HANZE: a pan-European database of exposure to natural hazards and damaging historical floods since 1870

Supplementary Information

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Domain of HANZE database

HANZE domain includes the following:

- all 28 European Union (EU) member states as of 2017,
- all four European Free Trade Agreement members (Iceland, Liechtenstein, Norway and Switzerland),
- four microstates located in Western Europe (Andorra, Monaco, San Marino and the Vatican)
- one Crown Dependency of the United Kingdom (Isle of Man).

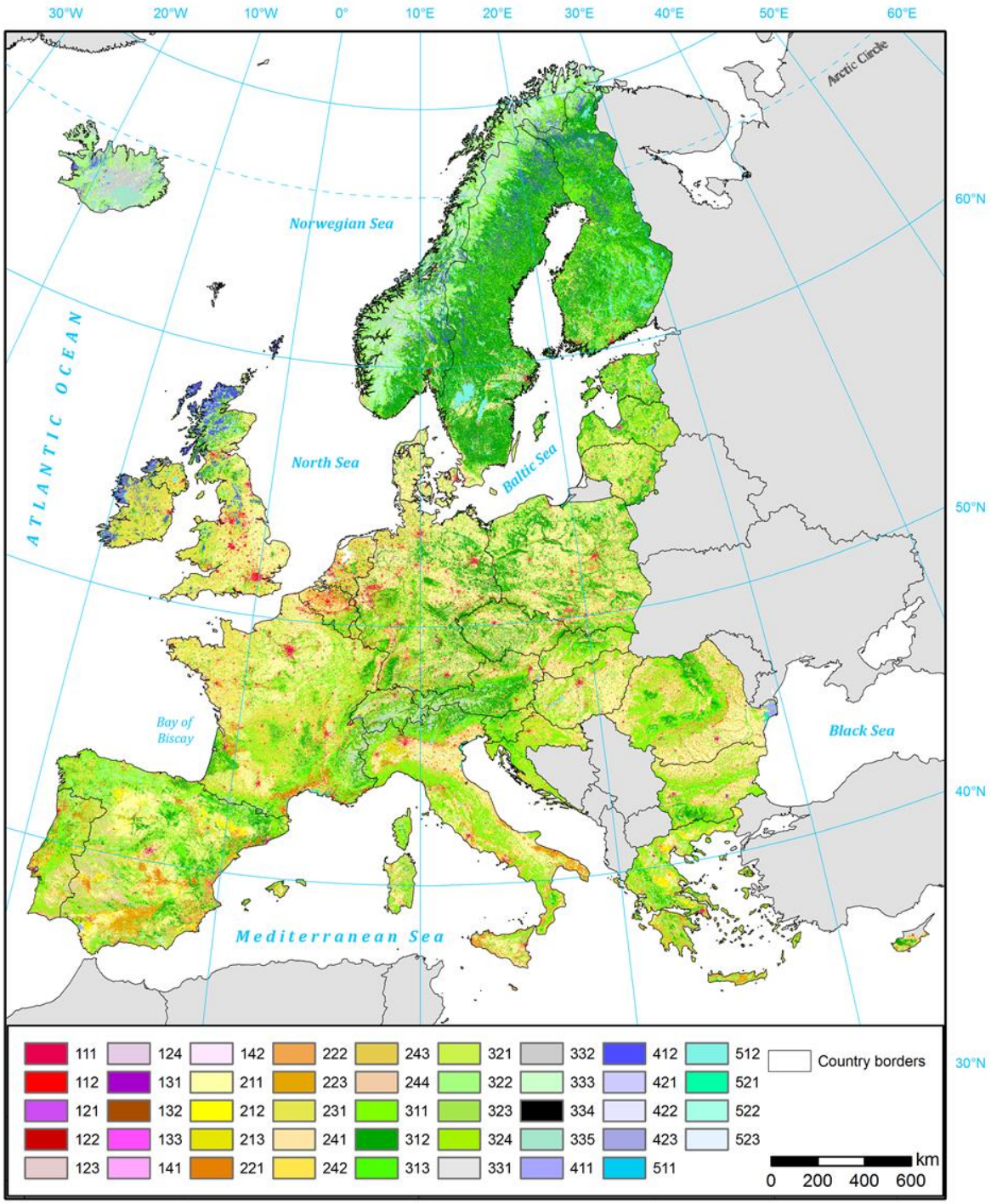
Excluded are non-EU successor states of the Soviet Union or Yugoslavia, as well as Albania and Turkey. Furthermore, certain EU territories are also excluded, namely:

- Canary Islands, Ceuta and Melilla (parts of Spain);
- The Azores and Madeira (parts of Portugal);
- All dependent or overseas territories of EU countries, with the exception of the Isle of Man.

All data for Cyprus exclude areas controlled by the Turkish Republic of Northern Cyprus, but include the Sovereign Base Areas of Akrotiri and Dhekelia and the United Nations Buffer Zone. The composition of the domain was chosen based on availability of historical data and coverage of the baseline high-resolution maps. The domain is shown in Supplementary Fig. 1.

Supplementary Figure 1. HANZE domain.

