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CHARACTERIZATION OF LAND USE COVER DATASETS FROM A GLOBAL TO AN ANDALUSIAN LEVEL: AN "OBSTACLE COURSE" FOR USERS

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ABSTRACT

Advances in the field of Geographic Information Systems (GIS) and in Remote Sensing (RS) have led to the production of a significant number of Land Use and Land Cover (LUC) datasets. These datasets show great diversity in terms of the extents mapped, the scale and spatial resolution, or the temporal and thematic resolution, among others. In this paper, we review 33 general (non-thematic) LUC datasets covering different extents (from global to regional level), which are currently available or will be in the future for Andalusia (Spain). 17 are global, 10 European, 3 cover Spain and 3 Andalusia. The aim is to analyze the spatial, temporal and thematic parameters of these datasets so as to enable users to choose the one that best suits their purposes. Spatial parameters include format, spatial resolution, cartographic scale, Minimum Mapping Unit (MMU) and Minimum Mapping Width (MMW); temporal parameters include temporal resolution or timeframe (single or time series), *i.e.*, the length of time and the number of available dates. The thematic parameters include the number of classes and their nature, compatible legends and group of classes. This comparative analysis shows that within these 33 datasets, at least 217 different products/maps are on offer to users. This wide variety of maps is a major source of uncertainty and makes the path to find the best LUC dataset a real "obstacle course" for users.

Keywords: Land Use Cover (LUC) datasets; general datasets; uncertainty; spatial, temporal, thematic scale/resolution.

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CARACTERIZACIÓN DE BASES DE DATOS DE USOS Y COBERTURAS DEL SUELO DESDE LA ESCALA GLOBAL HASTA LA REGIONAL (ANDALUCÍA): UNA “CARRERA DE OBSTÁCULOS” PARA LOS USUARIOS

RESUMEN

Los avances en el campo de los Sistemas de Información Geográfica (SIG) y la Teledetección han llevado a la producción de un número significativo de bases de datos de usos y coberturas del suelo (Land Use Cover, LUC). Estas bases de datos muestran una gran diversidad en cuanto a su extensión, escala y resolución espacial, o resolución temporal y temática, entre otros. En este artículo analizamos 33 bases de datos LUC generales (no temáticas) que cubren diferentes extensiones (desde la escala global hasta la regional) y que están actualmente disponibles para Andalucía (España) o lo estarán en un futuro. De estas bases de datos, 17 tienen una extensión global, 10 son europeas, 3 cubren España y 3 el territorio andaluz. El objetivo es analizar los parámetros espaciales, temporales y temáticos de estas bases de datos para que los usuarios puedan elegir la que mejor se adapte a sus propósitos. Los parámetros espaciales incluyen el formato, la resolución espacial, la escala cartográfica, Minimum Mapping Unit (MMU) y Minimum Mapping Width (MMW); los parámetros temporales se centran en la resolución temporal o marco temporal (una única fecha o una serie cronológica), es decir, la duración en el tiempo y el número de fechas disponibles. Los parámetros temáticos incluyen el número de clases y su naturaleza, aquellas leyendas que sean compatibles y los grupos de clases. Este análisis comparativo muestra que, a partir de estas 33 bases de datos, están disponibles, al menos, 217 productos/mapas diferentes. Esta amplia variedad de mapas es una fuente importante de incertidumbre y provoca que el camino para elegir la mejor base de datos LUC sea una verdadera "carrera de obstáculos" para los usuarios.

Palabras clave: Bases de datos de usos y coberturas del suelo; bases de datos generales; incertidumbre; escala/resolución espacial, temporal y temática.

1. Introduction

Land Use (LU), Land Cover (LC) or Land Use Cover (LUC) datasets are frequently used for a wide variety of purposes, the most common and accessible of which is Land Use Cover Change (LUCC) monitoring. LU refers to the current or planned use of a specific area of the earth surface, that is, the purpose for which one or several covers are used. LC refers to the biophysical covers of the earth surface. When mapped, land covers do not include information about their use. However, because of the difficulty to map LU and LC individually in a cost-effective way, LU and LC have been usually mapped together in LUC datasets, which are the common practice. LUCC analysis examines land use and cover change on the Earth’s surface, its drivers and effects (Moran *et al*., 2012), and its impacts on natural or human-induced processes (Gutman *et al*., 2012). LUCC studies are broadly used in research into loss of biodiversity, soil erosion, climate change, ecosystem services, etc. (Cebecauer & Hofierka, 2008, Sophie *et al*., 2011, Hu *et al*., 2008).

Great progress has been made in Land Use Cover Change Modelling (LUCCM) (Verburg *et al*., 2004) research in recent decades, at both an academic level and in real planning situations (Ferchichi *et al*., 2017; Sohl & Sleeter, 2012). LUCCM exercises rely on the availability of LUC data that meets the needs of the modelers. The availability of LUC datasets is also crucial for the validation of LUCCM simulations. LUC data validation also relies on LUC datasets to obtain statistical values

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about the accuracy or uncertainty of categories, together with metrics about the spatial patterns of these categories, or the size of individual or groups of patches (Camacho *et al*., 2022; Escobar, 2022).

