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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

DEM: Digital Elevation Model

EUDEM: Digital Elevation Model from GSGRDA project

GSGRDA: Geospatial Reference Data Access

EEA: European Environment Agency

EBK: Elevation Breakdown

JRC: Joint Research Centre

LEAC: Land and Ecosystem Accounting

CLC06: Corine Land Cover 2006

GEBCO: General Bathymetric Chart of the Oceans

EXECUTIVE SUMMARY

Elevation breakdown (EBK) has been used in the last years for different purposes in the EEA. The version that is still being used was done in 2006. It was performed with a 1 km resolution digital elevation model. With the arrival of more precise DEMs and with the wide use of different geographical databases far more precise than 1 km, the development of a new elevation breakdown was considered as a necessity. For the sake of continuation it was decided to follow a two ways approach. On one hand a new version of the elevation breakdown with the old methodology was going to be delivered and on the other hand, two more methodologies were going to be developed in selected test areas. These new methodologies were supposed to follow an approach more focused in the necessities of the elevation breakdown in relation to ecosystem assessment and services.

The reference scale was supposed to be 25 meters (same as EUDEM). However after some discussions with EEA counterpart it was decided to use a generalization of the DEM to 100 meters cell size. The main reasons for this resample were related to usability of data ensuring the dataset is standardized structure as the majority as the EEA datasets, being useful for further studies where the data is combined. With this new DEM, a new version of the traditional elevation breakdown has been done. Slight changes in the methodology had to be done due to the different response of a finer DEM to the cartographic tools used. The new version of DEM has the same categories based in the same intervals and thresholds of the old EBK. Of course both of them are quite similar, yet not totally equal due to technical reasons specified below.

The new methodologies for a new EBK are based on the ideas proposed by EEA about having a new elevation breakdown under a more ecological and geomorphological perspective. The using of this information to categorize or organize ecosystem accounting drives this necessity. The initial ideas proposed were discarded in part due to the need of quite complex ancillary data. Since elevation breakdown should be a layer based in elevation (and derivatives of this layer) the results are quite simple: mere combinations of elevation, distance to the sea and slope. Besides, the validation of the final results depends on the correct depiction of the different major landforms and morpho-structures of Europe. For this reason, final results have been calculated for the whole DEM. However, some final enhancement tools are not suitable to be done for a certain number of entities and a test result for Iberian Peninsula has been done for the new methodology on its ‘Version 2’.

1 OBJECTIVES

The arrival of new EUDEM during 2012 was the main reason to develop a new elevation breakdown. Although quite simple, the old methodology has been stable and has been used for the last 5 years when necessary. So the first objective was to calculate a new version of the elevation breakdown used until now. Minor changes in the methodology and processing have been necessary to obtain a classification equivalent to the old one. Changes in the resolution derived in some changes in the behaviour of some ArcGis tools and thresholds so the main aim was to achieve a result as similar as possible to the old database.

For the new methodologies an open view was proposed for EEA side. Some ideas came up in a series of meetings and email communications. The ideas were to use a well-known or proved methodology as much as possible, to append if possible the continental platform and to use an approach to integrate geomorphological and ecological features. Hence, these were the main objectives of the development of new methodologies.

2 ELEVATION BREAKDOWN UPDATE 2012

2.1 DEFINITION & PURPOSE

The Elevation breakdown is used to allocate Land cover changes into homogeneous areas as function of height, slope and distance to the sea. It defines five relief typologies: low coasts, high coasts, inlands, uplands and mountains based on parameters as simple as altitude, slope and distance to the sea. Areas next to the sea (< 10 km from the coastline) are considered ‘Coasts’ and split in two categories: ‘Low coasts’ (< 50 m) and ‘High coasts’ (> 50 m). ‘Inlands’ are the areas between 0 and 200 m outside the coastal strip. ‘Uplands’ are the zones between 200 and 500 m, plus the flat areas between 500 and 1000 m. The sloppy areas between 500 and 1000 m and all the areas over 1000m are classified as ‘Mountains’.

The elevation breakdown reference layer used in EEA until now was created using the LEAC 1 km grid as reference system. In 2012 a new 25 meters resolution *Digital Elevation Model (EUDEM)* was created in the framework of the project GSGRDA. EEA requested, as part of the activities of reception of the new EUDEM, to update the Elevation Breakdown applying, if possible, the same methodology.

2.2 INPUT LAYERS

The main input layers for this work are:

- Digital Elevation Model (EUDEM) and derived datasets
- Coastline and reference mask

Digital Elevation Model (EUDEM) and derived datasets

EUDEM is a 25 meters resolution DEM. The reception of this dataset by EEA was done during 2012. A number of problems with the using of the dataset and errors arose during the first stages of this task (Development of a Terrain Attributes Model and Landform Reference Layer, see report).

Derived datasets were created after EUDEM and are: resample of 100 meters resolution, slope layer at 100 meters resolution, standard deviations elevation and slope to minimize errors in the original dataset (see ‘Procedure steps’), coastline and reference mask (see next paragraph).

Coastline and reference mask

GSGRDA EUDEM coastline was not available because the deadline of GSGRDA project is end of 2012. Due to this fact it was decided as solution to use a coastline derived from a sea/land mask created in 2005 by GISAT, as it was the only one available that included Turkey and Black Sea coastlines, as well as other east European zones, for a 100 meters resolution. The mask was reclassified, corrected and an intermediate coastline was created. This coastline is essential as input to the DIST_REC raster, that represents the distance to the sea.

Description of the reference mask used to filter/clip all input layers:

Sea-Land mask based on GISCO and CLC2000 data in A/I grid format.

ArcGIS9 compliant geometry, compatible with EEA reference grids

The resolution of the data is 100 x 100 meters.