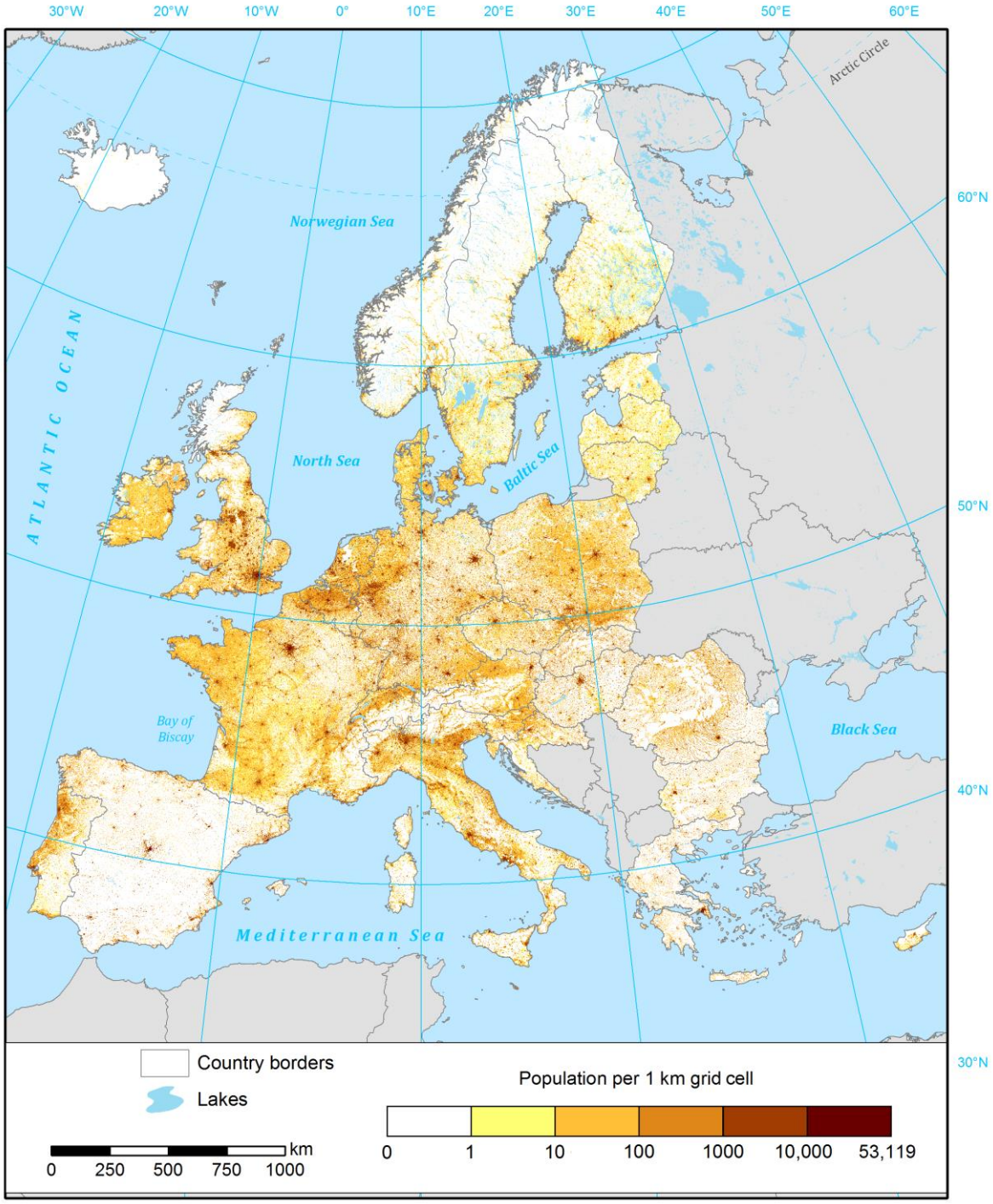
Baseline land cover/use map



Supplementary Figure 2. Baseline land cover/use from Corine Land Cover 2012 by Copernicus Land Management Service, except for Andorra. For explanation of CLC classes, see Supplementary Fig. 3.

Supplementary Figure 3. Corine Land Cover classes. Source: European Environment Agency, http://www.eea.europa.eu/data-and-maps/figures/corine-land-cover-2006-by-country/legend

Baseline population map

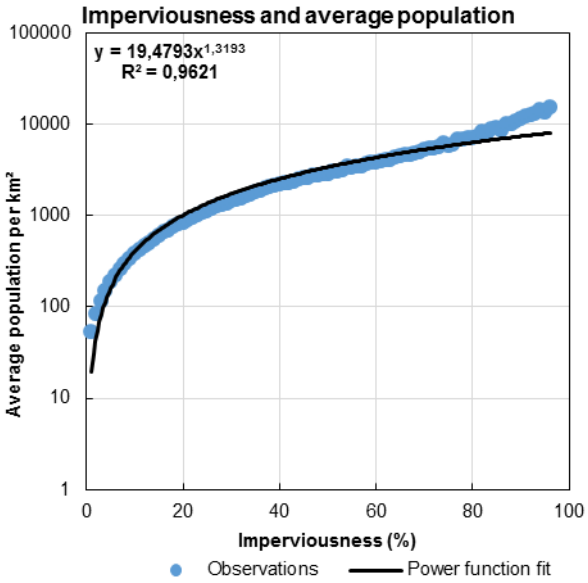


Supplementary Figure 4. GEOSTAT population grid from 2011 censuses, 1 km resolution, by Eurostat (2017).

Population map disaggregation

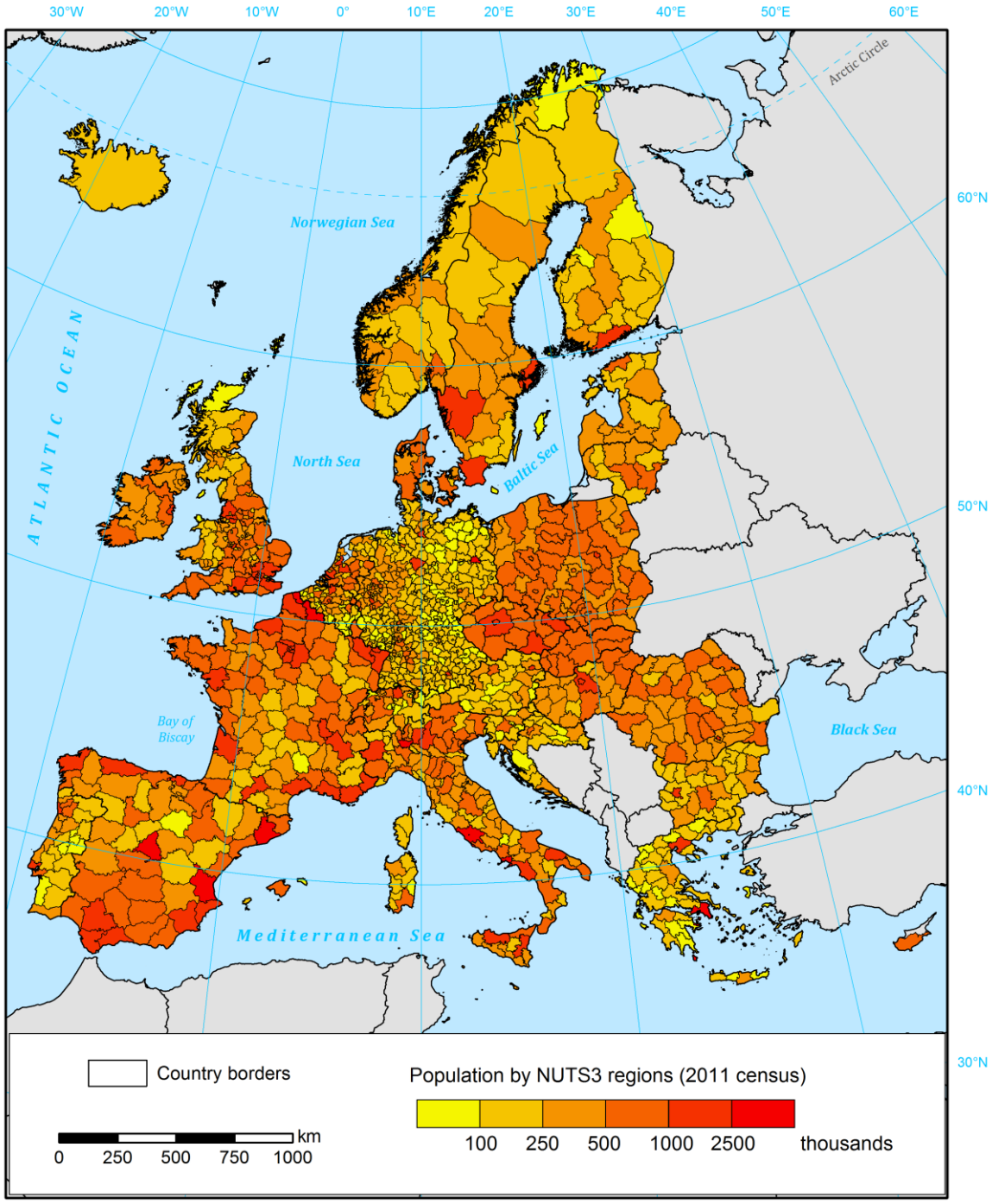
Supplementary Table 1. Thresholds for population disaggregation algorithm T_L

