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Contribution of Copernicus in support to monitoring of habitats, species and the Natura 2000 network

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1 Introduction

Copernicus land monitoring services present a landmark in European earth observation. The project provides a common framework for a frequently updated monitoring system of environmental change at European scale. The goal of the present work is to explore how the relevant product portfolio of the Copernicus framework (Table 1) could be used to contribute to the monitoring of habitats, species and the Natura 2000 network.

Table 1.1 Selection of available Copernicus products relevant for biodiversity. Brackets indicate that product is either not fully validated or completely available at the time of writing this report.

Component	Layer name	Year of production	Data format	Coverage
Pan-European	HRL natural and semi-natural grasslands	2012	Raster	EEA 39
Pan-European	HRL forest type / density	(2012)	Raster	EEA 39
Pan-European	HRL wetlands	2012	Raster	EEA 39
Pan-European	HRL permanent water bodies	2012	Raster	EEA 39
Pan-European	HRL imperviousness	2006, 2009, 2012	Raster	EEA 39
Local	Urban atlas	2006, (2012)	Vector	Thematic
Local	Riparian zones	2012	Vector	Thematic
	Green Linear Elements*			
Local	Natura 2000 (specific grassland types only)	2006, (2012)	Vector	Thematic

*Only available in areas mapped by Riparian zones

Gaining information on habitat quality and threats to biodiversity is essential to safeguard the success of protected area networks such as Natura 2000. When considering using Copernicus data for ecological assessments, it is important to bear in mind the limitations of remote sensing data for such an objective. Copernicus products are based on imagery ranging from 2.5m – 20m; biodiversity aspects on the other hand often require data on species composition and abundance to assess trends in species assemblages and habitats. Clearly such issues cannot be directly addressed with remote sensing data.

There are possibilities, however, to indirectly infer information on the status and threats to habitats. For instance, anthropogenic pressures stemming from land-use change affect habitats and the species associated with them and – as these processes take place at the landscape scale - are able to be quantified using Copernicus products. Previous assessments have therefore focused on quantifying land-cover changes, indicating the loss of certain habitats (e.g. Gerard et al., 2005). The latest indicator for land take in Europe is based on Corine Land Cover (CLC) changes from 2000-2006 ('Land take — European Environment Agency', 2016). This approach allows to quickly obtain quantitative information which is both relevant to ecologists and policy makers. At European scale, Corine land cover has long been the main tool for land cover based analysis; however, the introduction of High Resolution Layers (HRLs) has added a new dimension of spatial accuracy to perform such assessments.

2 Copernicus product portfolio

2.1 Pan-European component: High Resolution Layers

Copernicus is composed of four main components: Global, Pan-European, Local and In-situ. The High Resolution Layers belong to the pan-European component of Copernicus and are designed as mono-thematic raster data sets (imperviousness, forest, grassland, water & wetness), which are to be derived from satellite data in a highly automated process.

The aim of these layers is to provide more frequent updates on land cover and to serve as an early warning system for land cover changes.

2.1.1 General data specifications

All HRLs are produced from 20 m resolution satellite imagery through a combination of automatic processing and interactive rule based post-processing. Five themes have been produced to date by the GMES Initial Operations (GIO), corresponding to the main level 1 themes of CLC, i.e. the degree of sealed soil (imperviousness), tree cover density and forest type, (semi-) natural grasslands, wet lands and permanent water bodies. The HRLs are produced independently from one another (except for the water and wetness layer), resulting in potential spatial overlaps of the individual layers. Such overlaps are not only possible, they are actually typically desired given that, for example, an area covered by forest could by located on a wet area, or a patch of land with a low tree cover density might also contain some grassy vegetation.

The 20m resolution “raw” data are finally aggregated to 100m grid cells for dissemination and validation. The pan-European wall-to-wall products cover the EEA39 countries.

The individual HRLs are characterised by the following specifications: imperviousness, forest, grasslands, permanent water bodies, and wetlands. These are outlined in more detail below, and more information can be found at: http://land.copernicus.eu/pan-european/high-resolution-layers/view.

2.1.2 Imperviousness

Built-up areas are characterized by a substitution of original (semi-) natural land cover or water surfaces with an artificial, often impervious cover. These artificial surfaces are usually maintained over long periods of time and can be considered “irreversible”. The imperviousness HRL captures the spatial distribution of artificially sealed areas, including the degree of sealing of the soil (1 – 100%) per area unit. It therefore captures processes like urban sprawl as well as densification of already existing artificial (urban) areas.

The imperviousness layer is today the only one of the HRLs for which trend information is available, based on previous assessments (i.e. 2006-2009 and 2009-2012). The data layer is used for the EEA indicator on imperviousness and imperviousness change, showing the average annual change in imperviousness for a given reference unit (i.e. per 10 km grid).

2.1.3 Forest

The forest HRL actually consists of two individual products: Tree Cover Density (TCD) and Forest Type (i.e. coniferous / broadleaved). The tree cover density product maps the level of tree cover density in a range from 0-100%; it has no MMU (minimum number of pixels to form a patch) and a minimum mapping width of 20 m.

The forest type product comes as close as possible to the FAO forest definition. In its original (20m) resolution, it consists of two products: 1) a dominant leaf type product that has a MMU of 0.5 ha, as well as a 10% tree cover density threshold applied, and 2) a support layer that maps, based on the dominant leaf type product, trees under agricultural use and in urban context (derived from CLC and imperviousness 2009 data).

The strength of the forest layer lies in its ability to cope with different forest definitions based on different density thresholds and thus to make forest data more comparable internationally. For the final 100m product, trees under agricultural use and in urban context from the support layer are removed. Only three classes are maintained “coniferous”, “broadleaved” and “mixed”.

2.1.4 Grasslands

The product needs to differentiate between the layer produced under GIO (i.e. based on 2012 data) and the layer for 2015. The 2012 GIO product aimed at mapping natural and semi-natural grasslands as opposed to cultivated / managed grasslands used for grazing or hay production. The product strongly relies on the absence of signs of management, non-regular shapes of the patches, the absence of artificially limited parcels and the location in remote areas often on slopes or poor soils which in turn limit production.

The 2012 final product is a binary layer showing the presence / absence of natural grasslands.

The new 2015 grassland product consists of a grassland (grass and non-woody vegetation) mask with several supporting layers: a ploughing indicator to support the separation of grasslands from croplands and a grassland probability layer.

A better identification of grassland characteristics is of major importance for various biodiversity and ecosystem assessments as grasslands are under constant threat, yet they remain extremely difficult to map. The new layer will provide important support for the differentiation of grasslands and croplands in general and for the identification of high nature value farmlands in particular (i.e. the integration of management intensities).

2.1.5 Permanent water bodies

This layer maps permanent lakes and ponds, rivers and coastal water surfaces, such as lagoons and estuaries. It does not include the sea and ocean, nor liquid dumpsites. In addition to the 20m satellite data, the production of the layer uses seasonal time series of medium resolution images to determine the “permanence” of the water bodies.

Until now, CLC is the only wall-to-wall data set of water bodies in Europe, but is limited to water bodies above 25 ha in size. The HRL water layer aims to close this gap by providing information about permanent water bodies independent of a minimum size.

The final product is a binary layer showing the presence / absence of permanent water bodies.

2.1.6 Wetlands

The concept of this layer has been redefined following the problems with the GIO HRL on “wetlands”. The name of the previous layer has often led to misunderstandings, as the layer does not map “wetlands” in the ecological understanding of the idea, but rather different degrees of wet lands (i.e. wetness of the surface) and their permanence.

The ecological misconception has been overcome in the updated specifications of the 2015 HRL on “water & wetness”. The objective of the redefined layer is not to map wetlands per se, but to identify areas that are characterised by differently high degrees of soil water content and open water over different times during the year. Eventually this layer could be used to support the identification of (ecological) wetlands together with other ancillary information.

This new layer (together with the new grassland layer) will be an important source of information for the MAES – Mapping of ecosystems and their services – process as information on the extent and the changes (in quality and quantity) of grasslands and wetlands is currently not available in a spatially explicit manner at European level.

