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Evaluating Landscape Attractiveness with Geospatial Data, a Case Study in Flanders, Belgium

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Flemish Land Cover Map

A land cover map for Flanders at 5 m resolution is produced by Informatie Vlaanderen (i.e., Flemish agency tasked with the collection and distribution of geospatial data). The map is the result of an elaborate classification workflow which uses digital orthophotos collected in summer at roughly 1 m resolution at its base, supplemented with multiple existing geospatial datasets. Agricultural land cover classes are derived from the land parcel identification system and information concerning human infrastructure (i.e., buildings, roads, canals) is derived from a regularly updated reference geodatabase, also managed by Informatie Vlaanderen. The accuracy of the land cover map is 5 m, evaluated by the horizontal positional accuracy (at 95% confidence interval) of the datasets used [44]. The fourteen land cover classes of the map were simplified to six (visually differing) classes for the purpose of this paper and include human infrastructure (buildings, roads and rail roads), water, bare soil, annual cropland, grass/shrub (including meadows, pastures and orchards) and forest. The land cover map of 2012 allowed researchers to compute LCinf, LCED and LCD (Table 1). LCinf was calculated as the proportion of land that was covered by infrastructure (according to the Land cover map) for each geographical area of the studied scales of analysis. In order to allow calculation of the more advanced landscape metrics (i.e., edge density and Shannon diversity index), the land cover map was aggregated to a resolution of 30 m and subsequently converted to a polygon layer. This polygon layer was intersected with each geographical area to be processed (Figure 1). LCED was computed as the ratio of total edge length (perimeter) versus total surface area of the resulting intersection layers. The Shannon diversity index was computed based on the proportions of land covered by each land cover class according to the following equation (http://www.tiem.utk.edu/~gross/bioed/bealsmodules/shannonDI.html):

$$H = -\sum_{i=1}^{S} p_i \ln p_i \quad (1)$$

where p_i is the proportion of land covered by land cover class i and S the total number of landcover classes.

All of these indices were computed for (1) the whole of Flanders, (2) for each agricultural region as a whole, (3) separately for urban and rural areas in each individual agricultural region and (4) for urban versus rural areas across Flanders.

Boswijzer

The Boswijzer is a digital land cover map produced by Informatie Vlaanderen. This particular land cover map only consists of one class, i.e., forest, defined here as a patch of land covered by trees with a minimum surface area of 0.5 ha, a length/width ratio of at least 2.5 and a minimum tree cover of 50%. The map is produced through an elaborate hierarchical classification scheme based on digital orthophotos with a spatial resolution of 1.2 m. The accuracy of the Boswijzer is 0.59 m, evaluated by the horizontal positional

accuracy (at 95% confidence interval) of the orthophotos used [45]. Urban and agricultural areas are masked out based on available geospatial datasets. Vegetation is discerned from non-vegetation using the NDVI (Normalized Vegetation Index) and subsequently subdivided into high and low vegetation based on a digital surface model and a height threshold of 3 m. Further spatial analysis is used to derive forest cover from the high green class. The Boswijzer is available at a spatial resolution of 10 m. The Boswijzer from 2012 allowed to compute the proportion of Flanders (and its regions) covered by forest in 2012 (LCfor, Table 1). LCfor was calculated as the proportion of land that was covered by forest (according to the Boswijzer) for each geographical area of the studied scales of analysis.

Protected Nature Area Geodatabase

In order to calculate the proportion of land covered by protected nature areas in Flanders (LCnat, Table 1), the protected nature area geodatabase was consulted. The scale of this map is 1:10,000 [46]. This geodatabase describes for each nature reserve of Flanders its location, size and starting date of recognition. The latter feature allowed us to evaluate the evolution of the proportion of land that was covered by protected nature reserves from 2008 to 2018 for each geographical region of the studied scales of analysis (i.e., LCnat, Table 1). To this end, the protected nature reserves geodatabase was intersected with each individual geographical area, after which the resulting area of nature reserves was computed for each region and divided by the total land surface area of the respective geographical area.