CLC class name and code	Threshold (persons per km^2)
Continuous urban fabric (111)	22,666
Discontinuous urban fabric (112)	6,452
Other artificial (121–142)	59
Non-irrigated arable land (211)	32
Permanently irrigated land (212)	64
Rice fields (213)	9
Vineyards (221)	50
Fruit trees and berry plantations (222)	44
Olive groves (223)	60
Pastures (231)	40
Annual crops associated with permanent crops (241)	71
Complex cultivation patterns (242)	82
Land principally occupied by agriculture (243)	40
Agro-forestry areas (244)	10
Broad-leaved forest (311)	9
Coniferous forest (312)	6
Mixed forest (313)	9
Natural grasslands (321)	18
Moors and heathland (322)	18
Sclerophyllous vegetation (323)	10
Transitional woodland-shrub (324)	11
Sparsely vegetated areas (333)	40
Uninhabitable natural areas (331–332, 334–523)	0



Supplementary Figure 5. Relationship between average population density per imperviousness (soil sealing) class.

NUTS 3 regions



Supplementary Figure 6. NUTS 3 regions (2010 version) in the study area and their population. Region boundaries based on ESRI (see main paper for explanations).

Historical statistics

Total population

Total population refers to the overall number of persons living in a region. Population can be defined as *de facto* population, i.e. the number of persons physically present in an area at a given moment of time, or *de jure*, i.e. the number of persons usually resident in an area, excluding short-term movements or migrations of population (United Nations 2017). Countries typically have their own, specific rules what counts into their population figures, deviating to a various degree from the *de facto* and *de jure* concepts. Such differences are mostly not relevant relative to countries' overall population size. The prime sources of population figures are censuses, held typically every decade, supplement by annual balances of births, deaths and migrations. Starting with the 1970s, many European countries gradually replaced censuses with population registers, providing continuous information on population size.

For this database, statistics were generally compiled from country-specific sources, though for 1960-2010 data from Eurostat (2017) were mostly used, which included recalculation of historical census data to modern administrative divisions, and annual population estimates starting with 1990. Population projections up to 2020 were generally obtained from EUROPOP2013 projections by Eurostat, except for countries with no subdivision into regions, which were obtained from newer EUROPOP2015 projections or United Nations *World Population Prospects: 2015 Revision* (United Nations 2015).

However, data at current administrative divisions were not always available. In several cases, historical divisions were recalculated using one of two methods: the 'population method' and the 'territorial method'. The 'population method' recalculates the population of 'old' administrative divisions to 'new' ones by shifting overlapping proportions of population between the territorial units. More formally, the population X_A^t in each post-reform ('new') administrative unit *A* in year *t* is a sum of fractions F_{AB} multiplied by the population X_B^t of pre-reform units *B*:

$$X_A^t = \sum F_{AB}\, X_B^t \tag{1}$$

The fractions F_{AB} could only be determined if both populations X_A^t and X_B^t are known for the same year; in order words, F_{AB} is the percentage of B's population living within the boundaries of A. Yet, the extent of administrative changes may not allow to calculate the fractions. The 'territorial method', on the other hand, requires a digital map of both pre- and post-reform administrative divisions. The fraction F_{AB} is then the percentage of B's territory also belonging to A. This assumes equal population density within *A* and *B*, therefore this information could only be used determine population growth rates X_A^t/X_A^{t-1}. Those growth rates were used to extrapolate the population from the earliest year for which data for *A* are known. It should be noted that both methods could be used for different time periods for the same country, also multiple times, in order to achieve population estimates for the 2010 version of NUTS 3 regions. The two methods were used depending on the availability of data.

Urban fraction

The fraction of the overall number of persons living in a region that reside in areas defined as urban. The definitions of urban areas vary from country to country (United Nations 2014); the criterion could be administrative (legally designated cities or towns), demographic (all settlements or communes with more inhabitants than a given threshold) or statistical, based on multiple criteria (population number or density, percent of non-agricultural employment, distance between buildings etc.). For the purpose of this study, the urban population is defined as the population disaggregated into CLC classes 111 and 112 (urban fabric); the remainder of the population is therefore considered rural.

However, the disaggregation procedure (see main paper) was only done for the 2011 baseline map. Therefore, national definitions of urban populations were used to determine growth rates of urban and rural populations, which were used to extrapolate the urban fraction from the baseline map. For some countries, different definitions were used in different time periods. They could all be used, however, as the various time series overlapped, allowing them to be linked to the 2011 map. The data was mostly collected from national sources, supplemented by United Nations *World Urbanization Prospects* (United Nations 2014) and other international yearbooks.