2.2 Local component

The local component of Copernicus focuses on areas that are specifically sensitive and prone to environmental challenges and problems. Contrary to the products of the pan-European component, the local component products do not cover the complete territory in a wall-to-wall manner, but only selected areas of interest, with a specific challenge in terms of either environmental pressures and problems or spatial management. Examples include: cities above a given number of inhabitants, protected areas under the Natura2000 instrument, riparian zones along the hydrographic network or coastal zones etc….

As opposed to the pan-European component, which for national, regional or local applications is hampered by a relatively coarse spatial resolution (CLC 25ha MMU, HRLs 1ha grid), the local component provides a different level of spatial and thematic detail, going down from 1ha to 0.25 ha MMU. However, the offset is that these products are only mapped for specific areas of interest. The products are based on very high resolution imagery (2.5 x 2.5 m pixels).

2.2.1 Urban Atlas

The Urban Atlas provides pan-European comparable land use and land cover data for urban areas and their hinterland (i.e. mostly defined by the labour catchment). The mission of the first version of the Urban Atlas is to provide reliable, inter-comparable, high-resolution land use maps for 305 so-called Large Urban Zones (more than 100.000 inhabitants as defined by the Urban Audit) for the reference year 2006.

Version 2 of the Urban Atlas provides similar information for the reference year 2012, but for urban areas typically with more than 50.000 inhabitants (i.e. 697 sites). In UA2012, the commonly agreed concept between the EC and the OECD of Functional Urban Areas (FUA) has been taken as geographic extent for the areas to be mapped. Its mission is to provide very high-resolution mapping of Land Cover and Land Use, and to monitor changes in urban spaces and the fringe thereof, the so-called “rurban” areas, i.e. the transition of the urban tissue into the rural landscape.

As the Urban Atlas provides first and foremost a comparative geospatial basis for major cities in Europe, which is complementary to the statistical data from the Urban Audit, its primary use relates to decision-making in regional funding as implemented by the EC’s Directorate General for Regional and Urban Policy. However, the richness of included information makes the service suited for additional applications, such as the identification of green urban areas, the EEA online map book, the report on urban sustainability as well as for studies on urban green infrastructure, or monitoring the extent of urban sprawl.

Street Tree Layer (STL):

The Street Tree Layer (STL) is a separate layer from the UA2012 LULC Layer produced within the level 1 urban mask for each FUA. It includes contiguous rows or a patches of trees covering 500 square meters or more and with a minimum width (MinMW) of 10 meter over "Artificial surfaces" (nomenclature class 1) inside FUA (i.e. rows of trees along the road network outside urban areas or forest adjacent to urban areas should not be included).

Data specifications

Urban atlas

The Urban Atlas 2006 is a vector-based dataset with 17 urban classes and a minimum mapping unit (MMU) of 0.25 ha and an additional 3 rural classes with an MMU of 1 ha. The minimum mapping width between 2 objects for distinct mapping is 10m. On request by the user community, for UA2012 the number of rural classes was extended to 10 classes. The coverage of the UA2006 data is EU-28. In UA2012 the coverage was extended to EU28 + EFTA countries (CH, IS, NO). Further extension to the West Balkans and Turkey is programmed for 2017-18.

Street Tree Layer

The production of the Street Tree Layers was performed on the basis of SPOT 5 Supermode data used for the UA2012 production acquired between March and November with a preference with spring and late summer imagery. An interactive automated classification approach was applied to identify contiguous rows or a patches of trees covering 500m² or more and with a minimum width of 10 m. A post-processing routine was applied to provide the results in vector format.

Link to the data

http://land.copernicus.eu/local/urban-atlas

Link to product specifications

http://land.copernicus.eu/user-corner/technical-library/urban-atlas-mapping-guide

2.2.2 Riparian zones

Riparian zones represent transitional areas occurring between land and freshwater ecosystems, characterised by distinctive hydrology, soil and biotic conditions and strongly influenced by stream water. They provide a wide range of riparian functions (e.g. chemical filtration, flood control, bank stabilization, aquatic life and riparian wildlife support, etc.) and ecosystem services. The Riparian LC/LU product is providing a detailed LC/LU dataset for areas along a buffer zone of selected rivers covering EEA39.

The area to be mapped is approximately 525.000 km² and comprised of a merging of selected rivers with Strahler level 3 to 8 with different buffer sizes derived from the EU-HYDRO dataset and the area of the Pan-EU Flood Hazard Map produced by JRC for the 100-year return period (Alfieri et. al. 2013) with 100m grid size.

The rationale for this local component is provided by the need to monitor biodiversity at European level and to support the objectives of several European legal acts and policy initiatives, such as the EU Biodiversity Strategy to 2020 (COM(2011) 244 final) , the Habitats (Directive 92/43/EEC) and Birds (Directive 2009/147/EC) Directives and the Water Framework Directive (Directive 2000/60/EC). The mapping of land cover and land use along a buffer zone of selected areas has as main objective to support the Mapping and Assessment of Ecosystems and their Services (MAES), as part of the EU Biodiversity Strategy to 2020.

The actual product consists of three complementary data sets:

Land cover / land use (LCLU): The LCLU classification is based on the MAES typology of ecosystems (level 1 – 4) and is tailored to the needs of biodiversity monitoring in a buffer zone of along watercourses. The legend is defined in as a hierarchical system, maintaining a general correspondence to CLC and the Urban Atlas in the upper levels while including more EUNIS related habitat information on the lower levels. For a details of the nomenclature, please refer to the product specifications (link provided below).

Delineation of the Riparian Zones (DRZ): The delineation of Riparian Zones is based on a complex spatial modelling approach, making use of the Riparian Zones' LC/LU classification, large-scale earth observation data and a range of additional geo-data sources, as well as derived spatially explicit indicators. Inputs are regionally parameterised and weighted according to relative importance in a fuzzy modelling approach. The DRZ differentiates between the potential riparian zone as the result of the modelling approach and the actual riparian zone, the area with the highest probability to find recent riparian features on the ground.

Green Linear Elements (GLE): GLE are ecologically significant, structural landscape elements which act as important dispersion vectors of biodiversity. They compromise hedgerows and lines of trees.

Data specifications

The data specifications of the local component are slightly different for the different data sets:

LC/LU

The Minimum Mapping Unit (MMU) is 0.5 ha; the Minimum Mapping Width (MMW) is 10m

DRZ

Potential Riparian zones: Minimum Mapping Unit (MMU) is 50 ha.
Actual and Observable Riparian zones: Minimum Mapping Unit is 625m².

GLE

Small linear vegetation features such as hedgerows, scrub and tree rows with a minimum length of 100m and a width of up to 10m;Isolated patches of trees and scrub with a size between 500 m² and 0.5 ha.

Link to the data

http://land.copernicus.eu/local/riparian-zones

Link to product specifications

http://land.copernicus.eu/user-corner/technical-library/urban-atlas-mapping-guide

2.2.3 Natura 2000 – grasslands

The Natura2000 product offers a detailed land cover / land use map for a selection of Natura2000 sites and a surrounding 2 km buffer zone. The initial mapping exercise covers a selection of five endangered semi-natural and species rich grassland habitat types which have been assessed in order to investigate the effectiveness of the N2K network in halting the decline of certain grassland habitats. The mapping was conducted for 2006 and 2012 and change analysis is available.

In general this layer is designed for the needs of biodiversity monitoring as developments within N2K can be traced reliably. The nomenclature is designed according to feasibility of production and the MAES ecosystem types, a high degree of comparability with other LC/LU products, such as the Urban Atlas and the riparian zones is ensured.

The inclusion of the remaining grassland-rich N2K sites not selected in the first exercise are currently implemented in 2016 and an extension to other habitat types is also foreseen and under discussion.

Land cover / land use (LCLU): As stated above the LCLU classification is based on the MAES typology of ecosystems (level 1 – 4) and includes grassland-rich sites (5 grassland habitats types 6210, 6240, 6250, 6510 and 6520). The mapping extends 2km beyond site boundaries.