The Land Parcel Identification System (LPIS)

The land parcel identification system (LPIS) geodatabase was used to assess the role of agriculture in the rural landscape of Flanders by calculating the structural quality landscape indicators: LCagri and LCcrop (Table 1). Yearly LPIS data from 2008–2018 were available for Flanders. The registered information in the LPIS geodatabase includes the size of the agricultural landscape elements (i.e., based on registered polygon of fields and agricultural infrastructure) as well as the type of the agricultural landscape element (i.e., crop grown on field or type of agricultural infrastructure). This information is collected every year to determine direct EU support, support for AEA or other rural measures in the context of rural development or to comply with obligations specified in the manure decree. In order to evaluate changes in LCcrop, the LPIS variable crop group was used. This variable classifies crops in eleven different groups and also includes a class for agricultural infrastructure and water bodies. The field centroids were used to assign fields to the studied geographical areas for each scale of analysis. The scale of the LPIS maps is 1:2000 [47]. The LPIS geodatabase was used to calculate the proportion of land covered by agriculture (LCagri, Table 1), proportion of agricultural land covered by specific crop groups (LCcrop, Table 1), crop diversity Shannon diversity index (CDSD, Table 1) and the Crop diversity Shannon equitability index (CDEI, Table 1) for each geographical area of the studied scales of analysis. The Shannon diversity and equitability indices were computed according to the definitions provided at http://www.tiem.utk.edu/~gross/bioed/bealsmodules/shannonDI.html.

As grasslands dominate the agricultural landscape of Flanders, two analyses focused solely on grasslands. First, the LPIS dataset was used to detect changes in the grassland landscape between 2008 and 2018. The large temporal dimension of the LPIS dataset allowed us to assess the age of all grassland fields in 2018. The ecological value of a grassland field is directly affected by the consecutive amount of years the field has been maintained as grassland. A distinction in three groups, ordered from most to least ecologically valuable, i.e., ≥10 years old grassland (10 or more years), 10–5 years old grassland (equal or higher than 5 years) and <5 years old grassland (lower than 5 years), was made. The ecological quality landscape indicators 10G, 10–5G and <5G (see Table 1) were calculated to evaluate the relative number of ≥10 years old, 10–5 years old and <5 years old grassland fields, respectively.

The Biological Valuation Map

The biological valuation map of 2018 was used to calculate the ecological landscape indicators BioVV (Table 1). As there is no time series available for this map, we were not able to analyze changes in BioVV. The map inventories the vegetation and land cover of Flanders. Here, vegetation types, habitats and the structure of the vegetation are mapped based on field surveys, aerial photographs, maps and other spatial databases. The aim of this map is to visualize the biological value of the land cover. Therefore, the mapped land cover is classified into different classes of biological valuation, ranging from biologically less valuable to biologically very valuable. Landscape elements mapped as biologically very valuable were used to calculate the proportion of land covered by biologically very valuable landscape elements for each geographical area of the studied scales of analysis (BioVV, Table 1). The mapped landscape elements were intersected with the studied geographical areas for each scale of analysis. The scale of the biological valuation map is 1:3000 [48]. The biological valuation map is mainly used for the description of nature in Flanders but is also used for the implementation of several nature conservation policies such as the EU Habitats and Birds directives.

Small Landscape Elements Geodatabase

The small landscape elements geodatabase was used to calculate the management quality landscape indicator SLE (Table 1). This geodatabase indicates the location of SLE as a polygon for Flanders for 2015. Changes in SLE over time were not assessed as the small landscape elements geodatabase was only available for one point in time. Only small landscape elements located within agricultural fields were considered to calculate the area of agricultural fields covered by small landscape elements (SLE, Table 1). The field centroids were used to assign the calculated SLE to the studied geographical areas for each scale of analysis. The classification accuracy of the SLE geodatabase was equal to 80.28% based on a validation dataset of 2322 polygons. Small landscape elements are green line- or point-shaped landscape elements which form an important part of the landscape. The existence and appearance of small landscape elements is the result of human intervention. Examples of small landscape elements are tree lines, ditches and hedges. Small landscape elements are also an important habitat for several plant and animal species in the highly fragmentated landscape of Flanders.