Mean number of persons per household

The total population divided by the total number of households in a region. Typically, a household is defined as one or more people who occupy a single housing unit (Haupt et al. 2011). Households consists both of private households and collective households, i.e. institutions such as prisons, nursing homes, dormitories, homeless shelters, army barracks etc. (United Nations 1974). However, the statistics on the latter were not always available, though this has minor effect on the accuracy of the estimates, as population in institutions typically do not exceed 1% of total population, according to data published in United Nations yearbooks (United Nations 2017). Additionally, data on the number of dwellings was sometimes used if the number of private households was not available. Usually the difference between the two statistics is negligible (some dwellings may not be occupied, while some might contain more than one household). The data was mostly collected from national sources, supplemented by several international compendia.

Land use structure

The region's area, or its percentage, covered by different land use classes. The definitions vary between countries; for the purpose of this study, the 2012 statistics were obtained directly from the baseline land use map. The following land use classes were calculated:

- Croplands: CLC classes 211-213 "Arable land", 221-223 "Permanent crops" and 241-244 "Heterogeneous agricultural areas";
- Pastures: CLC class 231 "Pastures";
- Infrastructure: CLC class 122 "Road and rail networks and associated land".

For years 2000-2012, the data were obtained or interpolated from Corine Land Cover datasets, and the trend in land use change was extrapolated to 2020. For 1870-1995, are covered by croplands, pastures and forests was extrapolated using different data series following various definitions. For more recent years, regional data from Eurostat were largely used, otherwise national statistics, FAO (2017) or HYDE 3.2 (Klein Goldewijk 2017) provided the necessary data. Area covered by road and rail infrastructure was extrapolated using statistics on motorway and railway length, mostly from national statistics, Eurostat and Mitchell (1981).

GDP and its composition

GDP is the gross domestic product, i.e. value of an economy's total output of goods and services, less intermediate consumption, plus net taxes on products and imports, in a specified period. Here, we include estimates of GDP at constant prices, adjusted to 2011 price levels, with average currency exchange rates in 2011 used to convert GDP value to euro. The starting point for all countries, except for the microstates, are Eurostat's GDP data at regional level calculated using the 2010 European System of National and Regional Accounts, or ESA 2010 (European Union 2015). GDP was calculated in the past with a variety of methodologies, while for the early 20th and late 19th centuries GDP estimates are often based on proxies. Therefore, the different time series of data were linked to current Eurostat estimates.

Data on GDP by sector were also collected. Strictly, they represent the percentage composition of gross value added (GVA), a subcomponent of GDP (GDP minus net taxes), as data on net taxes are not collected by sector. Nevertheless, the GVA composition was applied to GDP. The following sectors were distinguished in this dataset, based on NACE Rev. 2 classification (European Union 2015):

- Agriculture: Agriculture, forestry and fishing (A);
- Industry: Mining and quarrying (B), Manufacturing (C), Electricity, gas, steam and air conditioning supply (D), Water supply; sewerage, waste management and remediation activities (E);
- Services: construction (F) and all remaining sectors (G-U).

As can be noticed, the difference between traditional three-sector split is the inclusion of construction in services rather than in industry. The data sources, apart from Eurostat and some international compilations, were mostly country-specific. For years 2017-2020, the GDP data were extrapolated using latest (April 2017) projections by the International Monetary Fund (2017).

Wealth and its composition

"Wealth" is considered here in a narrow sense, and relates to assets that could be destroyed during a natural hazard and conceivably contribute to reported losses. Therefore, "wealth" is comprised of tangible fixed assets. Fixed assets are produced non-financial assets that are used repeatedly or continuously in production processes for more than one year. They consist of dwellings, other (non-residential) buildings and structures, machinery and equipment, and cultivated biological resources. Therefore, the following items are excluded: all financial assets, intangible assets (e.g. patents and software),

inventories of produced goods, valuables, natural resources (incl. land, subsoil assets and non-cultivated biological resources) and consumer durables (European Union 2015). Potential inclusion of inventories, consumer durables and non-cultivated biological resources (mainly forests) was reviewed. Those categories are destructible, and of considerable monetary value. However, very little data is available for those. An analysis of inventories and consumer durables data from OECD (2017), Goldsmith (1985), Piketty and Zucman (2013) and some other country-specific sources has shown that those assets are rather stable relative to GDP. Therefore, the omission of the assets shouldn't affect the analysis of trends in vulnerability to natural hazards. More detailed classification of fixed assets is shown in Supplementary Table 1.

Statistics on tangible fixed assets according to ESA 2010 methodology are available from Eurostat for most, though not all, countries. However, the Eurostat series mostly start in 1995, and were amended with OECD, Goldsmith (1985) and several other compilations and country-specific sources. Historical series were linked to Eurostat's ESA 2010 estimates, where available. The value of assets is measured in current replacement costs, i.e. the market or basic cost of replacing an asset in the year, for which the statistic was calculated. The assets were grouped into five categories for the purposes of this study:

- Dwellings (residential buildings);
- Infrastructure, i.e. non-residential buildings and structures in 'transportation and storage' category (NACE sector H), which is intended to represent the value of roads, railways, airports, harbours and the like;
- Agricultural assets, i.e. non-residential buildings and structures, and machinery and equipment related to production in agriculture, forestry or fishery (NACE sector A), and cultivated biological resources;
- Industrial assets, i.e. non-residential buildings and structures, and machinery and equipment related to mining, manufacturing and utilities (NACE sectors B-E);
- Services assets, i.e. non-residential buildings and structures, and machinery and equipment related to other economic activity (NACE sectors F-U), and weapons systems, except assets under "infrastructure" category.

Value of dwellings and infrastructure was calculated and inserted into the database as a relative value, in % of GDP. For the remaining three categories, their value was calculated relative to GDP generated by corresponding categories of production – agriculture (NACE sector A), industry (sectors B-E), and services (sectors F-U).

Supplementary Table 2. Categories of non-financial assets included in, and excluded from, the study, according to ESA 2010 methodology. See European Union (2015), chapter 7, for detailed definitions and examples.