Coordinate Reference System (CRS) is EUR_ETRS89/LAEA1052

Projection: Lambert Azimuthal - Equal Area projection

Extension: Longitude of origin 10d00'00.0000'E, latitude of origin 52d00'00.0000'N, false easting 4321000.000, false northing 3210000.000

Datum: ETRS89 (European Terrestrial Reference System 1989), type geodetic

Valid area: Europe / EUREF

Ellipsoid: GRS 80 (New International), semi major axis: 6 378 137 m., inverse flattening: 298.257222101

Legend:

- 0 - sea
- 1 - land (gisco based coastline/border)
- 2 - land (CLC2000 based coastline/border)

Prepared by tomas.soukup@gisat.cz

08/2005 Gisat

The mask was reclassified into a 0 (non-land) 1 (land) layer (see picture below) and some errors in east Europe were corrected, mainly related to the border end of the DEM, where minus 0 values are included by error when computing the raw dataset, that lead to miscalculation of the slope.

Figure 1 Elevation breakdown mask

To avoid including this corridor of values we buffered the mask inside the DEM for 700m, excluding those values. Below there is an example of the slope with wrong values (red pixels at left picture) and the mask created excluding those values (white layer at right picture)

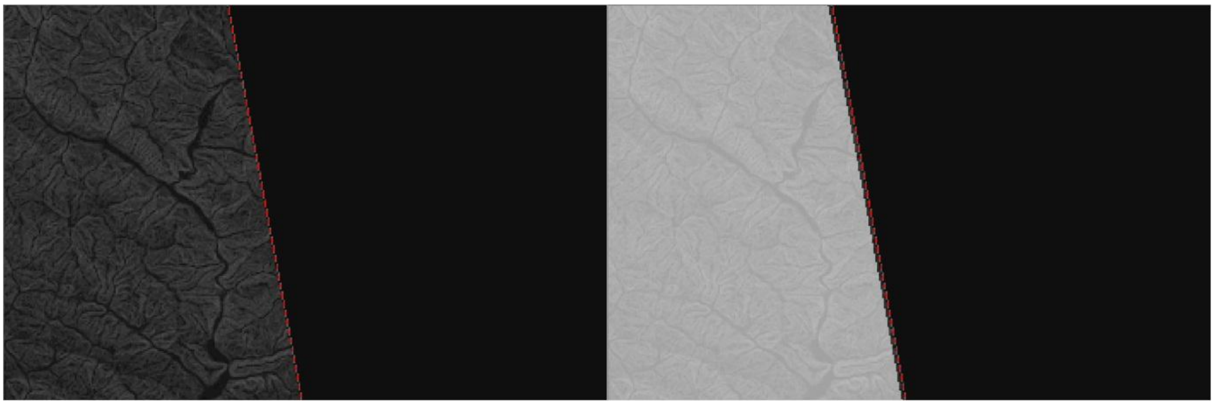

Figure 2 Border values excluded in EUDEM database

2.3 Software used

ArcGis 10 Desktop SP5

2.4 PROCEDURE STEPS

Transformations and DEM resample

52 EUDEM JRC rasters of 25 m resolution matching the European reference 1 km were used as main input for this activity. Those rasters were first of all converted into integer values, decreasing its total size in order to enhance processing time. After that it was possible to mosaic them into a single raster file maintaining the same resolution (25 meters). This raster was then resampled to 100 meters using CUBIC convolution technique, to be used further on as final input DEM.

'The CUBIC option, which performs a cubic convolution, determines the new value of a cell based on fitting a smooth curve through the 16 nearest input cell centers. It is appropriate for continuous data, although it may result in the output raster containing values outside the range of the input raster. It is geometrically less distorted than the raster achieved by running the nearest neighbor resampling algorithm.'

The decision to choose a 100 meter DEM is due to the big amount of temporary data that could be created during the methodological steps. The processing time as well as the amount of space needed to allocate such amount of data could be unreasonable. As well the output and the other input rasters are at 100 meters resolution and considering that EBK is a thematic, generalized that derived dataset, there is more sense to create a product with not too much resolution, maintaining all input/output layers with the same parameters. The decision to go for a 100 meter resolution DEM was agreed with the EEA with their acknowledgement that this change comprises a step forward and ensures its usability to many applications. The dataset matching with the EEA standard grid could be combined with many data at the same resolution and be useful for many applications and studies, for example as input to the LEAC cube.

From the other side some problems were found on many DEM tile borders, apart from the east Europe corridors explained above, where wrong values were found. An example is shown below:

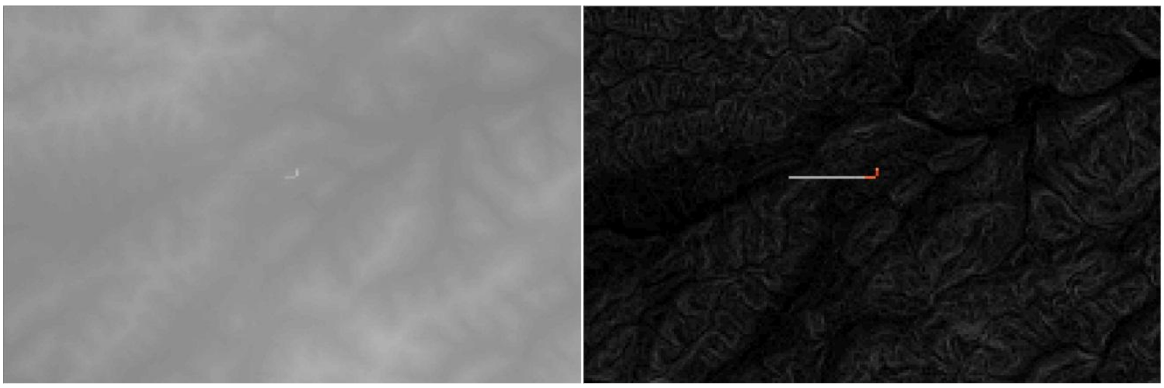

Figure 3 EUDEM errors in the corners of most of the tiles

The DEM area shown above (left picture) is shared by 4 tiles where one or more have a 'corridor' of pixels with wrong DEM values, mainly much higher or lower than the neighborhood, leading to miscalculations when creating the slope (right picture). To correct those errors we opt to generalize the DEM calculating the mean value in a 9x9 window with the tool focal statistics, as we do in a further step for the slope. With this step the problems found above are corrected and a generalized DEM is created, maintaining a mean value of the neighborhood.