In recent decades we have witnessed impressive growth in the production and distribution of datasets of this kind, due to the development of Geographic Information Systems (GIS) and Remote Sensing (RS) techniques, and also due to the culture of open data policies. As a result, a wide variety of products are now available. Although in theory this is highly beneficial for users, it can lead to a chaotic situation where users do not know which LUC dataset is most appropriate for their particular purposes. They have to set out on an "obstacle course" sifting through many datasets, each of which is characterized by different parameters. Another problem is that users are not always aware of all the available datasets, their metadata and how they might fit their needs. This increases the uncertainty and confusion when a user has to decide which LUC dataset to choose.

Two types of LUC datasets can be distinguished: those mapping a specific land use or cover, which we refer to as thematic LUC datasets, and those that map all the land uses or covers on the ground, with more or less thematic detail depending on the spatial scale and thematic resolution of the datasets. Reviews of the available LUC datasets, although increasingly common, usually focus on a relatively small number of products, a specific type of LUC dataset or a specific scale, mostly global.

Congalton *et al*. (2014) reviewed, compared and analysed the uncertainties of four popular general and global LUC datasets. Mora *et al.* (2014) reviewed 8 general and global LUC datasets in a chapter of a book coordinated by Manakos & Braun (2014), in which many national and continental LUC datasets and projects are explained in detail. Yang *et a*l. (2017) reviewed, compared and assessed the accuracy of 7 global and general LUC datasets over China. Liu *et al*. (2021) carried out a thorough review and uncertainty analysis of three recent general LUC datasets at global scale. Bratic *et al*. (2021) reviewed 6 thematic and 2 general LUC datasets at global scale. Klotz *et al.* (2016) focused on mapping artificial covers and reviewed 12 different datasets at global scale, comparing and analyzing the uncertainty of 5 of them. Potere *et al*. (2009) carried out a similar study in which they reviewed and analyzed 10 urban LUC datasets. For specific areas, Fritz *et al.* (2019) reviewed the available LUC datasets for monitoring land changes in mountainous areas of Ethiopia. Xu *et al.* (2019) reviewed and compared three African LUC datasets. For Spain, Valcárcel Sanz & Castaño Fernández (2012) carried out an overview of the historical LUC mapping practice in the country and García-Álvarez & Camacho Olmedo (2018) reviewed the available LUC datasets at global, continental and local scales that could be used to monitor land change in mountainous areas of Andalusia.

Grekousis G *et al*. (2015) carried out what at that time was one of the most comprehensive reviews of available general LUC datasets, characterizing 21 global and 43 regional LUC datasets. Shortly afterwards, the Organization for Economic Cooperation and Development (OECD) report carried out by Diogo & Koomen (2016) reviewed 27 general LUC datasets at global, continental and national scales. More recently, García-Álvarez D & Nanu SF (2022) reviewed 41 general and 62 thematic LUC datasets at global and continental scales in what is currently the most comprehensive review of available LUC datasets.

LUC datasets can be characterized by their spatial, temporal or thematic parameters, all of which determine their uncertainty (Castilla & Hay, 2007). The spatial parameters refer to the way the ground is spatially conceptualized, *i.e.*, how much ground is mapped, how it is represented over a surface (data model) and at what level of spatial detail. The temporal parameters refer to the temporal conceptualization of the datasets: to the time or times at which the ground is mapped. In general, LUC data is more useful the more historical information is available, as it allows us to track LUC changes over time (Verburg *et al.*, 2011; García-Álvarez & Camacho Olmedo, 2017). Finally, the thematic

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parameters refer to the way the thematic variable (*i.e.*, land uses / covers) is conceptualized, to the degree of thematic detail with which it is represented on the map.

In this paper, we aim to characterize and compare the available general LUC datasets at all possible scales for Andalusia (Spain). We focus exclusively on general (non-thematic) LUC datasets because they are the most commonly used in LUC change analysis and LUCC modelling. Users of thematic LUC datasets usually work in more specific fields, each one with their own specific needs, which may not be fully comparable. The region of Andalusia has been chosen as the area of analysis for operational reasons in that it is the usual area of work for the research team behind this paper and because it allows us to analyze the range of LUC products on offer at all scales, as many LUC datasets have been specifically developed for Andalusia. Although reviewing and characterizing all the available LUC datasets for all the regions of Spain, Europe and even worldwide would be of great interest, it would be beyond the scope of a paper of these dimensions.

2. Data and Methods

2.1. Data

Table 1 shows the 33 *general (non-thematic)* datasets analyzed in this paper. They are divided by the extent of their coverage area and, in the case of global datasets, due to their large number, we also differentiate between the datasets with a *single date* and those with *a time series of maps*. The datasets are classified in the following order: global general Land Use Cover datasets with a single date (García-Álvarez, Lara Hinojosa & Quintero Villaraso, 2022), global general Land Use Cover datasets with a time series of maps (García-Álvarez *et al*., 2022a), general Land Use Cover datasets for Europe (García-Álvarez *et al*., 2022b), general Land Use Cover datasets for Spain, and general Land Use Cover datasets for the Andalusia region. The datasets in the global and European groups are set out in chronological order, from the oldest to the most recent.

For these purposes, we have collected all the *available* general LUC datasets for the Autonomous Community of Andalusia (Spain). That means all the potential datasets that are currently available or ongoing for Andalusia, such as, for example, SIOSE AR, the most recent Spanish LUC dataset, which is not currently available for Andalusia, but will be published in the near future. Old LUC datasets that are now considered obsolete have not been analyzed. Our review also covers other datasets providing consistent LUC information for all the area they cover. This includes the *Mapa Forestal de España* (Forestry Map of Spain – MFE), whose legends at scales of 1:25,000 and 1:50,000 map all land use cover classes. With respect to the variety of MUCVA products, the 1:10,000 scale is not analyzed because its legend only focuses on forest categories. GLCC 2.0 Global[1] and MCD12Q1[2] offer different classifications of LUC products, some of them considered as general and others more focused on thematic categories. In this work, we only analyze the general and most common product in both datasets: the International Geosphere-Biosphere Programme (IGBP) classification.