Data specifications
The Minimum Mapping Unit (MMU) is 0.5 ha; the positional accuracy is less than 5m

Link to the data

http://land.copernicus.eu/local/natura

Link to product specifications

http://land.copernicus.eu/user-corner/technical-library/N2K_Nomenclature_Guidelines.pdf

3 SWOT analysis of Copernicus products

The following chapters summarize the strengths, weaknesses, opportunities and threats concerning the application of Copernicus products for biodiversity monitoring. **Strengths** and **weaknesses** are internal, meaning that they relate to the existing dataset. External **opportunities** and **threats** point towards issues that relate to the possibilities and limitations for the individual datasets in the future.

3.1 Pan-European component: High Resolution Layers

3.1.1 Imperviousness:

	Positive	**Negative**
Internal	Strengths: - Repetition rate - Spatial resolution - Pan-European wall-to-wall coverage	Weaknesses: - Time series analysis not fully robust yet - Actual change rate may be lower than noise in data processing (i.e. potentially high level of uncertainty in results)
External	Opportunities: - Frequent update on urban pressures - Re-analysis of 2006, 2009 and 2012 products to improve time series analysis	Threats: - None known at this point

3.1.2 Forest (Forest mask & tree cover density)

	Positive	**Negative**
Internal	Strengths: - Repetition rate - Spatial resolution - High reliability - Pan-European wall-to-wall coverage - Comparability of different forest definitions (based on density)	Weaknesses: - No time series available yet - No species information (coniferous and deciduous only) - No information on forest condition
External	Opportunities: - Change monitoring (2015 production) - Landscape metrics analysis	Threats: - None known at this point

3.1.3 Grassland (2012 definition)

	Positive	Negative
Internal	Strengths: - Spatial resolution - Pan-European wall-to-wall coverage	Weaknesses: - Known thematic quality issues - Large variation in quality/reliability between different MS - No assessment of all types of grassland areas, focus on natural and semi-natural areas only
External	Opportunities: - Re-definition of specifications for HRL 2015	Threats: - Limited reliability of the data set - Product definition will change entirely

3.1.4 Grassland (2015 definition)

	Positive	Negative
Internal	Strengths: - Mapping of all grass-covered areas - Based on time series to improve separation from arable land (ploughing indicator) - Multi-temporal & multi-sensor data, incl. SAR data - Spatial resolution - Pan-European wall-to-wall coverage	Weaknesses: - No direct information on management intensity - No information on grassland density
External	Opportunities: - Reference data for grassland mapping - Complementarity to CLC grassland maps - Detection of locations where grassland are lost	Threats: - Difficulties to map grassland types from space - Sparse grasslands in dry regions

3.1.5 Permanent water bodies (2012 definition)

	Positive	Negative
Internal	Strengths: - Spatial resolution - High reliability - Pan-European wall-to-wall coverage	Weaknesses: - Lower reliability at coastal inlets (transition between fresh – and saltwater) - Issue with temporarily flooded riverbeds. Large variation in quality/reliability between different MS
External	Opportunities: - Could potentially be used as base layer for piscifaunal distribution monitoring.	Threats: - Production will be discontinued

3.1.6 Wetlands (2012 definition)

	Positive	Negative
Internal	Strengths: - Spatial resolution - Pan-European wall-to-wall coverage	Weaknesses: - Misconception of layer with ecological concept of wetlands - Known thematic quality issues in areas with difficult mapping situations
External	Opportunities: - Wetland mapping	Threats: - Production will be discontinued

3.1.7 Water and wetness layer (2015 definition)

	Positive	Negative
Internal	Strengths: - Joint production of water and wetness product - Spatial resolution - Pan-European wall-to-wall coverage - Long-term multi-temporal & multi-sensor data, incl. SAR data - Introduction of in-situ data in processing chain	Weaknesses: - Wetness is not directly visible in any EO data - Mapping of water / wetness under vegetation
External	Opportunities: - Mapping of permanent and temporary water bodies - Mapping of wet areas, support to the identification of wetlands	Threats: - Processing of large amounts of EO data

3.2 Local component

3.2.1 Urban Atlas

	Positive	Negative
Internal	Strengths: - Spatial resolution (0.25 ha in urban areas, 1 ha outside) - Update frequency - Land cover product (ability to distinguish different classes)	Weaknesses: - Spatially restricted to urban areas and their surrounding - Thematic focus on urban classes, low thematic resolution of non-urban classes
External	Opportunities: - Change analysis - Potential to be used for population of N2K - Identification of urban pressures on N2K	Threats: - Not yet fully validated

3.2.2 Riparian Zones

	Positive	Negative
Internal	Strengths: - Spatial resolution - Land cover product (ability to distinguish different classes) - Detailed classes (level 3 & 4) aligned with MAES ecosystems - Very high thematic resolution	Weaknesses: - Spatially restricted to riparian areas (complex technical definition)
External	Opportunities: - Potential to be used for population of N2K - Dataset component "Green linear elements" could be used to monitor ecologically relevant structures within N2K.	Threats: - Not yet fully validated

3.2.3 Natura 2000 – grasslands

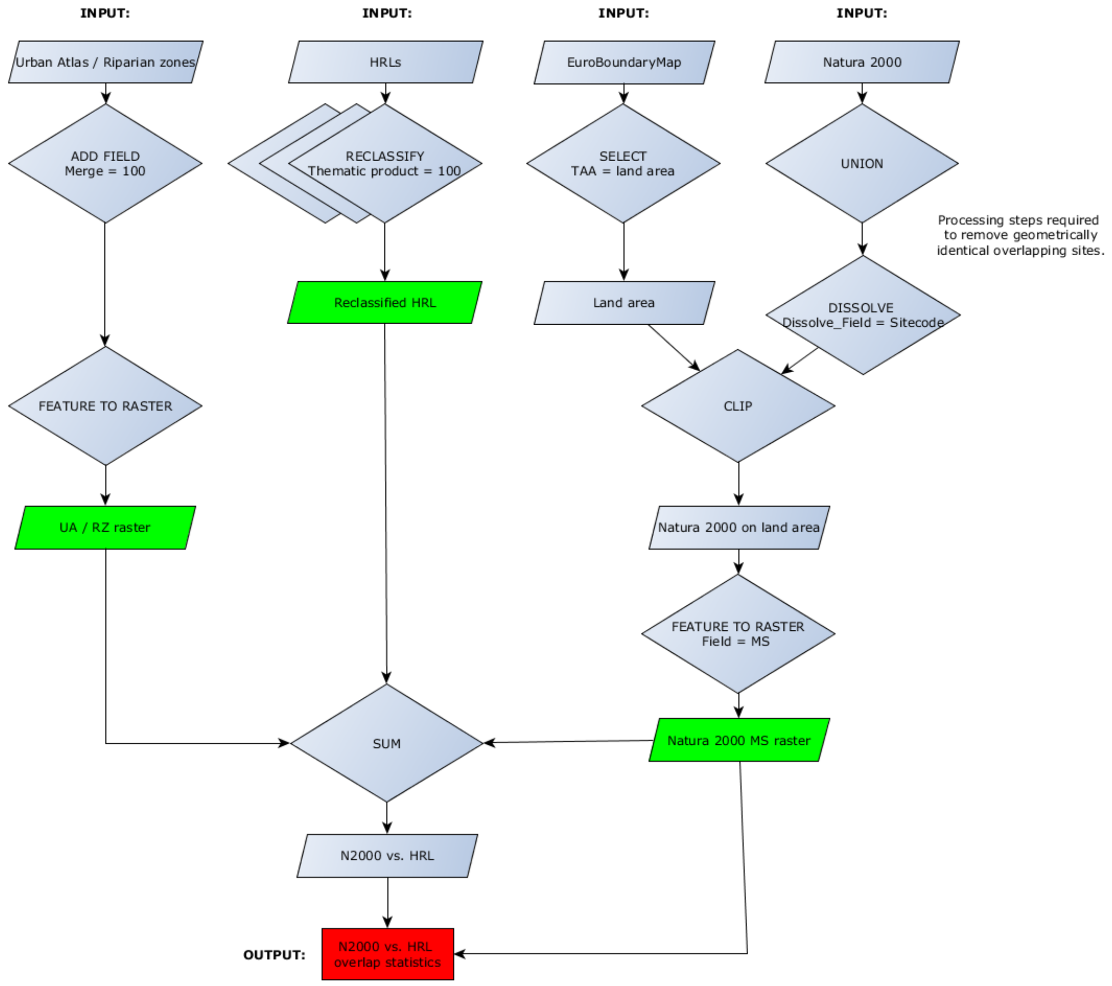
	Positive	Negative
Internal	Strengths: - Spatial resolution - Land cover product specifically targeting N2K sites - Very high thematic resolution - Detailed classes aligned with MAES ecosystems	Weaknesses: - Currently only available for a selection of grassland rich sites. -
External	Opportunities: - Assessment of high resolution changes within and in the immediate surrounding of N2K sites - Additional sites are supposed to be added towards the selection, thus increasing coverage. - Spatial information related to N2K tabular data	Threats: - Not yet fully validated

4 Spatial overlaps between N2000 and Copernicus

A first step towards elaborating applications for Copernicus in the monitoring of habitats was to establish how much surface area of Natura 2000 actually overlaps with Copernicus products.