The next steps are:

<u>DEM filtering</u>

Filtering the DEM layer by obtaining the **mean** value in a 9x9 window (Arctoolbox Spatial Analyst: Focal Statistics, rectangle, 9x9 cell, mean).

<u>Deriving and smoothing of slope</u>

Deriving slope (in %) from the DEM derived in the previous step.

Filtering the slope layer by obtaining the **mean** value in a 9x9 window (Arctoolbox Spatial Analyst: Focal Statistics, rectangle, 9x9 cell, mean). Normalize as necessary. (0-1)

<u>Preparation of the layer 'Slope'</u>

Reclassifying the smoothed values into two classes to obtain **SLOPE_REC** (Arctoolbox: Reclassify)

Value	**Description**
1	Flat (< 2%)
2	Sloping (> 2%)

Table 1 Reclassification of values for slope in EBK2012_update_100m (SLOPE_REC)

<u>Preparation of the layer 'Distance to the coast'</u>

Creating the 'Distance to the coast' layer (Arctoolbox: Euclidean distance or buffer)

There are 2 options to compute 'distance to the coast' layer:

- First option (applied) is to use Euclidean distance tool that gives distance from source till a specified limit (10km) calculating distance for each cell. The output should then be reclassified to 10 (coast) and 20 (no coast) and clipped using the reference mask for this project with 'extract by mask' tool.
- Second option (discarded) is to use a 10 km buffer (round) to the intermediate coastline layer derived from the reference mask, and then reclassify to 10 (coast) and 20 (no coast) and clip as well the output with 'extract by mask' tool, using again the reference mask.

In the old methodology the intertidal flats and estuaries, considered as sea and as starting line of the 10km buffer distance, were integrated using a different approach. The LEAC 1 km grid contains all the 1 km reference grid cells that intersect with CLC data including intertidal flats and estuaries. The reference coastline used to define the 10 km coastal buffer was created in the past omitting the intertidal flats and estuaries. This is the reason why in some areas the coastal strip is wider than 10 km. As in our case we are dealing with 100 meters data the method had to be changed.

Using the CLC06 v16 raster of 100mt 'extract by attributes' classes 39 (intertidal flats) and 43 (estuaries) to a single raster dataset, convert to polygon or line, use euclidean distance to buffer 10km from those areas, reclassifying then those values from the output distance to 10. Mosaic to 'Distance to the coast' leaving LAST option checked.

Reclassifying the 'Distance to the coast' layer to obtain **DIST_REC** (Arctoolbox: Reclassify).

Value	**Description**
10	Coast (< 10 km)
20	No coast (> 10 km)

Table 2 Reclassification of values for coastal zones in EBK2012_update_100m (DTM_REC)

<u>Preparation of the layer 'elevation slices'</u>

Reclassifying the elevation model into five classes to obtain **DTM_REC** (Arctoolbox: Reclassify). Values under 0 are included in the first class.

Value	**Description**
100	0 – 50 m
200	50 – 200 m
300	200 – 500 m
400	500 – 1000 m
500	> 1000 m

Table 3 Reclassification of values for altitude (elevation slices) in EBK2012_update (DTM_REC)

<u>Combination of the layers 'elevation slices', 'slope' and 'distance to the coast'</u>

Combining **DIST_REC**, **DTM_REC** and **SLOPE_REC**, Sum all 3 values inside combine into a new field and reclassifying the final values into five classes (Arctoolbox: Reclassify).

Value (combine SUM)	**Reclass**	**Description**

111	1	low coast
112	1	low coast
121	3	inlands
122	3	inlands
211	2	high coast
212	2	high coast
221	3	inlands
222	3	inlands
311	2	high coast
312	2	high coast
321	4	uplands
322	4	uplands
411	2	high coast
412	2	high coast
421	4	uplands
422	5	mountains
511	2	high coast
512	2	high coast
521	5	mountains
522	5	mountains

Table 4 Final combine and reclassification values for EBK2012_update

Corrections and preparation of the final layer

- Converting Raster to Vector (Arctoolbox: raster to polygon).
- Dissolving by value (1-5) with multi-part features unselected.
- Eliminating polygons smaller than 10 km^2 (Arctoolbox: Eliminate, select by border option). In the old methodology it was used a threshold of 100 km^2, but considering that now we are dealing with 100 m resolution, instead of old 1000 m pixel size, many coastal areas were deleted from the output using 100 km^2 threshold, inserting an error in the calculation of zones. For that reason the threshold was changed to 10 km^2 pixel areas.
- Rasterizing the resulting polygon layer (Arctoolbox: polygon to raster).
- Creating metadata, colormap files and defining projection.

2.5 OUTPUT LAYER

Layer name is **EBK_2012_100m**

Export is TIFF, with TZW compression.

Classification is the following:

ID	Description
1	Low coasts
2	High coasts
3	Inlands
4	Uplands
5	Mountains

Table 5 Classification of values in final result for EBK2012_update

3 NEW METHODOLOGIES FOR ELEVATION BREAKDOWN

3.1 OBJECTIVE/MOTIVATIONS

As said, the motivations to calculate a new elevation breakdown were open in the sense of obtain a better, finer and more useful EBK to be used from now on. The future using of EBK is mainly in ecosystem accounting as a way to organize the information in different ecological realms. However, the elevation breakdown, being a mere classification of the Digital Elevation Model is not suitable to represent accurately ecosystems. Ancillary data should be used in this process: geology, soils, vegetation and other databases such as landforms should be used to obtain a categorization of ecosystems.

