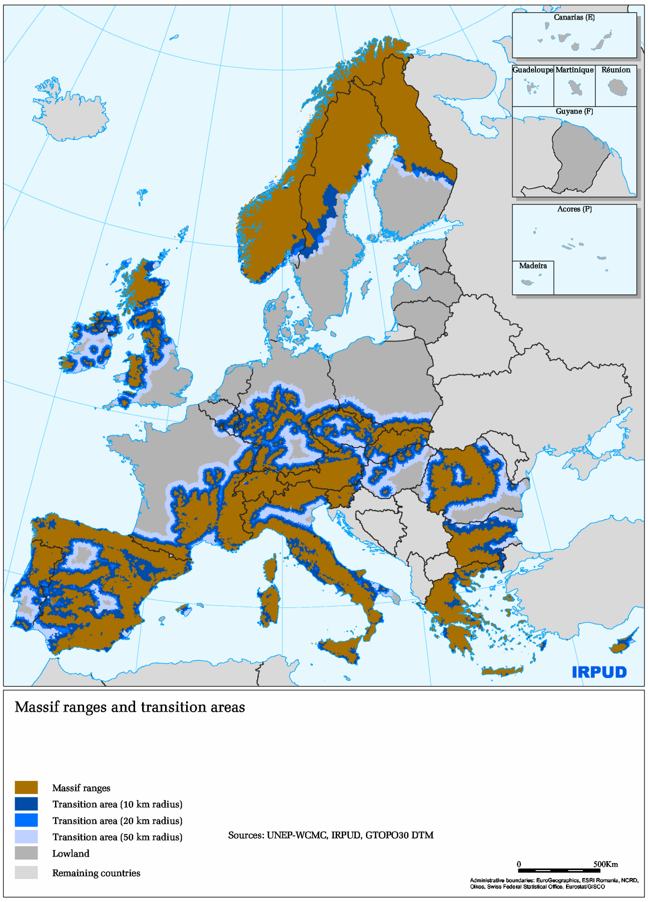

Figure 2. Massif ranges and transition areas.

Based on the mountain delimitation and massif identification described above, transition areas have been defined in order to explore the functional integration of mountain areas into their spatial context. These are assumed to have functional spatial-temporal linkages to the mountain areas they surround. Three buffer rings around mountains were generated with ArcInfo: rings with 10 km, 20 km and 50 km radius (see Figure 2). It is assumed that the greater the distance to the mountains is the lower the functional linkage is. Nevertheless, whether these transition areas really play an important role as intermediate space between mountains and lowland areas is still to be proved.

3. Use of GIS in the study

Indicators derived from GIS play an important role in the project as they complement quantitative statistical data collected at a national level. GIS data is stored in the database with seamless data that cannot be collected from statistics. The calculations of these indicators follow one common principle: a seamless pan-European GIS base layer is overlaid with the NUTS 5 municipality boundary layer (ArcInfo: *identity* command), and the indicators are then derived by using statistical functions.

The importance and benefits of these GIS indicators can be summarised as follows:
- GIS techniques allow the introduction of indicators that are hardly and, in some cases, not at all, covered by statistical databases, such as the accessibility of regions, the location of certain facilities, and detailed land-use types;
- usually, the GIS layers cover the whole of Europe, thus GIS indicators can be calculated for all municipalities, avoiding gaps in the final database;
- a common indicator definition and a common way of indicator calculation can be applied to all countries – which addresses one of the largest problems concerning the statistical indicators.

On the other hand, two disadvantages of the GIS approach must be mentioned as well. First, only a limited number of pan-European GIS layers are available. Second, in some cases the level of detail of these layers may not be appropriate for the study, with respect to the spatial resolution of the data on which the layers are based (e.g., the map scale is too coarse) and/or the number of attributes and value classes associated with them (e.g., only a limited number of land-use types are available). Despite these comparatively small drawbacks, indicators derived from GIS layers play an essential role in the analysis of the situation of mountain areas in Europe, particularly because the range of statistical indicators available at the European scale was found to be limited in many domains.

GIS layers have been received from Eurostat/GISCO and other GIS data providers as listed below (grouped by theme), with the source of each layer indicated in brackets. Those layers are used to do further analysis.