Category	Code	Name
INCLUDED	**AN.1**	**Produced non-financial assets**
	AN.11	**Fixed assets**
	AN.111	Dwellings
	AN.112	Other buildings and structures
	AN.1121	*Buildings other than dwellings*
	AN.1122	*Other structures*
	AN.1123	*Land improvements*
	AN.113	Machinery and equipment
	AN.1131	*Transport equipment*
	AN.1132	*ICT equipment*
	AN.1139	*Other machinery and equipment*
	AN.114	Weapons systems
	AN.115	Cultivated biological resources
	AN.1151	*Animal resources yielding repeat products*
	AN.1152	*Tree, crop and plant resources yielding repeat products*
EXCLUDED	AN.117	Intellectual property products
	AN.12	**Inventories**
	AN.13	**Valuables**
	AN.2	**Non-produced non-financial assets**
	AN.21	**Natural resources**
	AN.211	Land
	AN.212	Mineral and energy reserves
	AN.213	Non-cultivated biological resources
	AN.214	Water resources
	AN.215	Other natural resources
	AN.22	**Contracts, leases and licences**
	AN.23	**Purchases less sales of goodwill and marketing assets**
	AN.m	**Consumer durables**

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Supplementary Table 3. Contents of land use and population data file - Expo_input_CLC_Pop

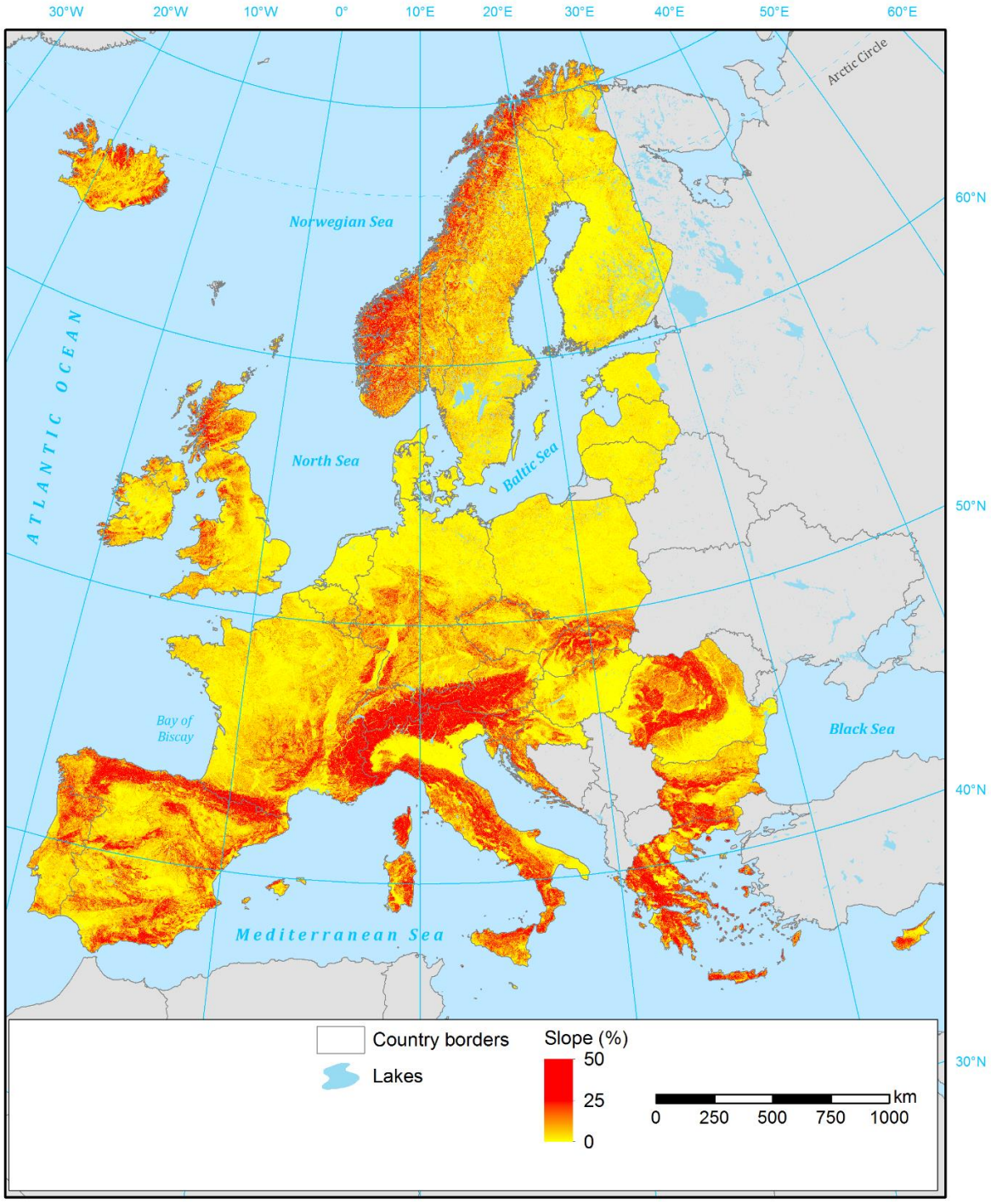
Variable	Unit	Table structure
Population	Thousands of persons	Code – NUTS3 region code Name – NUTS3 region name 1870…2020 – data by year
Urban fraction	Urban population as % of total population	
Persons per household	Mean number of persons	
Croplands	% of total area	
Pastures	% of total area	
Infrastructure	Area covered by road and rail infrastructure in ha	
Census information	Additional information on the 2011 censuses, which are the baseline population figures	Code – NUTS0 country code Name – country/territory name Date – census date Type – census type Source – method of collecting population data GEOSTAT accuracy – information on gridded data production methods
Airports	Airports identified in the CLC data	CLC2012 – Corine Land Cover 2012 vector polygon code Name – airport name Year – year of construction NUTS3 – NUTS3 region code ICAO – airport ICAO code IATA – airport IATA code
Reservoirs	Reservoirs identified in the CLC data	CLC2012 – Corine Land Cover 2012 vector polygon code Name – name of dam Year – year of construction NUTS3 – NUTS3 region code GRAND – reservoir code in GRanD database