One of the outputs of this Elevation Reference Layer task is the so called 'Landforms reference layer' which was delivered to EEA in August 2012. This is a database with a series of six basic landforms, calculated for the whole Europe. Elevation Breakdown is also a landforms layer, even though the valid scales for both are quite different. This duplicity of results can be somehow confusing and the using of both databases in ecosystem accounting should be thoroughly meditated. Mainly, the landforms reference layer refers to micro and meso-landforms. It was calculated with a methodology called topographic position index with a neighborhood calculation of 2000 meters. So it has the capacity to represent the landforms related to valleys, slopes and ridges. It works far better for steep terrain, where the altitude differences are higher, than in plain terrain. The elevation breakdown, however, aims to represent the big morpho-structures of Europe. In the final part of the process, algorithms of generalization are applied in order to have more massive landforms. The five classes' organization of the old methodology (coastal, plain, uplands, plateaus, mountains) is somehow big morpho-structures or topographic realms defined by geomorphologists. A mixed approach can be done resulting in a combining of both databases. This would lead into a meso-macro landform reference layer with the six meso-landforms for every topographic realm. However, the using of landforms integrated to EBK or other methodologies based on ancillary data should have to be taken into consideration later on.

3.2 MEANS

Elevation breakdown as defined in the technical guidelines is calculated as 'function of height, slope and distance to the sea'. The method to be selected should be based in this type of parameters. The new Elevation Breakdown would be a new method based on simple terrain attributes (distance to the coast, elevation, slope) or with the using of certain type of well known features (FECs or other similar features).

Firstly, an overview of the current approaches on Elevation Breakdowns/Elevation Zones/Landforms has been done. The results are on Annex I. Besides, an exploration of methodologies based on purely statistical characteristics of the data has been done. The conclusion on this research is that the issue has been addressed thoroughly since the 50's, especially by Hammond (1964) and Strahler (1952).

In fact, in the almost all the materials we have found are initial height intervals based on the work of Hammond, which was focused to research about identifying landforms and about specification of the input parameters for analysis of landscape/landforms in the 50th and 60th years. In his work, Hammond sets following initial classes: 0-30 m, 30-91 m, 91-152 m, 152 - 305 m, 305 - 915 m and 915 m. This classification is still used and serves as one of the 'landforms classification rules' in many research and models. By the way, publications of Hammond and his followers are very interesting and can bring interesting tips and ideas in our work, if the EBK will be delineated purely on DEM and its derivatives. Apart from the above one, two more classifications have been studied:

First of them has been published in 'Global Physiographic and Climatic Maps to Support Revision of Environmental Testing Guidelines' (http://www.dtic.mil/dtic/tr/fulltext/u2/a508853.pdf) and these 11 classes are defined (These type of classifications are not suitable for our purposes because many classes are overlapped):

Feature	**Range**
Coastal plain	0 - 150 m
Sand sea/dune	0 - 600 m
Arid river plain	100 - 200 m
Humid river plain	100 - 300 m
Low interior plain	150 - 600 m
High interior plain	300 - 1500 m
Plateau	300 - 2200 m
Basin and range	2200 - 5000 m
Low relief mountains	0 - 1200 m
High relief mountains	0 - 8850 m
Continental ice	0 - 4000 m

Table 6 Classification of the 'Global Physiographic and Climatic Maps to Support Revision of Environmental Testing Guidelines'

The other one has been published in the publication 'An SRTM-based procedure to delineate SOTER Terrain Units on 1:1 and 1:5 million scales'. This publication has been published by JRC in 2005 (http://eusoils.jrc.ec.europa.eu/esdb_archive/eusoils_docs/other/soter/SOTER_endre.pdf)

These initial height intervals are defined:

Range
< 10 m

10 - 50 m
50 - 100 m
100 - 200 m
200 - 300 m
300 - 600 m
600 - 1500 m
1500 - 3000 m
3000 - 5000 m
5000 m

Table 7 Classification of 'An SRTM-based procedure to delineate SOTER Terrain Units on 1:1 and 1:5 million scales'.

The main conclusion is that distribution of elevation slices have been studied in the basis of the whole emerged area. Studies for a continent as Europe are not frequent. Besides, the 'typical' statistical distribution can be changed with the inclusion of new territories (Turkey is a good example of how the distribution can change). So our assessment is that classifications have to be ad hoc, and even though partly based in statistics, they have to rely in the correct definition of well known structures, as explained in the chapter devoted to Version 2.

4 NEW EBK VERSION 1: CHANGING CATEGORIES AND APPENDING OF CONTINENTAL SHELF

4.1 DEFINITION & PURPOSE

The Elevation breakdown was proposed to be reviewed with new methodologies that could add precision and quality to the dataset by increasing the resolution and the number of classes, from 5 to 7-8. Another added value to the dataset was to include the continental shelf using the GEBCO dataset at 30mt resolution, which represents the bathymetry all over the world.

4.2 INPUT LAYERS

- *Digital Elevation Model over Europe from the GSGRDA project 25m*
- Coastline derived from a sea/land mask created in 2005 by GISAT (Explained in the previous section)
- GEBCO_08 bathymetry, 30 arc-second grid

4.3 SOFTWARE USED

ArcGis 10 Desktop SP5

4.4 PROCEDURE STEPS

The procedure steps for the new methodologies are quite similar to those taken to update the former methodology. Transformations and resample of the DEM, deriving and smoothing of slope and preparation of the layer 'slope' are exactly the same as the former method. Please, refer to that chapter if necessary. However, the layers 'elevation slices' and 'distance to the coast' have different thresholds.

The main differences are the reclassification of the DTM_REC into other values, the creation of 7 classes from the 20 values that came from the combine, the increase of the distance buffer from the coastline to 50km and the inclusion of an 8th class with the continental shelf.