Geography
- Digital terrain model (Eurostat/GISCO and USGS GTOPO30)
- Cities in Europe (IRPUD, 2003)
- Global Seismic Hazard Map (GSHAP)

The two digital terrain models were used as the main source for the physical delineation of mountain areas in Europe, together with the municipality boundaries layer and the climate layers. They were also used to derive some of the GIS indicators related to geography, which offer basic information on municipalities (e.g., on the location of municipality centres, altitude, slope). The 'Cities in Europe' layer was used to calculate some of the accessibility indicators. The original GIS layer „Global Seismic Hazard Map (GSHAP)" was not sufficient for the use in the study due to its rather coarse resolution (basing points in 10 km distances). This was solved through applying the Kriging interpolation (1 km grid) in ArcInfo.

Natural and land resources, climate
- CORINE land cover grid (Eurostat/GISCO, 2002) and PELCOM land cover grid (EC, 4th framework programme project)
- basic inventory of soil units and of natural vegetation (Eurostat/GISCO, 2002)
- major landscape types of pan-Europe (Eurostat/GISCO, 2002)

- internationally designated areas (Eurostat/GISCO, 2002)
- delineation of bio-geographical zones (Eurostat/GISCO, 2002)
- inventory of sites of major importance for nature conservation (Eurostat/GISCO, 2002)
- climate interpolated layer and climate point data (Eurostat/GISCO, 2002)
- mean annual radiation (IRPUD, based on Palz and Greif, 1995)
- rainfall (IRPUD, based on Westermann, 1997)

The climate datasets provided additional information for the delineation of mountain areas in Europe. These layers in addition to the other layers also contributed to the analysis of the natural potentials and environmental handicaps of mountain areas. In particular the two land cover grids were important for the characterisation of massifs. Originally, it was planned to use the CORINE land cover grid to assess land-use patterns (based on 44 different land use types). However, the layer provided by Eurostat/GISCO was lacking data for Cyprus, Norway, Sweden and Switzerland. Therefore it was dediced to use the PELCOM land cover grid, which differentiates 14 different land uses.

Infrastructure
- airport layer (Eurostat/GISCO) and Pan-European Aiport layer (IRPUD, 2003)
- port layer (Eurostat/GISCO, 2002)
- ferry links (Eurostat/GISCO, 2002)
- railways (Eurostat/GISCO, 2002) and Pan-European railway network (IRPUD, 2003)
- road network (Eurostat/GISCO, 2002) and Pan-European road network (IRPUD, 2003)
- nuclear power stations, energy production and energy transport (Eurostat/GISCO, 2002)

These layers contribute to the analysis of the geographical position, accessibility and transport network provision and network usage of mountain regions.

All map output of the project has been produced using ArcGIS 8.2 tools, in particular ArcMap. The first task in this respect was to create a map template which complied with the map design of the European Commission (with respect to projection, colours, map elements and layout). The actual map output was obtained by temporary joins of the basic municipality cover and the info-files containing the calculated indicator data to be displayed. After the work on the template has been finished once ArcMap offered a quite comfortable way to generate the maps.

4. Database

In relation to the software environment used by the European Commission, the study database uses data formats supported by ArcInfo (Vers. 7.x):
- ArcInfo Coverages (for storing vector data such as municipality boundaries).
- ArcInfo Grids (for storing raster data such as land cover data).
- ArcInfo Info Tables (for storing additional tabular data).

The quantitative data which have been collected and derived from both national statistical sources and GIS layers refer to categories that are crucial with regard to mountain regions. Accordingly, the database and so the indicators are sub-divided into the following seven main categories:
- *Geography*, comprising all data and indicators representing land use, geographical location, climatic and topographic conditions;

- *Demography*, including data such as total population, age structures, migration patterns, and spatial patterns of population distributions;
- *Economy*, including information about employment, education, GDP, qualifications, and commuting;
- *Agriculture*, including data on agricultural cultivated land, livestock, and income from agriculture;
- *Infrastructure*, including data on tourism, health care, educational facilities, and accessibility, particularly regarding the transport network provision;
- *Environment*, including data on settlements and protected areas;
- *Initiatives*, including information on regions eligible for the various EU Community support programmes for disadvantaged regions.

The database does not seek to duplicate any existing Eurostat database (e.g. New Chronos, GISCO), but rather provides a comprehensive, GIS-based spatial database. New Chronos Excel sheets (and other data sources) have been transformed into ArcInfo Info Tables or ArcInfo coverage or Grid formats. Aggregates calculated from seamless GISCO layers are linked directly to ArcInfo municipality layers, in order to unlock and enable the full potential of GIS tools to facilitate the analysis of mountain areas.