Natura 2000 safeguards the protection of numerous different habits across Europe. Due to their size, individual sites often contain multiple habitat types. Sites located along coastal areas or on islands, for example, also contain marine habitats. Copernicus products on the other hand do not contain marine environments. Simply overlaying Natura 2000 areas with Copernicus without excluding marine sites would therefore cause an underestimation of the calculated overlapping surface amount. For this reason, all Natura 2000 were clipped to the boundary of EU 28 Land mass as defined by EuroBoundaryMaps. Furthermore, sites were dissolved by sitecode to remove overlapping polygons. The spatial overlay between Natura 2000 and Copernicus was subsequently performed on a product basis (see Figure 4.1 for full workflow).

Figure 4.1 workflow to produce statistics of spatial overlap between N200 and Copernicus products.



In contrast to the local component of Copernicus (Urban Atlas, Riparian Zones) which is mapped for specifically defined spatial reference units, a full wall-to-wall coverage is available for all HRLs comprising full EEA 39 coverage. In other words, only those areas which are actually mapped as grassland/ forest/Urban Atlas etc. are included in the overlap statistics depicted in (Table 4.1). For HRL´s which are entirely in raster format pixels indicating any other type of cover or no-data are discarded. To be able to compare the continuous-range Imperviousness Density all pixels from 30% to 100% were reclassified to 100.

Table 4.1 coverage of Natura 2000 surface area by Copernicus products within EU28 [%]. RZ and UA have been intersected to show coinciding area of products overlapping with Natura 2000.

	Local			*High Resolution Layers*				
Country	**UA**	**RZ**	**RZ / UA Intersect**	**Grassland**	**Forest Density > 10% / Forest Type**	**Wetlands**	**Permanent water bodies**	**Imperviousness 2012 (Sealing >30%)**
AT	26%	14%	7%	9%	42%	1%	3%	0.3%
BE	20%	13%	4%	1%	58%	0%	2%	0.3%
BG	18%	9%	2%	4%	55%	0%	1%	0.0%
CY	52%	0%	0%	0%	63%	0%	1%	0.9%
CZ	30%	9%	3%	1%	67%	1%	2%	0.2%
DE	54%	20%	10%	1%	50%	2%	4%	0.1%
DK	46%	8%	0%	12%	19%	7%	9%	0.3%
EE	18%	8%	3%	3%	63%	22%	2%	0.5%
ES	8%	9%	1%	1%	47%	1%	2%	0.1%
FI	3%	10%	1%	2%	54%	8%	8%	0.9%
FR	22%	17%	4%	4%	42%	4%	3%	0.4%
GR	7%	8%	0%	3%	39%	1%	2%	0.1%
HR	14%	16%	4%	3%	54%	0%	2%	0.2%
HU	19%	34%	6%	7%	38%	4%	3%	0.7%
IE	13%	16%	0%	1%	11%	47%	10%	0.7%
IT	11%	10%	2%	12%	51%	1%	2%	1.1%
LT	9%	16%	0%	0%	63%	4%	8%	0.8%
LU	100%	9%	9%	0%	58%	0%	1%	0.3%
LV	13%	14%	0%	0%	62%	15%	6%	0.7%
MT	74%	0%	0%	10%	7%	0%	0%	0.1%
NL	54%	22%	12%	8%	32%	9%	18%	1.5%
PL	17%	18%	3%	1%	56%	1%	4%	0.2%
PT	6%	13%	1%	5%	23%	1%	1%	0.6%
RO	3%	21%	1%	3%	51%	6%	4%	0.9%
SE	4%	10%	1%	3%	33%	11%	9%	0.6%
SI	16%	9%	3%	2%	72%	0%	1%	0.2%
SK	19%	12%	2%	1%	70%	1%	1%	0.4%
UK	14%	7%	0%	1%	7%	23%	4%	1.0%
Mean (SD)	**25(23)%**	**13(7)%**	**3(3)%**	**4(4)%**	**46(18)%**	**6(10)%**	**4(4)%**	**0.5(0.4)%**

In general, the local components show high overlaps with 13-25%. UA features the highest coverage with a 100% of Natura 2000 areas covered within Luxembourg. This is due to the fact that all of Luxembourg is mapped as UA reference unit. For RZ the coverage varies between 0% (Cyprus, Malta) and 34% (Hungary). Unfortunately, only a small portion of Natura 2000 area covered by both local components. Here, the Netherlands feature the highest overlap with 12%.

Concerning the HRLs, Grasslands feature very small overlaps in most countries. Interestingly, Italy as well as Denmark both feature a comparably large amount of overlapping surface area despite the very different environments encountered in these two countries.

The calculated overlaps for HRLs indicate that most of Natura 2000 areas are in fact covered by forested area. Naturally the highest values for forest coverage are reached in Scandinavian countries. The remaining HRLs (Grassland, Water and Wetlands) all show vastly smaller overlaps ranging between 3-6% on average per country.

As expected, there is generally only a very small amount of sealed area detected within protected sites.

5 Potential applications of Copernicus for biodiversity related issues

Remote sensing has the potential to provide valuable support to habitat monitoring and conservation in general, and particularly for landscape scale processes. Although data from field observations is indisputably the backbone of habitat monitoring in Natura 2000 areas, Copernicus could assist in improving monitoring capacity. It enables comparisons across different Member States and could be used to identify hotspots of change and therewith inform policy decisions and contribute to an improved effectiveness of conservation efforts. Table 5.1 provides a quick overview of what the products could be used for. The listed applications are then explained in greater detail in the respective chapters.

5.1 Overview

Table 5.1 Overview showing the suitability of Copernicus layers for different potential applications. Red indicates that the layer is not useful for the application. Yellow highlights that the product could be used for the respective application, although this may require further exploratory analysis and outcomes are unpredictable. Green highlights that the layer is useful for the application, however restrictions may still apply.

Red	Not applicable
Yellow	Potentially applicable
Green	Feasible

	Population of N2K	Landscape metrics	Analysis of Ecotones	Population of CLC with HRL	Combination with Art. 17 data	Input for European Ecosystem Map	Pressures in- / outside N2K
HRL natural and semi-natural grasslands	Potentially applicable	Feasible	Not applicable	Feasible	Potentially applicable	Feasible	Not applicable
HRL forest type / density	Potentially applicable	Feasible	Not applicable	Feasible	Potentially applicable	Feasible	Not applicable
HRL wetlands	Potentially applicable	Not applicable	Not applicable	Feasible	Potentially applicable	Feasible	Not applicable
HRL permanent water bodies	Potentially applicable	Potentially applicable	Not applicable	Feasible	Potentially applicable	Feasible	Not applicable
HRL imperviousness	Potentially applicable	Not applicable	Not applicable	Feasible	Potentially applicable	Feasible	Feasible
Urban atlas	Feasible	Not applicable	Potentially applicable	Potentially applicable	Potentially applicable	Feasible	Potentially applicable
Riparian zones	Feasible	Feasible	Feasible	Potentially applicable	Feasible	Feasible	Feasible
Natura 2000 (grasslands)	*	Feasible	Feasible	Not applicable	Feasible	Feasible	Feasible

* Not relevant due to the fact that Natura 2000 (grasslands) is a population of N2K.