The 3 inputs are the same, DTM_REC, SLOPE_REC and DIST_REC. The procedure is done as follows:

<u>Reclassifying the smoothed slope values to obtain the layer 'slope'</u>

The two classes are the same than in the updated version. SLOPE_REC is obtained (Arctoolbox: Reclassify).

Value	Description
1	Flat (< 2%)
2	Sloping (> 2%)

Table 8 Reclassification of values for slope in EBK2012_new_V1 (SLOPE_REC)

Using the clc06 v16 raster of 100mt 'extract by attributes' classes 39 (intertidal flats) and 43 (estuaries) to a single raster dataset, creating a buffer of 50km from those classes inside the land and reclassifying then those values to 10. Mosaic to 'Distance to the coast' leaving LAST option checked.

Obtaining and reclassifying the layer 'distance to the coast'

The value used in this case is 50 km, to obtain **DIST_REC** (Arctoolbox: Reclassify).

Value	Description
10	Coast (< 50 km)
20	No coast (> 50 km)

Table 9 Reclassification of values for coastal zones in EBK2012_new_V1 (DTM_REC_V1)

Obtaining and reclassifying 'elevation slices'

Reclassifying the elevation model into five classes (different ranges to those in the updated version) to obtain **DTM_REC** (Arctoolbox: Reclassify). Values under 0 are included in the first class.

Value	Description
100	0 – 200 m
200	200 – 500 m
300	500 – 1000 m
400	1000 – 1700 m
500	> 1700 m

Table 10 Reclassification of values for altitude (elevation slices) in EBK2012_new_V1 (DTM_REC_V1)

Combination of the layers 'elevation slices', 'slope' and 'distance to the coast'

Combining **DIST_REC_V1**, **DTM_REC_V1** and **SLOPE_REC**, sum all 3 values inside combine into a new field and reclassifying the final values into five classes (Arctoolbox: Reclassify).

Value	Reclass	Description

(combine SUM)		
111	1	Low coastal lands
112	5	Hills
121	2	Interior plains
122	5	Hills
211	3	High coastal lands
212	5	Hills
221	4	Interior highlands
222	5	Hills
311	3	High coastal lands
312	5	Hills
321	4	Interior highlands
322	4	Interior highlands
411	6	Mountains
412	6	Mountains
421	6	Mountains
422	6	Mountains
511	7	High mountains
512	7	High mountains
521	7	High mountains
522	7	High mountains

Table 11 Final combine and reclassification values for EBK2012_new_V1

Obtaining of the layer 'continental shelf'

- Projecting GEBCO dataset into LAEA ETRS89 coordinate system
- Resampling of GEBCO dataset to 100m snapping to the mask created previously, ensuring the pixels overlap correctly
- Extracting values from 0 to -150m (threshold that delimitates the continental shelf) from the GEBCO dataset and reclassifying to value '8'.
- Mosaicking GEBCO values with combine using option LAST (combine)

Corrections and preparation of the final layer

As the sources of both elevation models (*GSGRDA* and *GEBCO*) are not the same, there are imprecision between the coastline of each dataset that leads to existence of 'holes' between the continental shelf and the EBK (combine) coastline. To correct the discrepancies between the coastline of the combine and the continental shelf created it was needed to run the following processes:

- Reclassifying GEBCO values from -150 to higher value (5472) into 9
- Mosaicking this reclassification with the combine using LAST (combine)
- Converting the output to polygon
- Selecting values from the output polygon dataset equal to 9 that intersect with the coastline and deselect manually those outside the EBK + continental shelf areas, if any left. Add to the selection all values from 1-8 and exporting to other dataset. Ensure no data is equal to 0.
- Reclassifying values '9' into '8'
- • Dissolving by field value (1-8) unchecking multi-part features
- Eliminating polygons smaller than 10 km2, including no data values (Arctoolbox: Eliminate, unselect by border option).
- Rasterizing the resulting polygon layer (Arctoolbox: polygon to raster).
- Creating metadata, colormap files and defining projection.

4.5 OUTPUT LAYER

Layer name is **EBK_2012_new_V1**

Export is TIFF, with TZW compression.

Classification is the following:

ID	Description
1	Low coastal lands
2	Interior plains
3	High coastal lands
4	Interior highlands
5	Hills
6	Mountains
7	High mountains
8	Continental shelf

Table 12 Classification of values in final result for EBK2012_new_V1

4.1 ASSESSMENT

The major changes of this New EBK version 1 comparing to the older versions of EBK (1 km and 100 m) are seen in the classes mountains, hills and coastal.

The former class mountains are now subdivided into two classes, mountains and high mountains, and in general lose area, being the most common loss to hills or coastal areas. There is a certain loss of area for interior highlands as well due to the fact that the threshold changed to include areas between 500 and 1000 m and slopes higher than 2% in the this class.

The class interior plains is quite similar to the former inlands, losing just area for the coastal classes, now occupying more area inside land due to the raise in the buffer threshold to 50 km. The low coastal land class is now clearly not completely homogeneous across Europe, being continuous and consolidated in plain coasts as in Northern Continental Europe and England and less consolidated in other areas as Italy, Iberian Peninsula, Norway etc, losing clearly area to class hills that acquires an identity.

The hills class is composed by hills, valleys and light canyons sometimes, and can be said that has the most controversial classification. From the other side it has its identity as a transition class from highlands into lowlands sometimes and other times as a single structure lost in the territory.

High coastal lands are defined as areas from 200 to 1000 m inside the coastal strip (50 km) where the slopes are not too high (< 2%) and it is represented in EBK as coastal plateaus.

The low coastal lands are areas till 50 km distance from the coast almost plains.

Finally the continental shelf class is representing the areas underwater below 0 and above -150 m.