We have downloaded the 33 datasets and their technical documentation from very varied sources: from websites that provide LUC information at global scale (FAO GeoNetwork, Land Processes Distributed Active Archive Center (LP DAAC), etc.), at European scale (Copernicus Land Monitoring Service), from Spanish servers (Centro Nacional de Información Geográfica del Instituto Geográfico Nacional, CNIG-IGN), and from the Andalusian geoportal REDIAM (Red de Información Ambiental de Andalucía).

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The information on the chosen LUC datasets was up to date on completion of this paper. However, we realize that it may have been updated since then.

Table 1 includes the full name, acronym and producer of each dataset. It also references the technical documentation, available in full in Appendix 1. Appendix 2 shows the main website for each dataset. For further reading and more detailed information about global and European datasets, please consult the references mentioned in this section.

Table 1. Full name, acronym, producer, and technical documentation of the analyzed LUC datasets

Land Use Cover datasets	**Acronym**	**Producer**	**Technical documentation (Appendix 1)**
Global general Land Use Cover datasets with a single date			
University of Maryland Land Cover Classification	UMD LC	Department of Geography of the University of Maryland	Hansen *et al.* (2000)
Global Land Cover Characterization 2.0	GLCC 2.0 Global	U.S. Geological Survey (USGS), Earth Resources Observation and Science (EROS) Center, University of Nebraska-Lincoln (UNL), Joint Research Centre (JRC) of the European Commission	Belward *et al.* (1999), Brown *et al.* (1999), Loveland & Belward (1997), Loveland *et al.* (2000), Reed *et al.* (2000)
Global Land Cover 2000	GLC 2000	Joint Research Centre (JRC) of the European Commission in collaboration with regional teams across the globe	Hua *et al.* (2018), McCallum *et al.* (2006), Neumann *et al.* (2007), Pérez-Hoyos *et al.* (2012), Tchuenté *et al.* (2011)
Geo-Wiki Hybrid	Geo-Wiki Hybrid	A group of researchers from different international institutions led by the International Institute of Applied Systems Analysis (IIASA)	See *et al.* (2015)
Land Degradation Assessment in Drylands	LADA LUC map	Food and Agriculture Organization (FAO) of the United Nations	Nachtergaele & Petri (2013)
Global Land Cover-SHARE	GLC-SHARE	Land and Water Division of the Food and Agriculture Organization (FAO), in collaboration with other institutions across the world	Latham *et al.* (2014)
OSM Landuse/Landcover	OSM LULC	GIScience research group from Heidelberg University	Schultz *et al.* (2017)
ESRI 2020 Land Cover	ESRI 2020 LC	Impact Observatory for Esri	Karra *et al.* (2021)
Global general Land Use Cover datasets with a time series of maps			
Global Land Surface Satellite – Global Land Cover	GLASS-GLC	A group of Chinese researchers led by the Tsinghua University	Liu *et al.* (2020)
Land Cover – Climate Change Initiative	LC-CCI	European Space Agency (ESA)	ESA (2017)
GlobeLand30	GLC30	Chinese government and the National Science Foundation of China	Chen *et al.* (2010, 2011a, 2011b, 2012, 2014, 2016), Tang *et al.* (2014), Xie *et al.* (2015), Zhu *et al.* (2010)
Global Land Cover 250m	GLC250	A group of Chinese researchers led by the Chinese Academy of Sciences and Tsinghua University	Wang *et al.* (2015)
MODIS/Terra+Aqua Land Cover Type	MCD12Q1	Research team led by the University of Boston	Friedl & Sulla-Menashe (2019), Friedl *et al.* (2002, 2010), Sulla-Menashe *et al.* (2019)
Global Land Cover by National Mapping Organization	GLCNMO	International Steering Committee for Global Mapping (ISCGM) in collaboration with the Geospatial Information Authority of Japan (GSI), Chiba University and national mapping organizations from different participant countries	Kobayashi *et al.* (2017), Tateishi *et al.* (2011, 2014)
GlobCover	GlobCover	European Space Agency (ESA) in collaboration with the Joint Research Centre (JRC) of the European Commission, the European Environment Agency, the FAO, the UN Environment Programme (UNEP), the Global Observations of Forest Cover Land-use Dynamics (GOFC–GOLD) programme and the	Bicheron *et al.* (2008), Bontemps *et al.* (2011)