Supplementary Table 4. Contents of economic data file - Expo_input_Econ

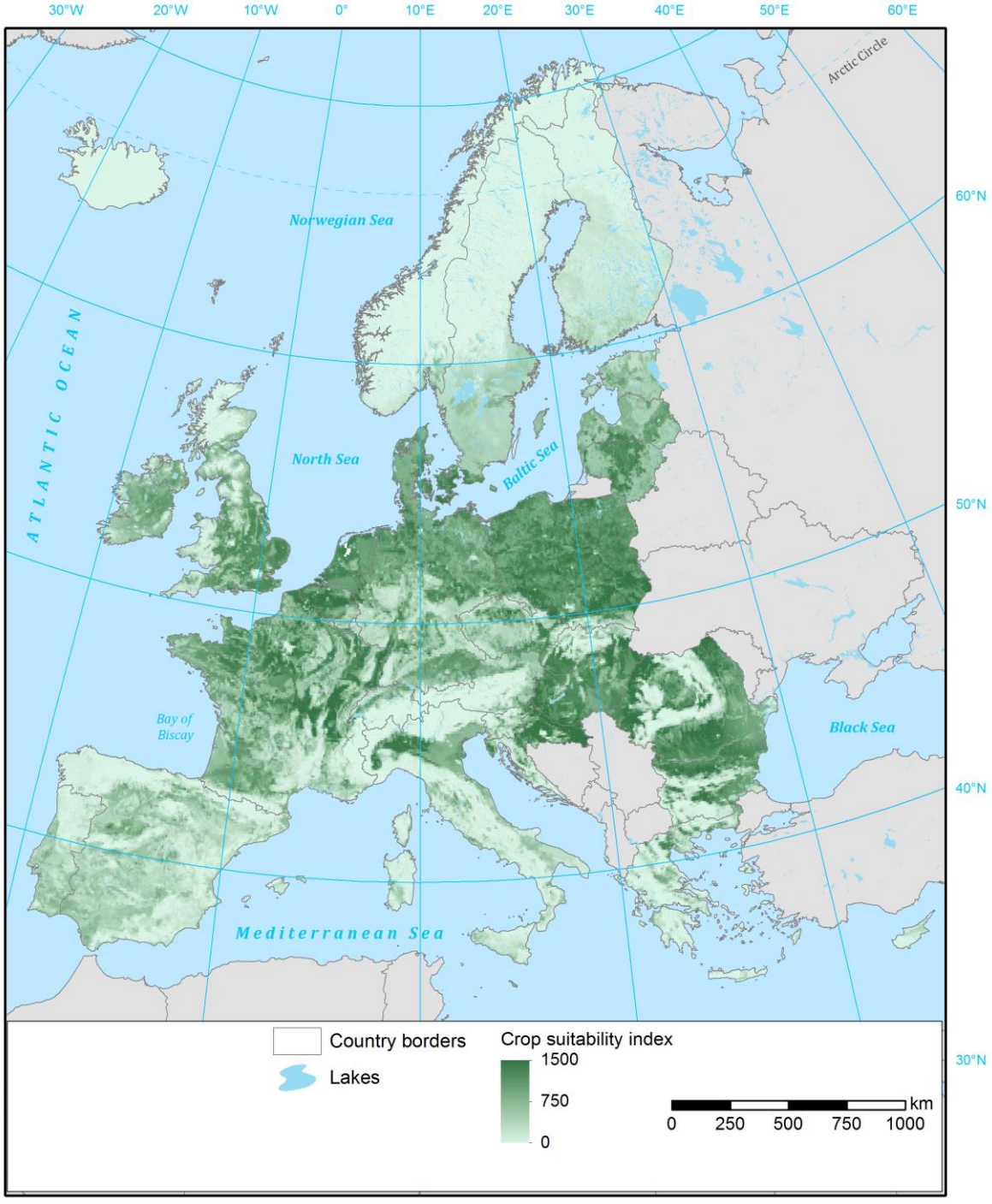
Variable	Unit	Table structure
GDP	Million euro in constant 2011 prices	Code – NUTS3 region code Name – NUTS3 region name 1870…2020 – data by year
GDP from agriculture	% of total GDP	
GDP from industry	% of total GDP	
Wealth in housing	% of total GDP	Code – NUTS0 country code Name – country/territory name 1870…2020 – data by year
Wealth in agriculture	% of GDP from agriculture	
Wealth in industry	% of GDP from industry	
Wealth in services	% of GDP from services	
Wealth in infrastructure	% of total GDP	
Forestry index	% of GDP from agriculture	Code – NUTS0 country code Name – country/territory name Index – 2011 share of forestry in agricultural GDP
Deflator	Index, 1990 or 2011 = 100	Code – NUTS0 country code Name – country/territory name 1870…2020 – data by year Unit – unit of measure (2011 = 100 or 1990 = 100)
Currencies	List of all currencies used in the period	Code – NUTS0 country code Name – country/territory name Currency – currency name* Code1 – 3-letter currency code* Code2 – ISO4217 numeric currency code Start date – date or year when currency first entered circulation End date – date or year when currency was withdrawn from circulation Conversion – conversion factor between new and old currency Note – other relevant information
Currency conversion	Conversion factors to euro (euro = 1). For countries not currently using euro, 2011 exchange rates were used.	Country – NUTS0 country code Currency – currency code* Code – merged NUTS0 and currency code Conversion – conversion factor

Note: * the currency name/code equals ISO 4217 currency name/code if the field 'Code2' is filled; otherwise the name/code is assigned solely for the purposes of disambiguation of different currencies in this database.