5.2 Populating the Natura 2000 network with land cover information

From a technical perspective, Natura 2000 is currently composed of two key components:

- *Spatial database: Including the outline or border of sites across Europe as specified by MS*
- *Descriptive database: Containing an extensive description of the site and its ecology*.

Currently, the information on different habitat types is stored as the total and relative surface area of a given site in a table format, which can then be linked to the geometric outline of the site by means of a common identifier. Therefore, there is no available information concerning the spatial distribution of certain habitat types within Natura 2000 sites. Land cover maps such as CLC are potentially suitable for this task, but the low resolution of this product reduces its usefulness.

By combining the products of the Urban Atlas, Riparian Zones, the Natura 2000 local component grasslands, Forests, Imperviousness, Wetlands as well as Permanent water bodies to a single layer, one could establish a basic high resolution land cover map to populate Natura 2000 areas and their surroundings (Figure 5.15.1). Clearly, this is not a simple merging process and is likely to exclude many classes targeted by HRLs outside of UA, RZ and N2000 – grassland zones. Furthermore, there are additional practical issues relating to the currently unfinished validation of some of the products.

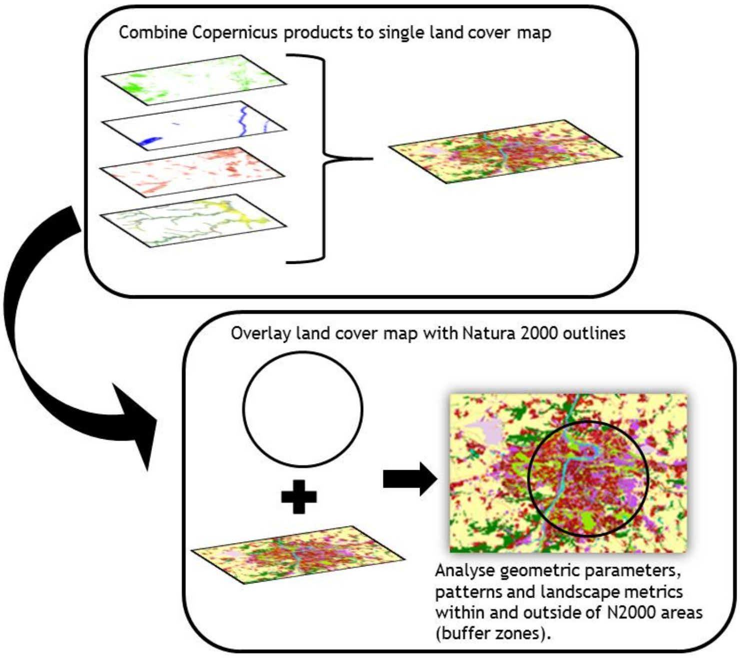


Figure 5.1 Schematic approach for populating Natura 2000 areas. A land cover map consistent of HRLs could enable new approaches to spatial analysis in Natura 2000 areas.

The combined approach could be used to cross-check the non-spatial surface cover information provided by the Member States within the Natura 2000 database. Naturally, exact habitat types will not be able to be pinpointed by this method but one could distinguish between, e.g. natural grasslands and forests. In comparison to available products for this purpose like Corine Land Cover, the advantage would clearly lie in the higher resolution.

5.3 Exploring spatial patterns and landscape metrics of HRLs

Environmental processes shape and influence ecological processes. The assessment of spatial patterns in the landscape on a grid-cell basis can therefore provide information on ecological dynamics within the landscape. There are a wide variety of ecological landscape metrics available, but these have not yet been calculated for HRL land monitoring products. Metrics relating to fragmentation, connectivity, landscape diversity as well as patch size could help to elucidate ecological issues at various spatial levels across the European Union and the landscape context of Natura 2000 sites. It could also provide an opportunity to shed light on pan-European ecological processes taking place especially in grasslands and forests. These metrics are easily calculated, but have been critiqued in terms of the ecological relevance they express (Kupfer, 2012).

The following exemplary metrics could be calculated for the Grassland Forest, as well as for the water and wetness HRL:

- *Area & edge*
- *Shape*
- *Core area*
- *Contrast*
- *Isolation*
- *Diversity*

To assess the condition of habitats, their phenological development serves as a key indicator. Phenological developments are documented via remote sensing data, but until now only exist in quite coarse resolution (300m-1 km). The new possibilities of combining Landsat 8 and Sentinel-2 will retrieve phenological information at a completely new spatial scale (10-30m).

Currently, no operational products for phenological indicators are available from the COPERNICUS programm, but discussions are ongoing to develop specific products for phenological characterisation. Typical indicators for the vegetation season such as start length, amplitude, peak high, etc. are currently the focus of the discussion.

5.4 Analysis of Ecotones in and outside of Natura 2000 areas

Ecotones are areas of transition between different biological communities. They can be defined at a range of different spatial scales. Using a combined map of HRL products to study these areas could give valuable insights into how ecotones change in terms of geometric aspects within and outside of designated sites but also across different MS. They could also be relevant for assessment of connectivity and there is potential to contribute to analysis of the Natura 2000 coherence.

5.5 Population of CLC with HRL

Similar to the spatial gap filling of Natura 2000, the information from the HRL products could be used to populate Corine Land Cover. Thereby, CLC could benefit greatly from the added information, making it more usable for conservation analysis. For example, the composition of different land cover classes could be assessed and gradual land cover changes (below the official 5ha MMU for CLC) could be anticipated.

5.6 Combination of Article 17 data and HRLs

Article 12 and 17 provide spatial information at a 10 x 10 km grid. It is suggested to study the possibility to transfer the Art. 12 & 17 information to the more detailed HRL (mainly forest and grasslands).

However, considering that MS could likely provide more detailed information on species distribution and abundance, this approach may not be necessary.

5.7 Support to the European Ecosystem Map

The European ecosystem map was created, following Action 5 of the EU Biodiversity Strategy to 2020. The map portrays ecosystem structures and functions. In the past, some components of the HRLs have already served as input data sources for the processing of the map. With the increased product portfolio, it is likely that more components will be integrated in upcoming versions.

5.8 Analysis of pressures in and outside of N2000

Pressures from urbanisation, agricultural intensification and habitat change pose threats to the ecological functionality of N2000 areas protected habitats. Natura 2000 areas located in the proximity of urban areas are particularly prone to the effects of urban sprawl. The Copernicus N2000 grassland product poses the most ideal product for change detection and thus pressure analysis in the included N2000 areas.

However, to include all N2000 sites in Europe, analysing the degree of soil sealing as determined by the HRL Imperviousness could provide insights into where hotspots for pressures are located. In general, pressures stem from changes in land cover and land use over time. Therefore, their analysis requires multi-temporal datasets and, given the size of some N2000 areas, highly spatially resolved data. The Riparian Zones layer could in particular provide improved possibilities for habitat and pressure change analysis. This is further explored in the following chapter.

6 Testing potential applications

6.1 Populating the Natura 2000 network with land cover information

As stated in chapter 5.2, Natura 2000 does not contain any spatially explicit information other than the actual boundaries of protected sites. All land cover information pertaining to the extent of different habitats within Natura 2000 areas are delivered in tabular form, indicating the percentage cover of specific habitats within a given site. Despite the availability of the Natura 2000 land cover map belonging to the local Copernicus component, it could be useful to use other Copernicus local components (Riparian Zones and Urban Atlas) to transfer the tabular habitat data into a spatial dimension. This is especially important against the background that the Natura 2000 land cover map is only available for grassland-rich sites.

When comparing the coverage of the test area with CLC, RZ and national in situ data (Figure 6.1), it quickly becomes clear that CLC is not useful to provide spatial information for Natura 2000 monitoring purposes as its MMU is not able to capture smaller structures within the site. At the same time, a comparison of RZ and national data based on field observations also makes the limitations of remote sensing data evident.

The procedure of identifying comparable mapping classes between two different land cover classification systems is generally referred to as a “crosswalk”. In order to test the operability of filling N2K with Copernicus data, a crosswalk between Natura 2000 and Riparian Zones was performed for a test site located in North Eastern Germany (Table 6.16.1). The established crosswalk was then applied to the test site (Figure)

The MAES nomenclature used to map the RZ features 4 thematic levels of increasing descriptive accuracy. With a total of 86 classes, it is comparably highly thematically resolved for a remote sensing derived land cover product. On the other hand, there are 234 individual Natura 2000 habitat codes. Clearly it is not possible to distinguish this large number of classes in a remote sensing product. Furthermore, classes cannot be unambiguously assigned to each other (e.g. one Natura 2000 habitat could be assigned to several different RZ classes and vice versa).