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		International Geosphere-Biosphere Programme (IGBP). The Université Catholique de Louvain (UCL) also contributed to the 2009 edition of the map.	
Finer Resolution Observation and Monitoring of Global Land Cover	FROM-GLC	Tsinghua University and a group of Chinese researchers and other international institutions	Chen *et al.* (2019), Gong *et al.* (2013), Yu *et al.* (2013), Yu *et al.* (2014)
Copernicus Global Land Service Dynamic Land Cover map	CGLS-LC100	Copernicus Land Monitoring programme of European Environment Agency (EEA)	Buchhorn *et al.* (2020a, 2020b, 2020c), Tsendbazar *et al.* (2019, 2020)
General Land Use Cover datasets for Europe			
HIstoric Land Dynamics Assessment	HILDA	Department of Geoinformation Science and Remote Sensing of Wageningen University	Fuchs *et al.* (2013, 2015a, 2015b)
Corine Land Cover	CLC	Copernicus Land Monitoring programme of the European Environment Agency (EEA)	Bossard *et al.* (2000), Büttner *et al.* (2002), Büttner & Kosztra (2011), Büttner *et al.* (2014), Büttner *et al.* (2012), European Environment Agency (1994, 2006a, 2006b, 2007), Jaffrain (2017), Kosztra *et al.* (2019), Soukup *et al.* (2017)
Pan-European Land Cover Monitoring	PELCOM	PELCOM project coordinated by the DLO - Winand Staring Centre (SC-DLO). It was a European project funded as a shared COST action	Champeaux *et al.* (2000), Mücher (2000), Mücher *et al.* (2000)
Annual Land Cover Product	Annual Land Cover	Geo-harmonizer project coordinated by the Czech Technical University in Prague	-
GlobCorine	GlobCorine	European Space Agency (ESA) in collaboration with the European Environment Agency (EEA) and the Université Catholique de Louvain (UCL)	Bontemps *et al.* (2009), Defourny *et al.* (2010), Defourny *et al.* (2010a, 2010b)
Urban Atlas	Urban Atlas	Copernicus Land Monitoring programme of the European Environment Agency (EEA)	Copernicus Programme (2020), Gallaun (2017), Hirschmugl *et al.* (2018), Silva & Poleman (2016), Silva *et al.* (2013)
Natura 2000	N2K	Copernicus Land Monitoring programme of the European Environment Agency (EEA)	Buck & Büscher (2018, 2021)
Riparian Zones Land Cover / Land Use – Riparian Zones (RZ)	Riparian Zones	Copernicus Land Monitoring programme of the European Environment Agency (EEA)	Vandeputte *et al.* (2018), Weissteiner *et al.* (2016)
Coastal Zones	Coastal Zones	Copernicus Land Monitoring programme of the European Environment Agency (EEA), in collaboration with the Copernicus Marine Environment Monitoring Service (CMEMS) and representatives from the potential community of users	European Environment Agency (2021)
Sentinel-2 Global Land Cover 2017	S2GLC 2017	European Space Agency (ESA), Space Research Centre of the Polish Academy of Sciences (CBK PAN)	Gromny *et al.* (2019a, 2019b), Kukawska *et al.* (2017), Malinowski *et al.* (2019), Nowakowski *et al.* (2017)
General Land Use Cover datasets for Spain			
Information System about Land Occupation in Spain in Andalusia (*Sistema de Información sobre Ocupación del Suelo de España*)	SIOSE	Teams from the Spanish Autonomous Communities led by the Instituto Geográfico Nacional (IGN)	Equipo Técnico Nacional SIOSE (2015, 2018), Caballero *et al.* (2012)
Information System about Land Occupation in Spain in Andalusia High Resolution (*Sistema de Información sobre Ocupación del Suelo de España Alta Resolución*)	SIOSE AR	Instituto Geográfico Nacional (IGN) in coordination with teams from the Spanish Autonomous Communities and the Spanish State Administration	Equipo Técnico Nacional SIOSE (2020)
Forestry Map of Spain (*Mapa Forestal de España*)	MFE	Dirección General de Biodiversidad, Bosques y Desertificación del Ministerio para la Transición Ecológica y el Reto Demográfico	Ceballos (1966), Vallejo Bombín (2005)
General Land Use Cover datasets for the Andalusia region			
Map of vegetation uses and	MUCVA	Consejería de Medio Ambiente de la Junta de	Moreira Madueño (2007)

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covers in Andalusia (*Mapa de usos y coberturas vegetales de Andalucía*)		Andalucía	
Information System about Land Occupation in Spain in Andalusia – Land Occupation (*Sistema de Información sobre Ocupación del Suelo de España en Andalucía -Ocupación del Suelo*)	SIOSEA OS	Consejería de Agricultura, Ganadería, Pesca y Desarrollo Sostenible de la Junta de Andalucía	Junta de Andalucía (2013)
Andalusia Natural Heritage Information System Land Occupation (*Sistema de Información sobre el Patrimonio Natural de Andalucía - Ocupación del Suelo*)	SIPNA OS	Agencia de Medio Ambiente y Agua de la Consejería de Agricultura, Ganadería, Pesca y Desarrollo Sostenible, de la Junta de Andalucía	Junta de Andalucía (2019)
TOTAL	33		

2.2. Methods

We have characterized and compared the reviewed LUC datasets in three different ways, according to their spatial, temporal, and thematic parameters. Specifically, in section 3 we analyze: spatial parameters (section 3.1.) including *format, spatial resolution, cartographic scale, Minimum Mapping Unit* (MMU) and *Minimum Mapping Width* (MMW); temporal parameters (section 3.2.) corresponding to *temporal resolution* or timeframe (single or time series), that is, the *timespan* and the *number of available dates*; and thematic parameters (section 3.3.) or *thematic resolution*, *i.e.*, *the number of classes* and their *nature, compatible legends* and *group of classes.*

The spatial parameters (section 3.1.) refer to the extent of the area covered by the dataset, how this is conceptualized in a spatial layer and the degree of spatial detail. The *format* of digital geographic information is represented through two data models, raster, and vector. The raster model consists of a systematic, complete division of space into minimal units called cells or pixels, as a matrix, with unique values for each pixel. The vector model, on the other hand, does not systematically divide the space into a series of equal units, and instead represents it using geometric elements (points, lines and polygons), with constant characteristics and attribute series for each one (Olaya, 2020).