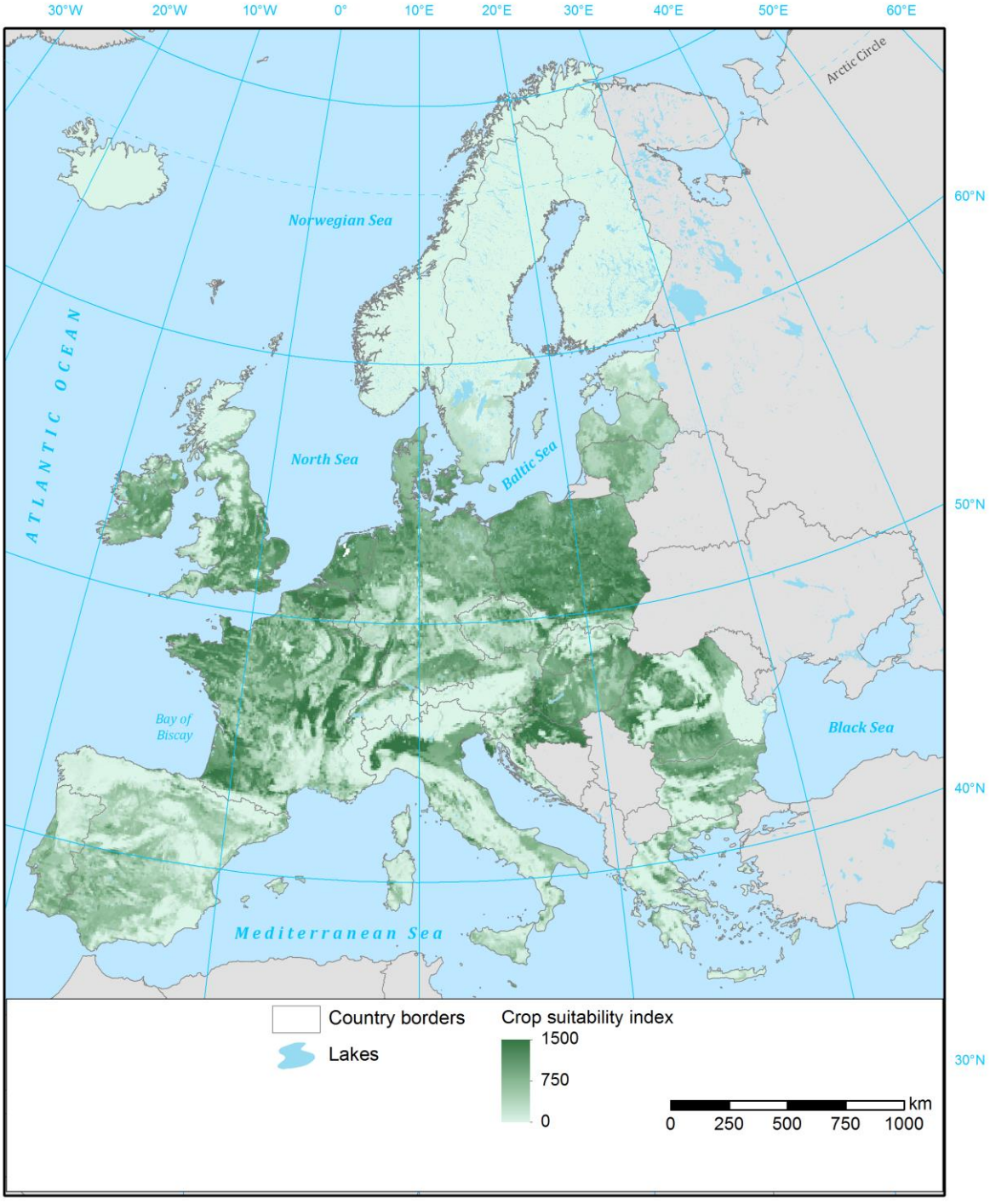
Agricultural land use



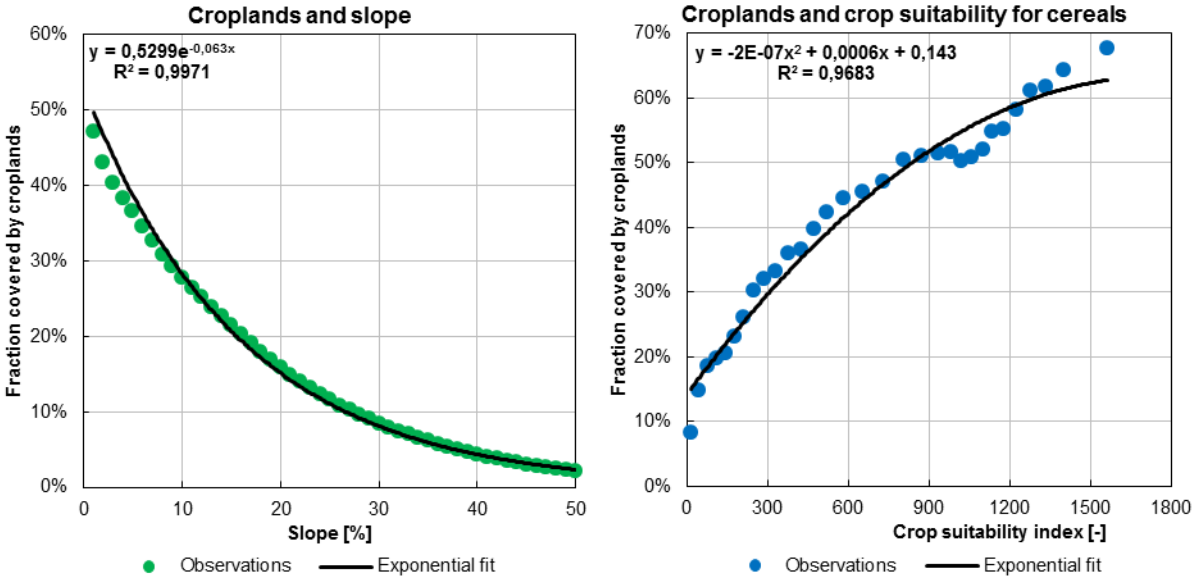
Supplementary Figure 7. Slopeness of terrain in Europe, according to EU-DEM (Eurostat 2017).



Supplementary Figure 8. Crop suitability index for high-input cereals, according to GAEZ (FAO 2016).



Supplementary Figure 9. Crop suitability index for high-input alfalfa, according to GAEZ (FAO 2016).



Supplementary Figure 10. Fraction covered by croplands compared with slope (left) and crop suitability index for high-input cereals (right). Average fractions were calculated for slope divided into classes by rounding slopes to full percentages, and for crop suitability divided into 32 bins.

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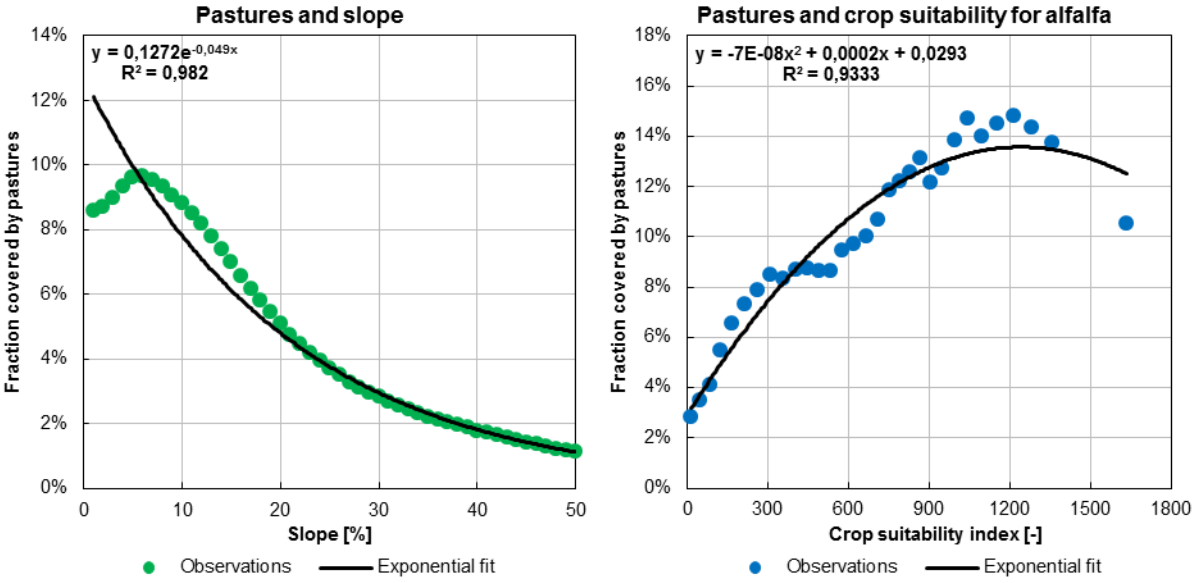