Establishing common classes therefore requires severely downgrading in thematic resolution within both classifications as well as careful consideration of overlapping class definitions. In order to overcome these difficulties, the habitat classes for Natura 2000 were used instead of the habitat codes as the basis for the crosswalk. These classes describe the general site character. This classification comprises 27 classes (cf **Erreur ! Source du renvoi introuvable.**) and is more easily transferred to the 22 classes of MAES at level 2. Moreover, they bear the advantage that they can also be transferred into EUNIS nomenclature as well as they include non-protected habitat classes that can make up a large proportion of the site.

Although it is possible to perform a crosswalk between MAES and Natura 2000 general site character classes, there can be discrepancies which affect the reliability of the spatial information. As can be seen in Table 6.16.1, the level of agreement between the percentage coverage calculated for each RZ class within the site and the proportion of area belonging to each Natura 2000 habitat class for the test is generally high. This means that some MAES classes can be used to spatially map specific habitat classes within Natura 2000 areas with comparably high accuracy.

Yet, it is important to consider that individual classes can deviate severely in the actual and calculated percentages.

The level of agreement was calculated as follows:

Equation 1 calculation of agreement between Natura 2000 and MAES classification

$$Level\ of\ Agreement = 100 - \sqrt{(\%\ cover\ N2K - \%\ cover\ MAES)^2}$$

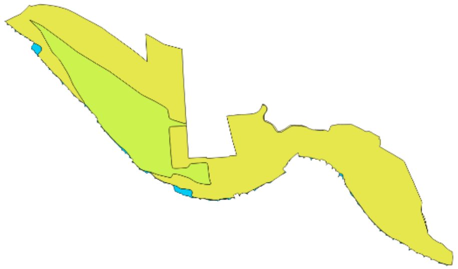
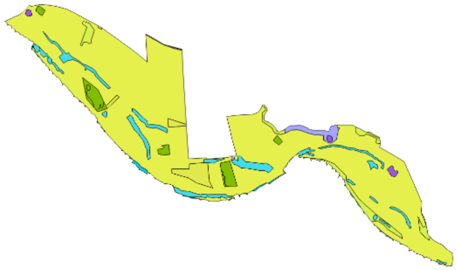
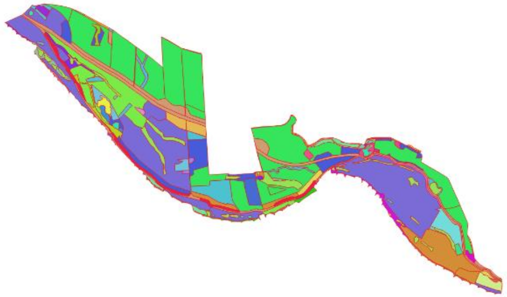
$\%\ cover\ Natura\ 2000$	Percentage cover for Natura 2000 class.
$\%\ cover\ MAES$	Percentage cover for MAES class within Natura 2000 site

Therefore, it may be possible to apply the crosswalk to support quality control or monitoring purposes but this would require additional testing with a larger sample and in different ecosystem settings.

RZ delivers a spatial dimension to N2K and can be easily used to identify artificial structures such as roads within N2K sites. The main disadvantage of RZ is that it is only available for N2K areas in the vicinity of rivers; that being said, these are very important as most human settlements tend be close or nearby watercourses.

Natura 2000 site "Lenzen-Wustrower Elbniederung" (DE2934302)

Number of different habitatclasses found within site boundaries: 6

Corine Land Cover	Riparian Zones	National In-Situ
		

Mapped classes	Polygon count	Mapped classes	Polygon count	Mapped classes	Polygon count
4	5	11	46	46	190

Figure 6.1 Comparison of CLC, RZ and national in-situ data for a selected Natura 2000 test site. Background image ©Google Earth.

Source: National in-situ: „Flächendeckende Biotop- und Landnutzungskartierung (BTLN) im Land Brandenburg - CIR-Biotoptypen 2009“http://www.lfu.brandenburg.de

Table 6.1 Exemplary crosswalk between N2K habitat classes and MAES level 2 nomenclature for test site “Lenzen-Wustrower Elbniederung” (DE2934302).

<table>
<tr><th>MAES level 2</th><th>MAES Description</th><th>Percentage cover</th><th>Habitat class</th><th>N2K Description</th><th>Percentage cover</th><th>Level of Agreement</th></tr>
<tr><td>12</td><td>Transport infrastructure</td><td>0.1%</td><td>N23</td><td>Other land (including Towns, Villages, Roads, Waste places, Mines, Industrial sites)</td><td>Not mapped</td><td>-</td></tr>
<tr><td>21</td><td>Arable land</td><td>0.0%</td><td>N15</td><td>Other arable land</td><td>Not mapped</td><td>-</td></tr>
<tr><td>31</td><td>Broadleaved forest</td><td>2.7%</td><td>N16</td><td>Broad-leaved deciduous woodland</td><td>1%</td><td>99%</td></tr>
<tr><td>41</td><td>Managed grassland</td><td>84.6%</td><td>N14</td><td>Improved grassland</td><td>66%</td><td>81.4%</td></tr>
<tr><td rowspan="2">42</td><td rowspan="2">Natural grasslands prevailingly without trees and scrubs</td><td rowspan="2">5.1%</td><td>N09</td><td>Dry grassland, Steppes</td><td>1%</td><td rowspan="2">99.1%</td></tr>
<tr><td>N10</td><td>Humid grassland, Mesophile grassland</td><td>4%</td></tr>
<tr><td>71</td><td>Inland marshes</td><td>1.1%</td><td>N07</td><td>Bogs, Marshes, Water fringed vegetation, Fens</td><td>25%</td><td>76%</td></tr>
<tr><td>91</td><td>Water courses</td><td>5.8%</td><td rowspan="2">N06</td><td rowspan="2">Inland water bodies (Standing water, Running water)</td><td rowspan="2">3%</td><td rowspan="2">96.8%</td></tr>
<tr><td>92</td><td>Lakes and reservoirs</td><td>0.4%</td></tr>
</table>

Note: Natura 2000 habitats which can be assigned to multiple MAES classes have to be merged to allow mapping. MAES nomenclature features 4 thematic levels, however, a crosswalk was only possible at level 2 due to unclear designation of Natura 2000 classes towards MAES. The classes “Arable land” and “Transport infrastructure” are not included in the Natura 2000 databases. They have been introduced through clipping RZ to the N2K boundary and only make up for a marginal amount of surface area (<1%).