In raster format, the degree of spatial detail depends on the *spatial resolution*, *i.e.*, pixel size or cell size. A large cell means a low resolution and vice versa (Olaya, 2020). In vector format, the spatial detail is dependent on the *cartographic scale*, the *Minimum Mapping Unit* (MMU) and the *Minimum Mapping Width* (MMW). Cartographic scale, which is used to photo-interpret the data and obtain the layers, is the ratio between the size of an element on a map and the size of that same element on the ground. The MMU determines the minimum area of the features to be drawn on a map. The MMW defines the minimum width of linear features such as roads and railways (Manakos & Braun, 2014). The three parameters are inter-dependent.

Temporal parameters (section 3.2.) refer to the timespan covered by the dataset and the number of points analyzed on this timespan. The *timespan* refers to the length of time covered by the dataset, from the oldest layer to the most recent one. The *temporal resolution* refers to the number of *available dates* in each dataset. Usually, the longer the timespan, the higher the temporal resolution. Depending on the temporal resolution of the dataset, we differentiate between single-date datasets and time-series datasets. The former are only available for one date, while the latter cover several different dates.

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Finally, the thematic parameters (section 3.3.) include the thematic resolution, *i.e.*, the *number of classes* in the datasets, and also their *nature*, *compatible legends* and *group of classes*. Relative to the *nature of classes*, we differentiate datasets that show Land Cover (LC) categories, Land Use (LU) categories, both Land Use and Cover, differentiating between them (LU/LC) or not (LUC), or other types such as Land Use Systems (LUS). The legends used in the datasets normally follow standard classifications so as to ensure compatibility. The nature of the classes and, in some cases, their number may depend on the *compatible legends* for each dataset.

Thematic parameters also focus on the detail of the thematic variable, that is, the detail at which land uses and covers are mapped in each dataset. To this end, we focus above all on the *number of classes*. When multiple levels of legends are available, as in the case of hierarchical legends, we only include the most detailed legend for each (as for example in CLC, N2K, Riparian Zones, Coastal Zones or SIPNA OS). However, in those cases in which the different temporal (as in FROM-GLC), spatial (MFE), temporal and spatial (MUCVA) or thematic (SIOSE, SIOSE AR) versions of the dataset have different legends, we show all of them. To homogenize the datasets, we have excluded from all of them categories such as "No data", "Unclassified", "Interrupted areas", "Missing data", "Clouds", "No input data", "Data of gaps", "Out of scope" or similar[3]. This means that, in some cases, the number of classes specified here may differ from that specified in other references.

Finally, we grouped the categories of all the analyzed datasets into various *groups of classes*. In order to enable us to compare the different datasets, we chose a simple LUC classification or group of LUC classes as a reference: artificial (a), agriculture (ag), natural vegetation (v), agriculture/natural vegetation mosaic (m), water, wetlands, snow, ice (w), bare ground, barren, sparsely vegetated area (b). As regards the LUC datasets with different spatial and temporal versions, we only compared the most detailed, most recent versions. For SIOSE and SIOSE AR —the only datasets that differentiate LU from LC— the comparison is only possible with the LC classes.

3. Results and Discussion

3.1. Spatial parameters

The LUC datasets analysed in this paper are produced and/or distributed in both raster and vector data *format* (Table 2). The global LUC maps are only produced and distributed in raster, while the European datasets appear in either raster or vector format in similar proportions, except for CLC, which is distributed in both formats. The Spanish datasets are only in vector format while most of Andalusian datasets are available in both the original vector and transformed raster formats. In most cases, the datasets that are distributed in both formats were originally produced in vector format and later, to make them easier to use and to meet the needs of users, were converted into and distributed (at lower levels of detail) in raster format.

While raster-type datasets are obtained using traditional Remote Sensing techniques (supervised and unsupervised classifications), vector-type datasets are usually obtained using traditional photo-interpretation techniques or data fusion, which allow mappers to increase the precision and detail of what is being mapped, although at the cost of a certain degree of subjectivity of each photo interpreter. This explains why the vector format is more frequent in high-detail datasets, such as the Spanish, Andalusian or European thematic datasets produced as part of the Copernicus program (Urban Atlas, N2K, Riparian Zones, Coastal Zones), while the raster format is more common in global and European

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datasets. Other reason is that, comparatively, the raster format generates smaller files than the vector ones.

The most commonly used format in raster datasets is .tif (Tagged Image File), while in vector datasets the formats vary between .gdb (Geodatabase), .gpkg (Geopackage) and .shp (Shapefile) (Table 2). The .tif format is very common in raster data due to its flexibility and its capacity for storing decimal values. The shapefile format is widely used in vector data, although due to its various limitations, alternative formats, such as geopackage, have become increasingly common in recent years.