Supplementary Figure 11. Fraction covered by pastures compared with slope (left) and crop suitability index for high-input alfalfa (right). Average fractions were calculated for slope divided into classes by rounding slopes to full percentages, and for crop suitability divided into 32 bins.

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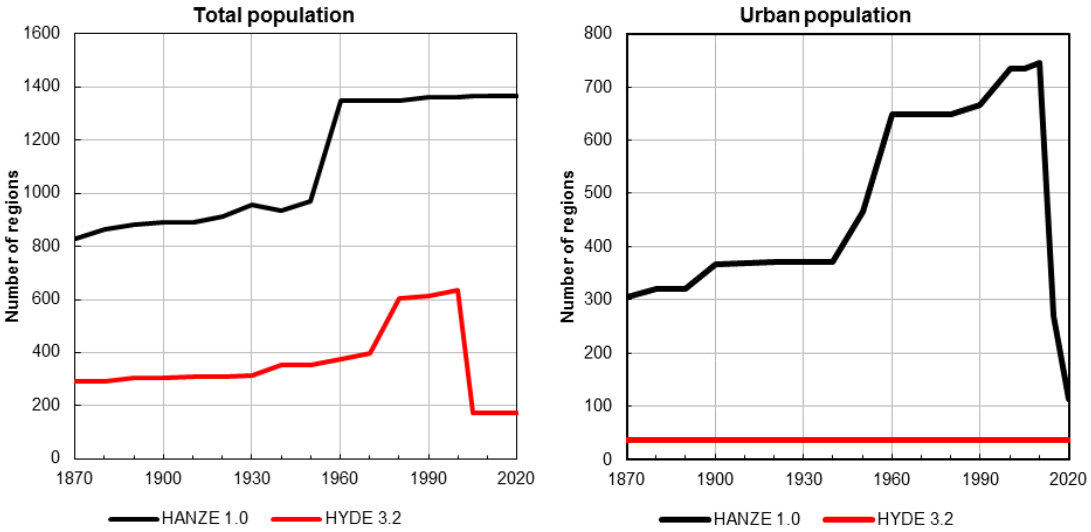
Comparison of HANZE with HYDE 3.2



Supplementary Figure 12. Comparison of number of regional-level population estimates used in HANZE and HYDE 3.2 (Klein Goldewijk 2017) databases.

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Historical urban population

Supplementary Table 5. Estimates of urban population density. A, b – exponential function parameters. D – maximum distance from the city centre (km), for which population data were used to calculate exponential function parameters (values marked with an asterisk * are estimates, as the source does not specify the distance).

Name	Region	Year	A	b	D	Source
Aarhus	DK042	1950	279	0,96	8*	Clark 1967
Berlin	DE300	1885	1120	0,68	8	Clark 1951; Clark 1967
Berlin	DE300	1900	1580	0,59	10	Clark 1951; Clark 1967
Birmingham	UKG31	1921	401	0,50	10*	Clark 1967
Birmingham	UKG31	1938	201	0,29	12*	Clark 1967
Budapest	HU101	1935	1080	0,56	5	Clark 1951; Clark 1967
Copenhagen	DK011	1940	231	0,37	10*	Clark 1967
Cork	IE025	1926	199	1,02	3	Hourihan 1982
Cork	IE025	1936	177	0,88	3	Hourihan 1982
Cork	IE025	1951	176	0,91	4	Hourihan 1982
Cork	IE025	1961	114	0,70	4	Hourihan 1982
Cork	IE025	1971	158	0,62	4	Hourihan 1982
Dublin	IE021	1901	391	0,68	4	Hourihan 1982
Dublin	IE021	1911	379	0,65	4	Hourihan 1982
Dublin	IE021	1926	352	0,59	4	Hourihan 1982
Dublin	IE021	1951	106	0,25	8	Hourihan 1982
Dublin	IE021	1961	105	0,21	8	Hourihan 1982
Dublin	IE021	1971	113	0,17	8	Hourihan 1982
Dublin	IE021	1936	270	0,53	6	Clark 1951; Clark 1967
Frankfurt am Main	DE712	1890	550	1,16	5*	Clark 1967
Frankfurt am Main	DE712	1933	340	0,57	7*	Clark 1967
Leeds	UKE42	1951	116	0,31	10*	Clark 1967
Limerick	IE023	1961	136	1,09	3	Hourihan 1982
Limerick	IE023	1971	126	0,88	3	Hourihan 1982
Liverpool	UKD72	1921	1275	0,50	9	Clark 1951; Clark 1967
London	UKI11	1871	865	0,38	17	Clark 1967
London	UKI11	1901	660	0,23	20	Clark 1967
London	UKI11	1921	443	0,17	25	Clark 1967
London	UKI11	1931	475	0,17	26*	Clark 1967
London	UKI11	1939	320	0,14	28*	Clark 1967
London	UKI11	1951	240	0,12	29	Clark 1967

London	UKI11	1961	205	0,09	33	Clark 1967
Manchester	UKD31	1931	155	0,16	18	Clark 1951
Manchester	UKD31	1939	143	0,18	20*	Clark 1967
Oslo	NO011	1938	308	0,50	4	Clark 1951; Clark 1967
Paris	FR101	1896	1430	0,50	12	Clark 1951; Clark 1967
Paris	FR101	1931	1820	0,47	14	Clark 1951; Clark 1967
Paris	FR101	1946	695	0,21	16*	Clark 1967
Stockholm	SE110	1880	610	1,30	5*	Clark 1967
Stockholm	SE110	1940	425	0,48	8*	Clark 1967
Vienna	AT130	1890	660	0,50	7	Clark 1951; Clark 1967
Zurich	CH040	1936	328	0,29	10*	Clark 1967

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