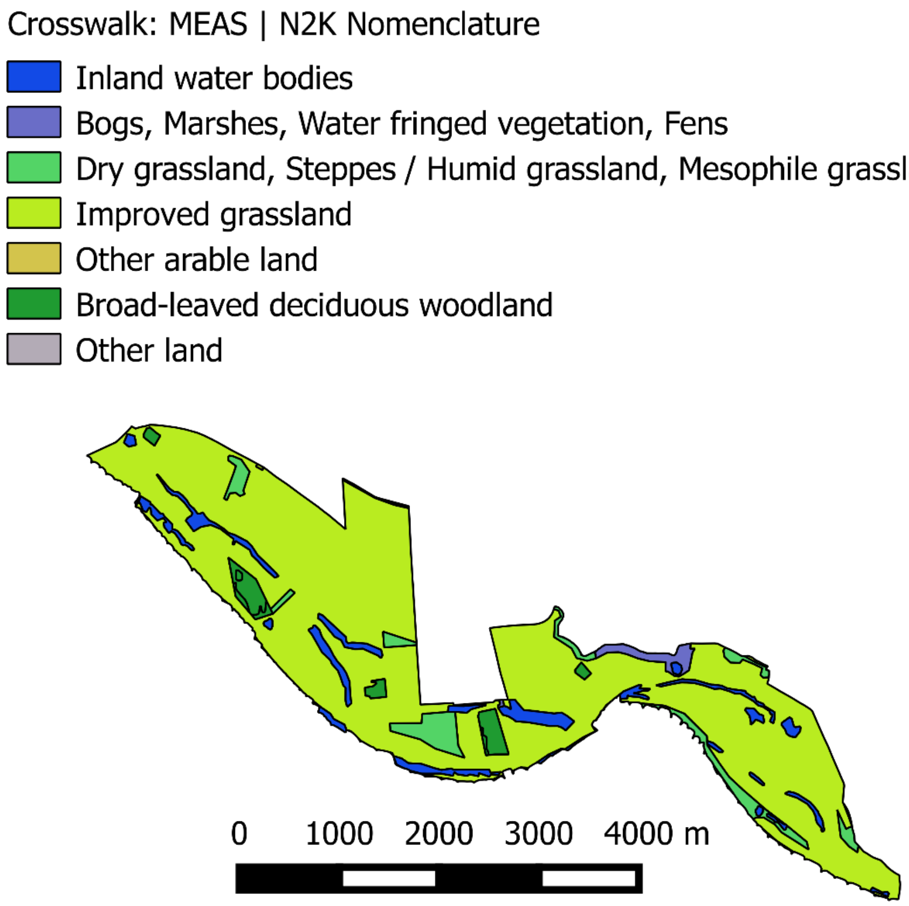


Figure 6.2 Crosswalk applied to test site.

Note: The classes “Other arable land” and “Other land” cannot be seen as they are only marginally included. This is a result of clipping the RZ to the N2K boundaries. The classes “Dry grassland, steppes” as well as “Humid grassland, mesophile grassland” both comply with MAES class “Natural grasslands” (4.2) these had to be displayed as one class.

6.2 Pressure from urban sprawl on N2000

The potential of using remote sensing technology to support the analysis of pressures within and outside of Natura 2000 has long been realised (EARSeL, Symposium, Maktav, & IOS Press, 2009). Land cover products such as Corine land cover have proven to be useful to determine and identify different pressures stemming from land management.

Urbanisation and urban sprawl present very pressing issues to the development of a consecutive and pristine network of protected areas. With a minimum mapping unit (MMU) of 25 ha CLC increasing pressure from land sealing, especially in residential areas, may go unnoticed within change detection. Here, the Imperviousness change layer 2009 - 2012 (IMC) offers the opportunity to analyse urban sprawl at vastly improved resolution (0.16 ha). At this point, it may be important to mention that a direct comparison between the CLC change layer (2006 – 2012) and the IMC would present itself as a straightforward opportunity to assess possible advantages of Copernicus. However, due to the different reference timeframes for change layers of CLC and Imperviousness in combination with further issues relating to technical changes, we refrained from this after testing an initial approach of combining the Imperviousness 2006-2009 and 2009-2012 change layers to comply with the 2006-2012 change period for CLC.

For this reason, we only included the IMC (2009-2012) in our analysis.

The following workflow was applied to derive hot and cold spots urban pressures within and outside of Natura 2000 areas. As the aim was not to provide an extensive pan-European analysis, but rather to test potential applications of Copernicus; the analysis was restricted to seven countries.

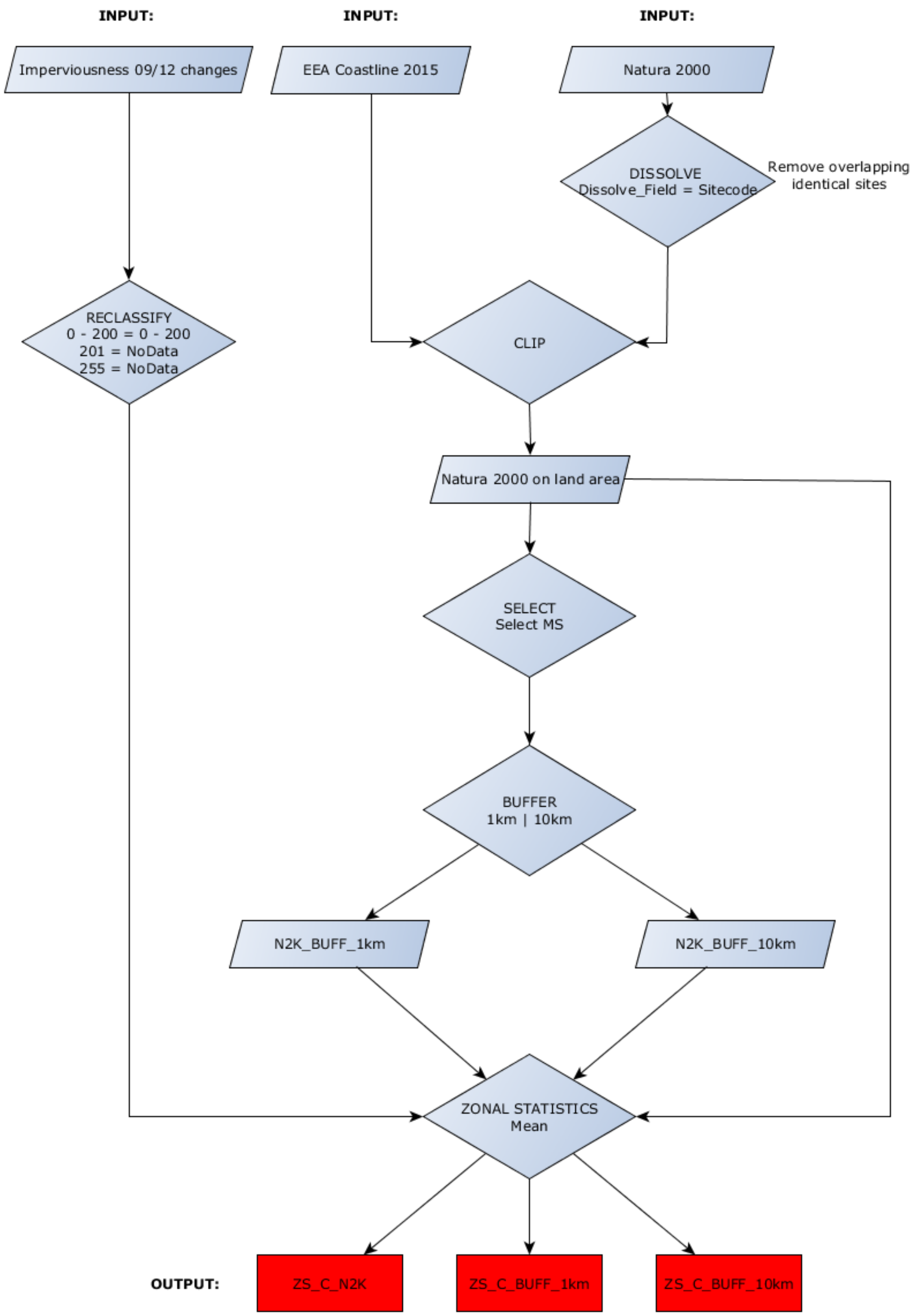


Figure 6.3 Workflow of pressure analysis.

6.3 Results

A preliminary comparison of soil sealing within and outside of Natura 2000 sites in seven test countries revealed that the degree of imperviousness over the period from 2009 and 2012 showed only marginal increases inside of protected sites on national level (Figure 4.1). For technical reasons relating to the encoding of the imperviousness change layer, the percentage change is not relative to the entire N2000 site area, but to sealed pixels within the site. The mean degree of imperviousness within and outside (both 1km, 10km) of protected sites differed significantly by country (Kruskal-Wallis rank sum test: $\chi 2(2) = 390.29$, $p < 0.01$). Cyprus showed the overall highest increases (M (SD) = 1.52% (2.82%). Estonia and Czech featured zero and 0.01% increase, respectively. Bulgaria and Denmark were the only countries which showed stronger incremental soil sealing inside protected sites in comparison to the outside areas. A decrease in soil sealing was not observed in any of the test countries.