Table 2. Produced and/or distributed format, spatial resolution, cartographic scale, Minimum Mapping Unit (MMU) and Minimum Mapping Width (MMW) of the LUC datasets

Land Use Cover datasets	Produced and/or distributed format		Spatial resolution	Cartographic scale	Minimum Mapping Unit (MMU)	Minimum Mapping Width (MMW)
	Data model	Data format[4]				
Global general Land Use Cover datasets with a single date						
UMD LC	Raster	.tif	1 km	-	-	-
GLCC 2.0 Global	Raster	.tif	1 km	-	-	-
GLC 2000	Raster	.adf	1 km	-	-	-
Geo-Wiki Hybrid	Raster	.img	300 m	-	-	-
LADA LUC Map	Raster	.adf, .bil	≈ 9.2 km	-	-	-
GLC-SHARE	Raster	.tif	1 km	-	-	-
OSM LULC	Raster	.tif	10 m	-	-	-
ESRI 2020 LC	Raster	.tif	10 m	-	-	-
Global general Land Use Cover datasets with a time series of maps						
GLASS-GLC	Raster	.tif	5 km	-	-	-
LC-CCI	Raster	.tif, .nc	300 m	-	-	-
GLC30	Raster	.tif	30 m	-	-	-
GLC250	Raster	.tif	250 m	-	-	-
MCD12Q1	Raster	.hdf	500 m	-	-	-
GLCNMO	Raster	.tif	1 km, 500 m	-	-	-
GlobCover	Raster	.tif	300 m	-	-	-
FROM-GLC	Raster	.tif	30 m, 10 m	-	-	-
CGLS-LC100	Raster	.tif	100 m	-	-	-
General Land Use Cover datasets for Europe						
HILDA	Raster	.tif	1 km	-	-	-
CLC	Raster/Vector	.tif, .gdb, .gpkg	100 m	1:100,000	25 ha	100 m
PELCOM	Raster	.adf	1 km	-	-	-
Annual Land Cover	Raster	.tif	30 m	-	-	-
GlobCorine	Raster	.tif	300 m	-	-	-
Urban Atlas	Vector	.gpkg	-	1:10,000	0.25-1 ha	10 m
N2K	Vector	.gdb, .gpkg	-	1:5000-1:10,000	0.5 ha	10 m
Riparian Zones	Vector	.shp	-	1:10,000	0.5 ha	10 m
Coastal Zones	Vector	.gdb, .gpkg	-	1:10,000	0.5 ha	10 m
S2GLC 2017	Raster	.tif	10 m	-	-	-
General Land Use Cover datasets for Spain						
SIOSE	Vector	.gdb, .gpkg	-	1:25,000	0.5-2 ha	15 m
SIOSE AR	Vector	.gdb, .gpkg	-	1:1000-1:5000	-	-
MFE	Vector	.shp	-	1:50,000	2.5-6.25 ha	25 m
				1:25,000	0.5-2 ha	-
General Land Use Cover datasets for Andalusia region						
MUCVA	Vector	.gpkg	-	1:50,000-1:100,000	-	-
	Raster/Vector	.tif, .gdb, .gpkg, .shp	35 m, 38 m	1:25,000	0.25 ha	-
SIOSEA OS	Raster/Vector	tif, .gdb, .gpkg, .shp	16 m, 38 m	1:10,000	0.005-0.02 ha	10 m
SIPNA OS	Raster/Vector	tif, .gdb, .gpkg, .shp	23 m, 48 m	1:10,000	-	-

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As regards the *spatial resolution* of raster datasets (26 out of the 33 described in Table 2, Fig. 1), most global LUC datasets with a single date have a spatial resolution of 1 km, while the rest range from 10 meters, in the case of OSM LULC and ESRI 2020 LC, to 9.2 km for the LADA LUC Map. In LUC datasets with time series, a more heterogeneous group, the spatial resolution varies between 10 m for a FROM-GLC product (which is based on Sentinel-2 imagery) and 5 km for GLASS-GLC. Some of the datasets in this group, such as GLCNMO and FROM-GLC, are distributed in two different spatial resolutions. For example, FROM-GLC has been produced on different dates with satellite images from Landsat (the 2010, 2015 and 2017 editions, with a spatial resolution of 30 m) and from Sentinel (the 2017 edition, with a spatial resolution of 10 m). (Chen *et al*., 2019; Gong *et al*., 2013).

The spatial detail of the LUC datasets is usually determined by the level of detail of the satellite images from which they are generated. With the development of Remote Sensing and the consequent creation of new sensors and missions that provide satellite images with higher levels of spatial and spectral resolution, the availability of more detailed data sources becomes greater every day, which explains the increase in spatial resolution of the LUC datasets over the years (Belward & Skøien, 2015). One example is UMD LC, which was produced between 1992 and 1993 using supervised classification of satellite images with AVHRR sensors, with a pixel size of 1 km, while S2GLC 2017, produced more recently with automated classification of images from Sentinel 2, has a spatial resolution of 10 m.

Producing a time series of LUC maps depends on the availability of a historical time series of satellite images that is coherent over time at the same or very similar spatial resolutions, and captures the same or very similar portions of the electromagnetic spectrum. As a result, the spatial resolution of the available LUC datasets providing a time series of LUC maps is the same as in the available archives of historical satellite imagery: the archive of MODIS imagery (250-500 m), used in the production of GLC250, MCD12Q1 and GLCNMO; the MERIS imagery (300 m), used in the production of LC-CCI and GlobCover; and the Landsat imagery (30 m), used in the production of GLC30 and FROM-GLC.

The spatial resolution of LUC datasets also depends on their intended purpose. Hence, the coarse spatial resolution used in LADA is due to the fact that it was produced within the framework of the Land Degradation Assessment in Drylands (LADA) project, whose main objective was to analyze global land degradation (Nachtergaele and Petri, 2013). The LADA datasets characterize the main land use units where land degradation could happen, in line with the objectives of the project. Other global LUC datasets at higher resolution do not pay enough attention to land use, or fail to properly characterize the land use units required for analyzing land degradation.