5 NEW EBK VERSION 2: INTEGRATION OF ECOLOGICAL AND GEOMORPHOLOGICAL PERSPECTIVES

5.1 DEFINITION & PURPOSE

As said elevation breakdown are depicting the main macro-landforms of Europe. Experiences of landform mapping of Europe should be taken into account prior to any calculation. A reference work in this sense is Embleton's Geomorphology of Europe. It is also the European mirror of the Geomorphological World Map. Unfortunately we were not been able to achieve the geomorphological map which would have been a main input for validating the classes proposed. Geoporhology of Europe nevertheless was used during this work as a reference work. Validation is also supported by the comparison of the resulting layer with the main features defined in reference works for every major zone or country. As an example, the major structures defined for France are: the Seine and Aquitaine basins, the Bretagne and Central Massifs and also Pyrenees and Alps as mountain ranges. Of course other landforms are pointed out in the references. Our goal is to check a series of major features selected throughout Europe. The main macro landforms which are defined in the work of Embleton and that have been our focus areas are:

- Coastal zones: differences between Variscan and Caledonian Massifs Coasts (Norway, North of England and Scotland, and Portugal and North-West Spanish coast, North West French Coast) and sedimentary coasts.
- Plains: North European plain, Seine and Aquitaine Basins, Pannonian Plain, medium river systems (Guadalquivir, Po, Rhone)
- Uplands: mainly the uplands of Central Europe
- Plateaus: Iberian Plateau, Transylvanian Plateau, Anatolia.
- Mountains: all the alpine arch mountains namely. Cantabrian Range, Iberian Range and Pyrenees, Alps, Dynaric Alps, Carpathian Alps, Mountains of Turkey.

Besides, thanks to the digital elevation model, statistics of the data can be obtained in order to be used as an approach for the best classes' selection. Natural Jerks in ArcGis is a useful tool to define where the main accumulations of data are. It sets classes which are more different to the others, that is, the data contained in them that are the most homogeneous and differences are depicted. According to Online help of ArcGis 'Natural Breaks classes are based on natural groupings inherent in the data. Class breaks are identified that best group similar values and that maximize the differences between classes. The features are divided into classes whose boundaries are set where there are relatively big differences in the data values'. This is why natural breaks were used as a starting point the new EBK methodologies.

The idea behind this classification is to obtain an ecological classification by using just the information about elevation, distance to the sea and slope, or other well-known DEM based databases as ECRINS. Following are the classes (italic) proposed in an email exchange between ETC-SIA and EEA and a comment about the possibility to infer the class with the commented databases):

Floodplains (Those zones related to riparian vegetation & Based on the floodplains developed for ECRINS). This feature cannot be represented by elevation slices or relation between elevation and slope. The major alluvial plains in Europe could be represented by a combination of slope and altitude.

Coastal zones (zones with coastal influence & Coastal FECS -those coastal FECS with a given mean slope or mean altitude-) FECS are entities related to drainage system and drainage system is directly related to elevation. Moreover it could be selected those FECS with a given mean altitude or slope).

The idea is to define the costal zones with the next parameters: those FECs which either:

- Are coastal
- Are at least 10 km. from the coast AND are at least less than 100 m. above the sea level.

In this case, for example, those FECs which were out would be those which are above 100 meters above the sea level or those which are further than 10 km (or the threshold marked)

All the other FECs which are at a given distance to the sea (let's say 10km or 50km) but with an altitude above 100 meters would be coastal

Mountain areas (High mountain, medium and low mountain & Classified by bioclimatic levels)

Divide into high, medium and low is possible with the attributes we want to use. It could be a nested classification. In our opinion, to include bioclimatic regions is out of the scope of this work.

Valleys, plateaus, plains, massifs

Plateau is a geographic term with a meaning related to slope and altitude (low slope and a certain altitude). Massif is a geographic term related to the geologic formation that is usually related to hilly zones situated in medium altitudes or can be seen as the extended area of the main mountain chains (for instance in the report Europe's ecological backbone: recognizing the true value of our mountains. Fulfilling given requirements).

Plain refers to a zone with low slope. It always is situated in the last stage of the big rivers. It can be directly related to any of them or as a zone related to different last stages of rivers. So plains will be always defined by low slope and low elevation

Valleys are a relation between altitudes. This makes difficult to use just elevation and slope to define them. However, major valleys usually are related to big alluvial plains.

Other possibilities: Very steep areas / cliffs,… (As an indicator of bare rock / erosion problems. Very steep areas is a class with a clear focusing). Very steep areas are an interesting class but it can be mixed with other classes, making them confusing.

5.2 INPUT LAYERS

- *Digital Elevation Model over Europe from the GSGRDA project 25m*
- Coastline derived from a sea/land mask created in 2005 by GISAT
- C_ZHYD (ECRINS' FECS)

5.3 SOFTWARE USED

ArcGis 10 Desktop SP5

5.4 PROCEDURE STEPS

The procedure is similar to the mentioned methodologies with the next specificities:

- To use the ECRINS' FECS as a proxy for coastal areas combined with altitude and distance to the sea.
- To use another category for slope and enrich the analysis in this sense.
- To divide the mountains into three categories: mountain massifs, mountains and high mountains.

<u>Obtaining the layer 'coast FECS'</u>

To obtain purely 'coastal' FECS (Coastal strip), a selection of those coastal FECS by the field 'IsCoast' must be performed. This selected features are transformed into raster and stored as coastal zones (final value= '1')

Obtaining FECS with coastal influence (Coastal influence): those FECS situated at least 10 km from the coastline <u>and</u> with at least altitude less than 100 meters.

- Select all the coastal FECS with the field 'Is coast' of Ecrins C_ZHYD
- Select the FECS that fulfill next two requirements:
  - Buffer 10 km from the coast. Intersect with Ecrins C_ZHYD
  - Extract <100 meters DEM. Intersect with Ecrins C_ZHYD

The specific steps afterwards are:

- Reclassifying raster to values under and above 100 meters of altitude.
- Transforming raster to polygon (Under100)
- Buffering 10 km from the coast (Near10)
- Selecting FECS (ECRINS' C_ZHYD) intersecting layers 'Under100' AND 'Near10'
- Exporting to file

For the sake of raster calculations next values are assigned to the file **COAST_FECS** in relation to coast characterization

Value	Description
0	No coast
2	Coastal influence
1	Coastal strip

Table 13 Values assigned to the layer COAST_FECS in relation with their coastal footprint (COAST_FECS)

Reclassifying layer 'slope'

Reclassifying the smoothed values into three classes to obtain **SLOPE_REC_V2**

(Arctoolbox: Reclassify).