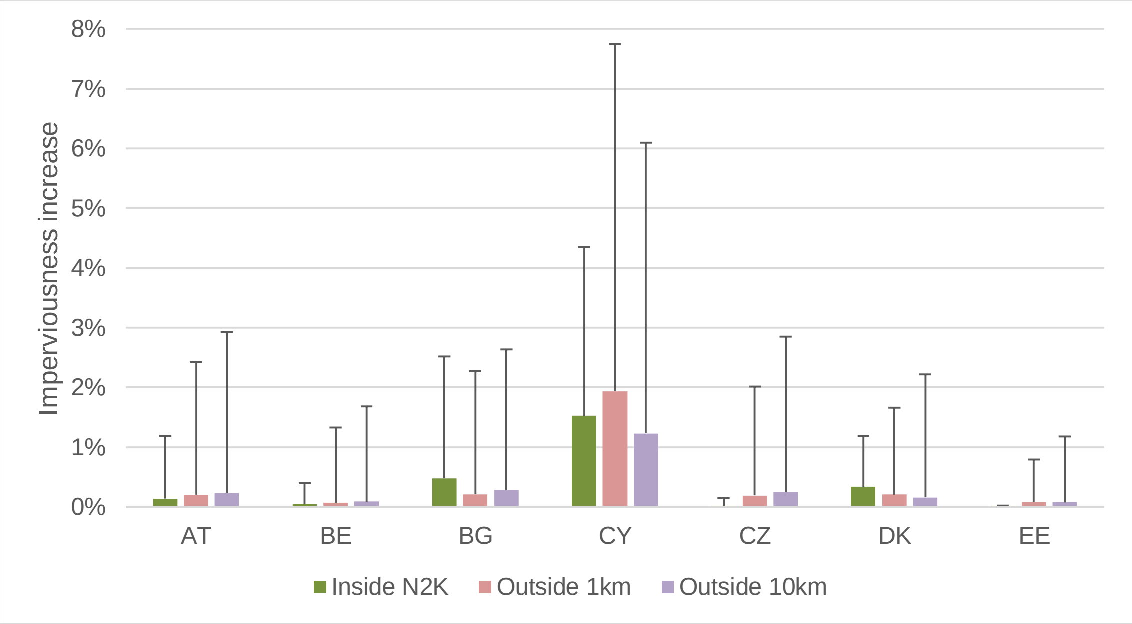


Figure 2.4 Changes in the degree of imperviousness relative to sealed surfaces within and outside of Natura 2000 from 2009 to 2012. Error bars represent standard deviations.

The analysis reveals that the increased level of spatial detail allows for a much higher precision and location of hotspots for human intervention by increased building activity within N2000.

Figure shows a Danish site with a strong increase in sealing degree (24.16%). This change was not captured by the CLC change layer (2006-2012) due to its much larger MMU.

2005 **2011**

Figure 6.5 Increased soil sealing by extension of farming complex within boundaries of N2000 (red outline) identified on the basis of the imperviousness change layer. Change not present in CLC change layer (2006-2012).

As building developments usually take place incrementally, CLC will not register a change until they have reached the specified MMU. This can result in vast amounts of small sealed surface areas not being recognised as changes and thus not being registered as pressures. This applies in particular to rural areas where there are many individual farm buildings and houses. Applying Copernicus to detect these developments offers a solution to incorporate even these small developments and thereby provide valuable insights for the monitoring of Natura 2000.

7 Summary

The main target of this report was to identify methods and approaches to explore how the Copernicus product portfolio could contribute to the monitoring of habitats, species and the Natura 2000 network.

The findings showed that Copernicus products are mainly suitable to refine a range of different analyses previously performed at coarser spatial resolution. Novel applications, such as the combination of HRLs with Art. 17 data, will require more extensive testing and development; the potential outcomes of such a process remain unknown. When considering using remote sensing products as well as European databases for ecological assessments, it is important to bear in mind the limitations that the spatial scale of the data sets for such applications. The gap between the data needed by ecologists and that able to be provided by remote sensing data remains a large obstacle for monitoring applications. In general, remote sensing data can instead provide information on quantity, such as elucidating e.g. how much area is under forest canopy, rather than providing information on quality (e.g. how many species are present). This applies even to products that have been specifically designed to address the biological quality of particular ecosystems (e.g. New Grassland layer).

One of the key benefits of the Copernicus products is their more frequent updating as compares to the traditional CLC updates. Moving from 6 to 3 years in combination with an increased minimum mapping unit opens up a range of opportunities for environmental monitoring.

Products such as the Copernicus local component Natura 2000 – grasslands are specifically designed for certain monitoring purposes and provide valuable information on land cover changes within and outside of Natura 2000 areas. Therefore, this layer could be used to study the loss of grasslands in detail. Yet, the limited coverage and thematic focus of this product makes it less universal in terms of addressing changes within the entire protected network.

Testing of selected applications (c.f. chapter 6) provided indications that, for instance, the Imperviousness layer is suitable to address the issue of urbanization as a threat to Natura 2000 across Europe. This could feed into monitoring schemes focusing on this aspect in N2K networks at pan-European level. The report demonstrated that there are a variety of different applications for Copernicus to support habitat monitoring. However, whether or not a given a product is really up to a task will always depend on the issue to be addressed.

8 Outlook

With continuous efforts to improve the available HRL layers and new data versions on the verge of production the importance and informational value of HRL for the monitoring of habitats is likely to increase in the future.

In some instances, the improvement of the product definitions will come at the cost of the possibility to detect changes over time. However, this is a necessary sacrifice in view of the potentially increased reliability of the products.

9 Annex

Table 2 Natura 2000 general habitat classes.

Habitatcode	Description
N01	Marine areas, Sea inlets
N02	Tidal rivers, Estuaries, Mud flats, Sand flats, Lagoons (including salt work basins)
N03	Salt marshes, Salt pastures, Salt steppes
N04	Coastal sand dunes, Sand beaches, Machair
N05	Shingle, Sea cliffs, Islets
N06	Inland water bodies (Standing water, Running water)
N07	Bogs, Marshes, Water fringed vegetation, Fens
N08	Heath, Scrub, Maquis and Garrigue, Phygrana
N09	Dry grassland, Steppes
N10	Humid grassland, Mesophile grassland
N11	Alpine and sub-Alpine grassland
N12	Extensive cereal cultures (including Rotation cultures with regular fallowing)
N13	Ricefields
N14	Improved grassland
N15	Other arable land
N16	Broad-leaved deciduous woodland
N17	Coniferous woodland
N18	Evergreen woodland
N19	Mixed woodland
N20	Artificial forest monoculture (e.g. Plantations of poplar or Exotic trees)
N21	Non-forest areas cultivated with woody plants (including Orchards, groves, Vineyards, Dehesas)
N22	Inland rocks, Screes, Sands, Permanent Snow and ice
N23	Other land (including Towns, Villages, Roads, Waste places, Mines, Industrial sites)
N24	Marine and coastal habitats (general)
N25	Grassland and scrub habitats (general)
N26	Woodland habitats (general)
N27	Agricultural habitats (general)

10 Bibliography

EARSeL, Symposium, Maktav, M. D., & IOS Press. (2009). Remote sensing for a changing Europe proceedings of the 28th Symposium of the European Association of Remote Sensing Laboratories, Istanbul, Turkey, 2-5 June 2008. Amsterdam; Washington, DC: IOS Press. Retrieved from http://public.eblib.com/choice/publicfullrecord.aspx?p=448781

Gerard, F., Petit, S., Smith, G., Thomson, A., Brown, N., Manchester, S., Feranec, J. (2005). Linking pan-European land cover change to pressures on biodiversity - Biopress final report 1st January 2003 - 31st December 2005, sections 5 and 6. (No. CEH Project Number: C02129, EC-FPV Contract Ref: ENV-CT-2002-00178) (p. 57pp). NERC/Centre for Ecology & Hydrology. Retrieved from http://ppg.sagepub.com/cgi/doi/10.1177/0309133309360141

Kupfer, J. A. (2012). Landscape ecology and biogeography: Rethinking landscape metrics in a post-FRAGSTATS landscape. Progress in Physical Geography, 36(3), 400–420. http://doi.org/10.1177/0309133312439594

Land take — European Environment Agency. (2016, June 21). Retrieved 12 July 2016, from http://www.eea.europa.eu/data-and-maps/indicators/land-take-2/assessment-2