European LUC datasets have a pixel size that ranges from 10 m for S2GLC 2017 to 1 km for HILDA and PELCOM. The converted CLC raster map has a resolution of 100 m. As in the case of global datasets, their spatial resolution depends mainly on the satellite imagery used in their production and their intended purpose. HILDA is a historical dataset of LUC covers obtained using a backward modelling methodology (Fuchs, 2015). This process of modelling backwards into the past can only be conducted at coarse resolutions, as there is insufficient data available to simulate detailed LUC maps of the past with a minimum degree of certainty.

As regards the raster maps (converted from the original vector data) used in the Andalusian LUC datasets, the spatial resolution is high, ranging from 16 to 48 meters, and two datasets are available in two different resolutions.

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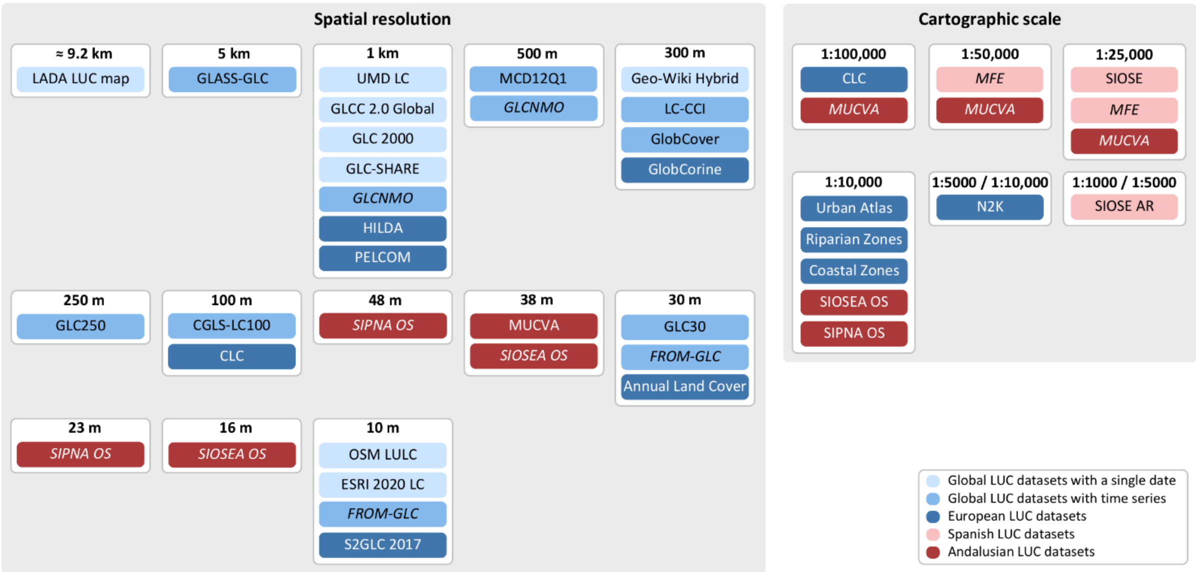

Figure 1. Spatial resolution and cartographic scale of the LUC datasets

As a result, the 26 datasets in raster format have a total of 30 different products/maps. This is due, as commented earlier, to the fact that 4 of the datasets have more than one resolution.

In general, there is an inverse relationship between spatial resolution and the area covered by the datasets: the greater the extent, the lower the spatial resolution and vice versa, despite the fact, as commented earlier, that most groups of extents contain LUC datasets with the highest resolution (10 m). Notwithstanding, as general rule, the smaller the area to be mapped, the easier it is to find more detailed data and the more feasible it is to invest resources to map land uses and cover in high detail. At global or continental scales, mapping at this level of detail requires a much higher commitment in terms of financial and personnel resources. The CORINE Land Cover project is a good example of this, in that it requires the coordinated efforts of 39 national production teams (European Environment Agency, 2007).

As regards the LUC datasets in vector format —11 of the 33 datasets—, the *cartographic scale* of European LUC datasets ranges from the 1:5,000 scale used in N2K to the 1:100,000 scale used in CLC. Most of the Copernicus datasets were produced at a scale of 1:10,000 (Table 2, Fig. 1). N2K has two display scales (1:5,000 – 1:10,000), depending on the landscape and feature class because larger objects are mapped at the coarser scale.

The scales used in the Spanish LUC datasets vary from 1:25,000 for SIOSE and 1:50,000 for one of the MFE products. In SIOSE AR, rather than defining a specific scale, a range of scales (between 1:1,000 and 1:5,000) is recommended depending on the data included in each product. This is because SIOSE AR is obtained by merging data from different sources with a high level of detail and is not, therefore, based on the photo-interpretation of aerial or satellite images at the same scale (Equipo Técnico Nacional SIOSE, 2020). As regards the Andalusian datasets, the cartographic scale ranges from 1:10,000 for SIOSEA OS and SIPNA OS, and 1:25,000, 1:50,000 and 1:100,000 for the different versions of MUCVA. The low level of detail of this last scale is due to the source from which the data were obtained and their best level of detail: historical flights such as the American Series B flight (Moreira Madueño, 2007).

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From these 11 datasets in vector format, a total of 16 products/maps are available at different scales, including the two display scales for N2K and for SIOSE AR.