Agri-Environmental Agreements Geodatabase

In Flanders, a farmer can enter into a so-called agri-environmental agreement (AEA) with the Flemish Government. In exchange for a yearly payment, a farmer commits him/herself to take certain measures to increase local biodiversity, protect the local environment or landscape. Each agreement lasts for five years and can be renewed after completion. Throughout the last decade, the Flemish Government has introduced various sets of measures, all serving a slightly different purpose, ranging from supporting a specific group of animal species to a more general protection of vulnerable nature areas. All these measures, including for instance the delaying of mow events, planting hedges, sowing rich mixtures of flowering plants, have clear and positive effects on the visual attractiveness of the landscape. Therefore, the number of AEA being active in a certain region was adopted here as an indicator of landscape attractiveness. The Flemish Land Agency "Vlaamse Landmaatschappij", a governmental agency responsible for landscape in a broad sense, keeps track of these AEA in a geodatabase. For each agreement, the location, type, size and date are recorded in this database. Locations of the measures are based on GPS recordings in situ and hence, are characterized by typical positional accuracies in the order of magnitude of a few meters. Based on this, the number of AEA initiated per year for Flanders, in urban versus rural areas, and the seven agricultural regions was derived. In case an individual AEA was located in more than one zone, it was included in the analysis of all zones involved.

Fraction of Bare Fields in Winter: Landsat NDVI

The practice of sowing so-called cover crops on agricultural fields during winter serves many purposes. It allows the nutrient balance in the soil to be restored (especially in the case of nitrogen fixating cover crops such as yellow mustard), prevents soil erosion, increases the ecological value of the parcel and has a positive impact on the visual appearance of the parcel during winter months. Therefore, the presence of cover crops was considered as a management quality indicator, which affects landscape attractiveness in a positive way. Specifically, the relative number (fraction) of bare fields for each crop group during wintertime (fBFw) in the period from 2011–2018 was calculated (Table 1). Cloud-free Landsat-7 and -8 time series (30 m resolution) for the period from November to January between 2011 and 2018 were extracted for each parcel registered in the LPIS system with Google Earth Engine. Landsat-7 imagery was harmonized with Landsat-8 according to the procedure described by [49] to ensure inter-comparability between the two sensors. Based on these time series, the average normalized difference vegetation index (NDVI) from November–January for each year was calculated for each field in Flanders, urban versus rural areas and the agricultural regions. This yearly winter NDVI value was used to determine if a parcel was bare (NDVI < 0.4) or vegetated by a cover crop (NDVI >= 0.4) during winter. In this analysis, all parcels either fully or partially intersecting with the zone of interest were considered.

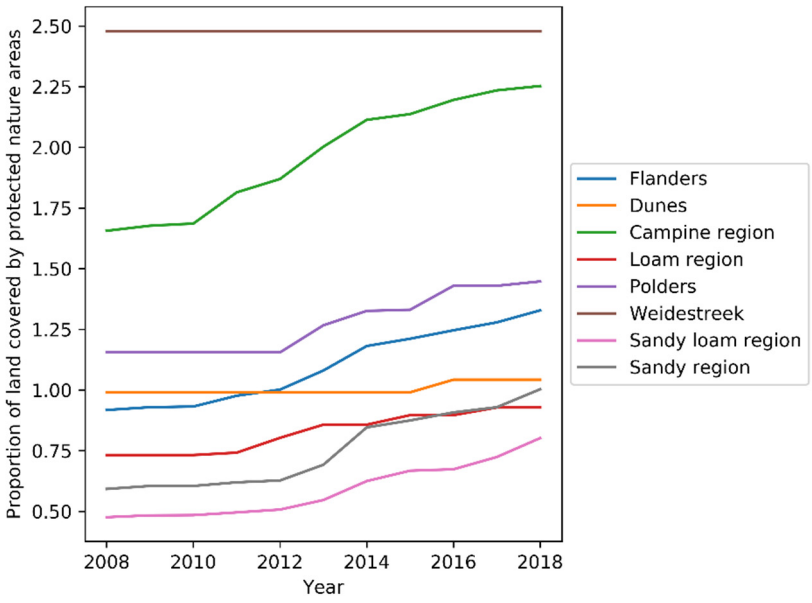

Figure S1. Evolution of proportion of land covered by protected nature areas (LCnat) from 2008 to 2018 for the different agricultural regions and Flanders as a whole. (Data source: Protected nature area geodatabase).