Value	Description
10	Flat (< 2%)
20	Sloping (>2%-<5%)
30	Very steep (>5%)

Table 14 Reclassification of values for slope in EBK2012_new_V2 (SLOPE_REC_V2)

Reclassifying 'elevation slices'

The digital elevation model is reclassified into six classes (different ranges) to obtain **DTM_REC_V2** (Arctoolbox: Reclassify). Values under 0 are included in the first class.

Value	Description
100	0 – 200 m
200	200 – 500 m
300	500 – 1000 m
400	1000 – 1500 m
500	1500 - 2000 m
600	>2000 m

Table 15 Reclassification of values for altitude (elevation slices) in EBK2012_new_V2 (DTM_REC_V2)

Combination of the layers 'elevation slices', 'slope' and 'coast FECS'

Combining **COAST_FECS**, **DTM_REC_V2** and **SLOPE_REC_V2**, Sum all 3 values inside combine into a new field and reclassifying the final values into five classes (Arctoolbox: Reclassify).

Value (combine SUM)	Reclass value	Zone
110	3	Plain
112	1	Coastal strip
120	3	Plain
130	3	Plain
132	1	Coastal strip
122	1	Coastal strip
232	1	Coastal strip
222	1	Coastal strip
212	1	Coastal strip
230	4	Uplands
220	4	Uplands
210	4	Uplands
322	1	Coastal strip
312	1	Coastal strip
332	1	Coastal strip
310	5	Plateau
320	6	Mountain massifs
330	7	Mountains
111	2	Coastal influence
121	2	Coastal influence
131	2	Coastal influence
231	2	Coastal influence
221	2	Coastal influence
211	2	Coastal influence
422	1	Coastal strip
420	6	Mountain massifs
432	1	Coastal strip
412	1	Coastal strip
430	7	Mountains
311	2	Coastal influence
331	2	Coastal influence
321	2	Coastal influence
421	2	Coastal influence
410	5	Plateau
411	2	Coastal influence
431	2	Coastal influence
532	1	Coastal strip
530	8	High mountains
520	7	Mountains
522	1	Coastal strip
521	2	Coastal influence
531	2	Coastal influence
510	7	Mountains

512	1	Coastal strip
511	2	Coastal influence
630	8	High mountains
620	8	High mountains
610	8	High mountains
621	2	Coastal influence
631	2	Coastal influence
632	1	Coastal strip
622	1	Coastal strip
612	1	Coastal strip
611	2	Coastal influence

Table 16 Final combine and reclassification values for EBK2012_new_V2

Creating metadata, colormap files and defining projection.

Unfortunately, due to the high quantity of polygons, it is not possible to eliminate those small polygons to make the layer more useful. Eliminating process should be reconsidered if this classification is of interest for EEA.

5.5 OUTPUT LAYER

Layer names are:

- **EBK2012_new_V2** (Elevation breakdown 100mt)
  - Please note: this layer is European wide but it does not have the last generalization process where features smaller than 10 km^2 are integrated in other bigger. Calculations are possible and the layer is perfectly fine but might not be useful for representation at broad scales.
- **EBK2012_new_V2_IberianPeninsula**
  - Please note: this is a test site for the application of generalization procedures. It is cut by the mask of Iberian Peninsula FECS so the coastline may differ.

Export is TIFF, with TZW compression.

Classification is as follows:

ID	Description
1	Coastal strip
2	Coastal influence zones
3	Plains
4	Uplands
5	Plateaus

6	Massifs
7	Mountains
8	High mountains

Table 17 Classification of values in final result for EBK2012_new_V2

5.6 ASSESSMENT

Using of FECs is considered a great output of this work. In contrast to the other methodologies, the limits of FECS are quite natural. The processing time is relatively quick and the resultant class is homogenous.

The class: ‘coast’ depicts all the FECS which are stored as coastal in ECRINS. The influence of the sea in this zone is out of doubt. A flaw in this class is that is its width is dependent on the size of the FECS. However, FECS are smaller where the relief is steeper so due to the altitude the influence can be lesser.

The class coastal influence is very useful in our opinion. It is dependent on altitude and distance to the coast. It is very useful to differentiate the two types of European coasts: erosive and sedimentary. Hence, it is much wider in the central plains of Europe than on the coastal highlands of Norway or Scotland. Quite useful to depicted better the sea influence on the sea in the Nederland, where a purely ‘distance to the coast’ calculation can lead in the definition as non-coast to ones permanently flooded by sea water.

The class plains work very well with the threshold used in the former EBK. 200 meters of altitude contour is a very useful limit to depict not only the north and central European plain and the Danube basin but also the medium sized valleys of Mediterranean Sea.

Uplands are perhaps a more tricky class. The objective is to the hilly zones of central and Western Europe, associated with old eroded massifs. However it depicts also those zones of transition between plains and mountainous massifs, especially around the alpine arch. In these zones, however, the class is quite narrow and hence can be distinguished from the real upland zones.

Plateaus as well depicted in the resulting layer. They are situated normally above 500 meters and are characterized by the very flat deposits on an erosional surface. By selecting area above 500 meters and slope under 2%, Iberian Plateau is perfectly defined, as well as some flat erosional surfaces of Massif Central and mid height ranges of central Europe. The relief roughness of Transylvania and maybe its small six does not allow having a good picture of this feature. Also the Anatolian plateau is not defined very clearly in this class because of the multiple small ranges that crosses it and the very high attitude of the plateau, falling in the mountain massif class.