The GIS database to be submitted at the end of the study will be based on mountain ranges (massifs), i.e., each massif is represented by one individual region entity, comprising one or several polygon entities (municipalities). All NUTS 5 municipality data are stored as polygon data, and also in aggregated form, representing the overall massifs.

5. GIS application, methods and adaption of data

The municipality coverage contains more than 115,000 polygons which gives a hint to one of the characteristics of this study: the huge amount of data. This determines long calculating times for pulling out the results of the *identity* command within ArcInfo even by using state of the art PC processor technology. The needed calculation time is of course also influenced by the number of polygons of the second input coverage, the so called identity cover. In some cases ArcInfo actually came to its limits and the *identity* command couldn't be accomplished. In these cases ArcEdit was used for splitting up the coverages into smaller parts.

Moreover some preparatory work had to be done in order that overlay techniques could be used at all. Some of the original data was stored as raster data (grid) that first had to be transformed into a coverage with topology using the *gridpoly* command under the workstation and *build poly* afterwards. In some cases, the upper mentioned fragmentation method had to be applied for the grid data as well.

Having data available at NUTS 5 level for the whole study area the next step was to do some statistical calculations which included averages, weighted averages over areas, standard deviations and minima/maxima values. The particular *statistics* were produced within *Tables* for several spatial references: at NUTS 5 level and at massif level, some of them were also calculated for the national level or the EU15, the Candidate Countries and others. By doing so, a ranking (benchmarking) of the values within massifs or countries could be achieved.

Moreover some of the layers showed a wrong spatial reference system and therefore the projection had to be adapted using the ArcInfo. In order to be compatible with the Eurostat/GISCO databases, the GIS database is based on the standard GISCO spatial reference system. This standard planar projection is a Lambert Azimuthal Equal Area projection (Eurostat, 2002). It is best suited for large areas, preserving as much as possible the shape of the continent. For French Overseas Territories, alternative projection systems were used, defined in collaboration with Eurostat.

Because of the amount of data, metadata information is crucial. To manage this information more effectively, an Access database has been developed, including some tools programmed in VBA.

One issue, applying to a number of countries, is the change of municipality boundaries over time. This challenge was overcome by transforming all data to the 1997 boundary system. The statistical problem of different sizes of municipalities was solved by standardising all indicators per capita or per area, by calculating percent shares, or by calculating index values (with the average value set to 100).

6. Typology development and examples of analysis results

This chapter presents the development of typologies and some examples of analysis results. In general, maps were produced for a wide range of indicators, following the categories described in Chapter 4. They revealed profiles of the various European mountain regions. Nevertheless, in order to create a typology, more comprehensive indicators and methodologies need to be developed. Their definition is a key element in order to identify different kinds of territorial policies which could be envisaged in mountain areas. Three different typologies are developed in order to have different composite perspectives on mountain areas:

- Social and economic capital
- Environment, land covers and land use
- Infrastructure, accessibility and services.

It is planned to derive each of the above mentioned typologies using statistical approaches, such as factor or cluster analysis, or multi-criteria analysis. As an example the approach of typology about social and economic capital is explained in more detail. There, the following four measurable aspects are considered to be relevant:

- population density;
- population trend (i.e. population development, and/or ageing of population);
- economic profile (i.e. share of different sectors on employment);
- accessibility.

Those four dimensions can be differentiated as high and low (population density, population development, accessibility) resp. relatively predominant compared to the European average (economic profile). Therefore, there is a grid of 6 times 4 fields (Table 2). One goal by the end of the project will be to categorise the massifs by the presented grid.

Table 2: Grid to define typology of social and economic capital

			Population density					
			low			high		
			Emp. I	Emp. II	Emp. III	Emp. I	Emp. II	Emp. III
Population development	growth	High acc.						
		Low acc.						
	decline	High acc.						
		Low acc.						

Main over-represented employment sector: Emp. I = Agricultural sector, Emp. II = Manufacturing sector, Emp. III = Industrial sector
Acc. = accessibility

As examples of how the analysis of single indicators is displayed, the following map is showing some results concerning land use at NUTS 5 level, generated from the PELCOM layer (Figure 3). In general, results can be either be shown for all municipalities, for mountain municipalities only, or at massif level.

Beyond that, it is possible to use the data to do some further calculation and to develop different display formats. To calculate the absolute predominant land use per massif (Figure 4), an AML Script has been developed, which extracts the sought land use.