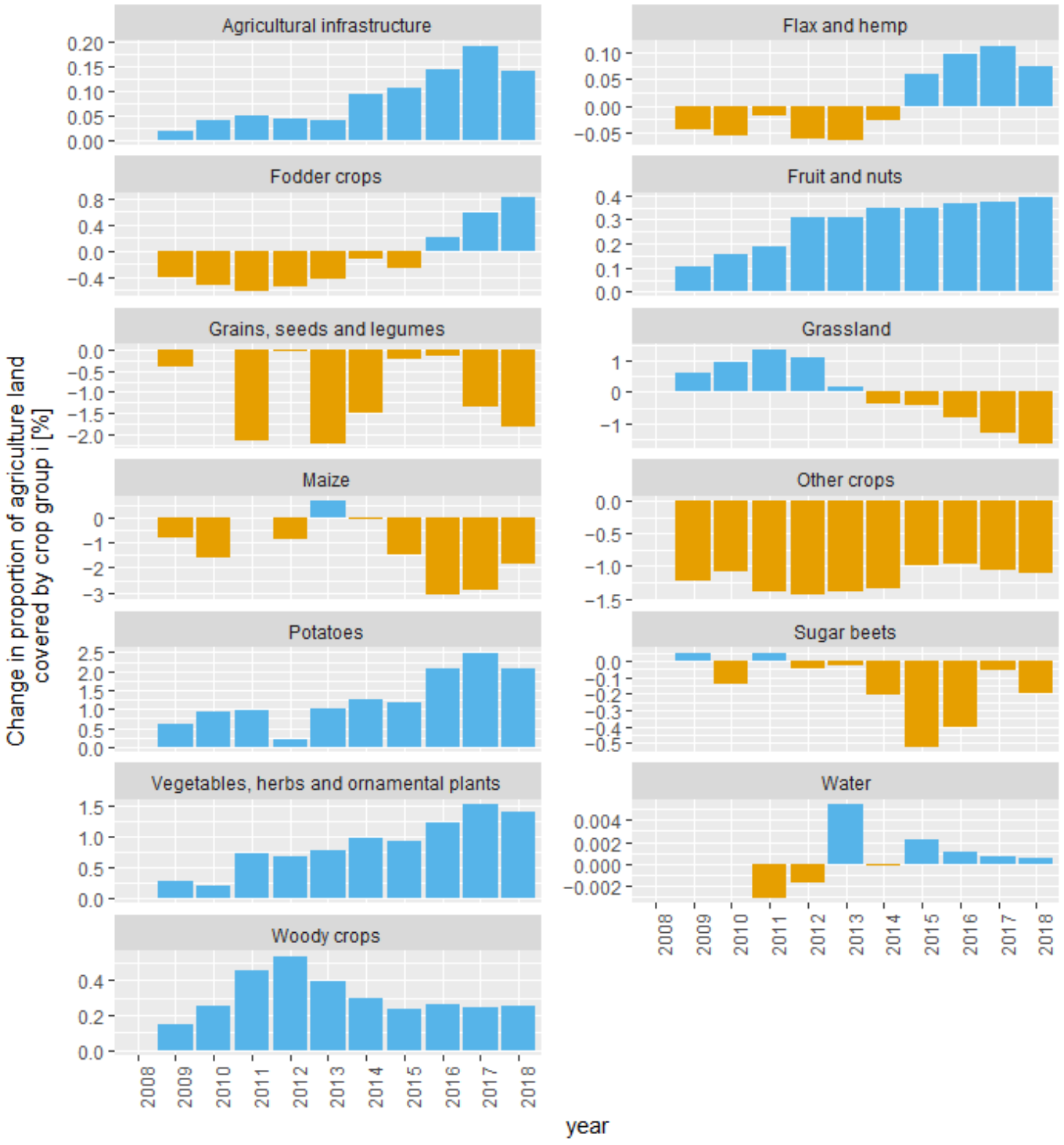

Figure S2. Change in proportion of agricultural land covered by specific crops groups (LCcrop) between 2008–2018 in Flanders. With change in proportion of agriculture land covered by crop group i = (area of crop group i in year j-area of crop group i in 2008)/(total area of