Mountains are defined by three classes. There is a differentiation between mountainous massifs, which are areas belonging the alpine arch due to its altitude. Here some features out of the alpine arch are shown as the mountains of Norway.

Mountains and high mountains, defined by the higher altitudes in Europe, and defining a more specific ecosystem

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6 ANNEX I: OVERVIEW OF CURRENT APPROACHES TO THE DEFINITION OF THE ELEVATION BREAKDOWNS/ELEVATION ZONES/LANDFORMS

Currently, there are three main approaches used for height zoning of terrain:

1) A purely mathematical approach based on altitudes
2) An approach which is based on characteristics derived from the DEM
3) An approach which combines elevation data (or derivatives of DEM) and other characteristics of the landscape

6.1 A PURELY MATHEMATICAL APPROACH BASED ON ALTITUDES

In the simplest case the area is divided into zones with appropriately chosen step height, the size of which depends on the details to the newly derived layer. This procedure basically follows the colorful expression of relief in the maps (hypsonometry)

An alternative to this simplest method is dividing of the area into vertical zones so that the area of each zone is approximately the same. This method is used when examining small, relatively homogeneous areas – eg. watersheds. Example of this approach is here:

http://www.hubbardbrook.org/watersheds/maps/w6_zones.htm

This method is not suitable for use on large areas, since the division into classes is rude and it does not cover sufficiently different characteristics of the territory.

6.2 AN APPROACH BASED ON CHARACTERISTICS DERIVED FROM THE DEM

This approach also uses a purely mathematical methods, but the direct values of DEM (elevations) are not used, but data, which are derived from the DEM (slope, aspect or more complicated derivatives such as Topographic Position Index), are used.

This approach is the basis of Elevation Breakdown (Landform definition) system currently used within the EEA. The system is applicable to both small area and at the level of countries or continent too. This approach gives a comprehensive view of the height / morphological division of the territory, but does not include any other characteristics of the territory.

Some examples of using of this approach are illustrated in next links:

- The system, which uses a altitude and different DEM derivatives (slope, aspect) for dividing the territory to 31 Elevation Breakdown/Landform classes:

http://apps.icarda.org/wspublications//Water_management_series/KRB_report_series/Agro-ecological.pdf

- The Landforms definition (area is divided into 12 height/landform classes) based on the slope and on a comprehensive morphological parameter – Land Position Index:

http://www.mass.gov/dfwele/dfw/nhesp/land_protection/biomap/pdf/biomap2_tech_report_full.pdf

- The approach based on the characteristics of DEM and using fuzzy logic for Landform extraction:

http://kelab.tamu.edu/standard/restoration/documents/landform%20paper.pdf

6.3 An approach which combines elevation data (or derivatives of DEM) and other characteristics of the landscape

This approach uses a combination of elevation data (or values derived from elevation data) with some additional characteristics (vegetation, geology, geomorphology, etc.).. Number of classes (zones) depends on the details required and on the application for which the zoning is purposed. With such a comprehensive approach we can talk about of Ecological Land Units rather than about affordable elevation zones, because it includes both the height characteristics, as well as other additional parameters describing the territory. This approach is similar to the approach used so far in the definition EBK within the EEA, but is even more complex. Thus defined zonation is applicable to both small territories as well as the level of the province, country or continent - it just depends on what level details are defined by the input data. The advantage is a more comprehensive view on the area, including other aspects (ecological, geological ...) in addition to purely morphological point of view. This approach is, however, difficult to choose the data because the input data should be consistent with the level of generalization, diversification into classes etc.

Examples:

- One possible approach, which combines data obtained from DMT and data about vegetation, geology, and so on is here:

east.tnc.org/east-file/62/NAC-Ecoregional-Plan.doc

- Another approach, which combines parameters derived from DEM (slope and morphology) and hydrogeological characteristics is shown here:

http://www.ncgia.ucsb.edu/conf/SANTA_FE_CD-ROM/sf_papers/fels_john/fels_and_matson.html

This approach introduces hierarchical structure - the first level (6 classes) is defined by DEM derivatives and second level (up to 10 subclasses) is based on the hydrogeological characteristics.

- The USGS has developed a detailed system, (27 classes) for classification of heights, which combines the basic height division with geological and geomorphological data:

http://nh.water.usgs.gov/projects/ct_atlas/ELU30nap_overview.doc

and

http://nh.water.usgs.gov/projects/ct_atlas/ELU30lne_overview.doc

The described application is available on the map server:

http://maps.gcs-research.net/usgs/ctriveratlas/

- The system, defining the height zone, based on a combination of data from DMT and geological data are described in:

http://books.google.cz/books?id=OmBP8Xixij0C&pg=PA8&lpg=PA8&dq=%22landform%22+and+%22elevation+zones%22&source=bl&ots=LcIApF8nlF&sig=FswiuaOEyZkrCR-bI9JhI7RVpmw&hl=cs&sa=X&ei=xx6qUJenNczDswbt9oHYCg&sqi=2&ved=0CB4Q6AEwAA#v=onepage&q=%22landform%22%20and%20%22elevation%20zones%22&f=false

Disadvantage of this system is the low number of classes, but it is possible choose a more detailed breakdown of heights or detailed data on the geological bedrock and thus make a more detailed classification system.

- Another example might be a system combining elevation data segmentation and Land Use:

http://www.eu-watch.org/media/default.aspx/emma/org/10363769/WATCH+Technical+Report+Number+20+Hydrological+drought+characteristics+of+the+Nedo%C5%BEery+sub+catchment,+Upper+Nitra,+Slovakia,+based+on+HBV+modelling.pdf

- The final example shows a complex approach, combining heights, derivatives of DMT (landforms and aspect) and geological data (the system has a total of 21 classes):

https://fishandgame.idaho.gov/ifwis/idnhp/cdc_pdf/aquari97.pdf