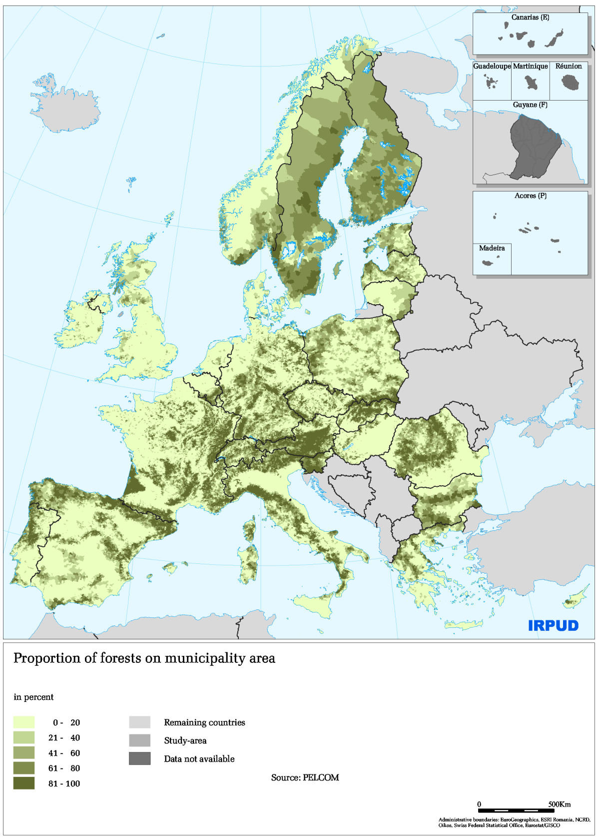

Figure 3: Proportion of forest land on municipality area.

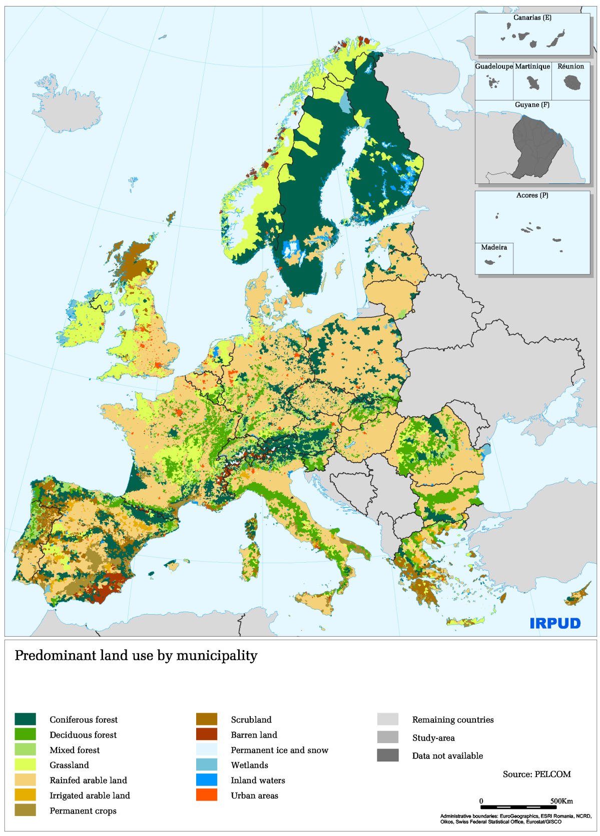

Figure 4: Predominant land use by municipality.

7. Conclusions/Outlook

Having delimited mountain areas, and gathered statistics at the appropriate scales, two main types of questions arise: First, are mountain areas structurally different from the rest of the European territory? Second, if a general typology of mountain areas can be established, how would it differ from traditional typologies of European regions? The latter aspect is particularly important to explore as mountains often correspond to border areas, which implies that their specificity often fail to appear in traditional national or regional analyses.

Finally, looking at the internal structure of each mountain area is particularly important, as the succession of valleys and ridges implies that densely populated areas with intense activity often coexist with nearby unexploited and fragile natural environments. This also calls for combined analyses of physical characteristics and social and economic dimensions.

Overall, GIS proved to be a powerful tool within the project, used in a variety of tasks. Nevertheless, the capacity even of the most current personal computer processor technology was reached in some cases while working with GIS and European wide data at municipality level.

Because the study is scheduled to be completed end of October, the presented results are still work in progress. More results and maps will be shown at the presentation in Innsbruck. Further work will especially focus on the creation of typologies.

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