all crop groups in 2008)×100. Orange and blue bars represent negative and positive changes, respectively. (Data source: LPIS).

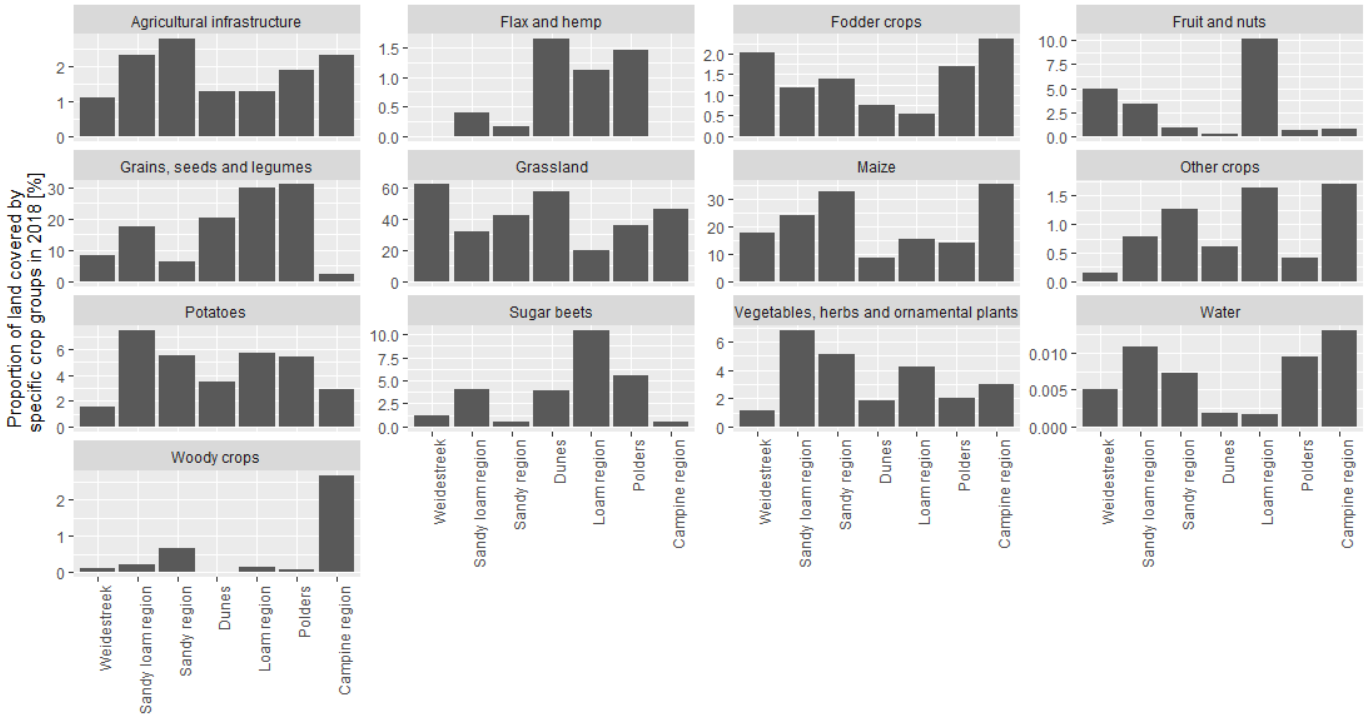

Figure S3. Proportion of agricultural land covered by specific crop groups (LCcrop) in 2018 in the seven agricultural regions. (Data source: LPIS).