The cartographic scale does not vary in line with the extent of the datasets, as occurs with the spatial resolution in raster-type datasets. Most European vector datasets have a scale of 1:10,000, similar to or even greater than the cartographic scale of the Spanish and Andalusian datasets. This is because most European datasets map specific areas of Europe, such as urban areas, riparian areas, coastlines or protected areas, with a high level of detail. For its part, CLC maps the entire territory of Europe in a generic way at a scale of 1:100,000.

In the European datasets, the MMU ranges from 0.25 ha in Urban Atlas to 25 ha in CLC, and the MMW from 10 m in most datasets to 100 m in CLC. The Spanish datasets show different MMU, from 0.5 ha to 6.25 ha, depending on the cartographic scale. SIOSE AR has no fixed MMU, but for technical reasons the minimum mapped object has an area of 1 m^2 (Equipo Técnico Nacional SIOSE, 2020). As regards the Andalusian datasets, the MMU ranges from SIOSEA OS with 0.005-0.02 ha to 1:25,000 MUCVA product with 0.25 ha. In some vector datasets, MMU and MMW values are not specified in their technical documentation and, therefore, they are omitted in Table 2. As in the case of the cartographic scale, there is no direct relationship between the MMU and MMW used in the different datasets analyzed and their spatial extent.

Traditionally, there has been a relationship between the spatial extent of the dataset and the detail of the data it provides: the greater the extent, the less the spatial detail. However, this tendency has been changing in recent years due to technical improvements, which enable more datasets with large extents to be produced with higher levels of detail. This dissociation between extent and detail could be a problem for users, and a source of doubt regarding, for example, the potential and usefulness of data with that degree of detail at global or other large extents or the computational ability of normal computers to process and manage such large quantities of information. As a potential solution, generalized versions of these datasets at lower levels of spatial detail can be produced that meet the needs of users working with large extents and coarse detail. On the other hand, computing barriers for global extends are diminishing, for example using platforms like the Google Earth Engine Platform.

For those users that require datasets at higher levels of spatial detail for specific areas of the Earth or who wish to compare different study areas across the Earth in a consistent way, these new approaches to LUC mapping may be useful. However, regardless of the higher levels of spatial detail, it is clear that global or large extent datasets will be not able to compete with regional or local datasets, with mapping production workflows adapted to the specificities of each study area. This approach increases the chances of mapping real ground land covers and uses with lower levels of error and uncertainty.

3.2. Temporal parameters

In Figure 2, the LUC datasets are shown on a timeline in order to offer readers a clearer picture of the dates or years for which information about them is available. There are four LUC datasets that cover a long timeframe with many time points, namely the Global GLASS-GLC, LC-CCI, MCD12Q1 and European Annual Land Cover datasets. They have one map per year from 1982 to 2015, 1992 to 2018, 2001 to 2020, and 2000 to 2019 respectively. The datasets with the oldest LUC information are the European HILDA and the Andalusian MUCVA; the first has one LUC map per decade from 1900 to 2010, while the second has ten LUC maps over the period 1956 to 2007.

The datasets with the most recent LUC information are the Global Esri 2020 LC, GLC30 and MCD12Q1 datasets, and the Andalusian SIPNA OS, all of which have LUC maps up to 2020. Apart

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from GLC30, they are all projects that began in recent years (Friedl & Sulla-Menashe, 2019; Junta de Andalucía, 2019). From the 2000s onwards, more and more LUC datasets have been produced, a trend which may be due to the improvements in geospatial technologies and the increasing demand for this type of information.

If we group the datasets together according to their timespans, we find various different global LUC datasets with a single date from 1992 to 2020 (Fig. 2 and 3). These datasets are not very useful for studying changes in the Earth's surface, in that they offer a single picture at a specific moment in time. Some of these datasets for only one date were obtained by classifying satellite images gathered over a period of two or more years. These include UMD LC, GLCC 2.0 Global and GLC 2000, gathered over two years, and Geo-Wiky Hybrid, over six years. Other datasets, such as GLC-SHARE or OSM LULC, were obtained by aggregating various different LUC datasets (Latham *et al*., 2014; Schultz *et al*., 2017), so that, although they have one single reference year, the coverage was mapped on a different date for each region of the Earth, corresponding to the particular dataset used to map that territory. This is an important source of uncertainty when it comes to using datasets of this kind in any form of temporal analysis. There can also be an issue when using them to characterize certain elements of the Earth's surface for a specific moment in time, as normally we do not know the exact time at which each LUC image of the Earth is taken.

11 of the 33 datasets have just one date. Many of the others have 2 or 3 dates, although the maximum number is 34 (GLASS-GLC) (Fig. 3). As a result, the 33 datasets offer a total of 187 different products/maps.

GLC250 and GlobCover are available for just two dates (2001, 2010, and 2005, 2009, respectively), which is sufficient for a temporal study, although they have not been updated recently. Of the three datasets with three dates (GLC30, GLCNMO and FROM-GLC), the most appropriate for a temporal analysis would seem to be the first, due to the regularity and distance between the dates: 2000, 2010 and 2020. The remaining datasets have higher temporal resolution, from five dates in the case of CGLS-LC100 (over a relatively short period from 2015 to 2019), to twenty dates for MCD12Q1 (from 2001 onwards), twenty-seven dates for LC-CCI (from 1992), and thirty-four for GLASS-GLC, which began in 1982. These latest datasets would be a good source for a complete temporal study of LUC over their respective periods, although none of them have been updated within the current decade.

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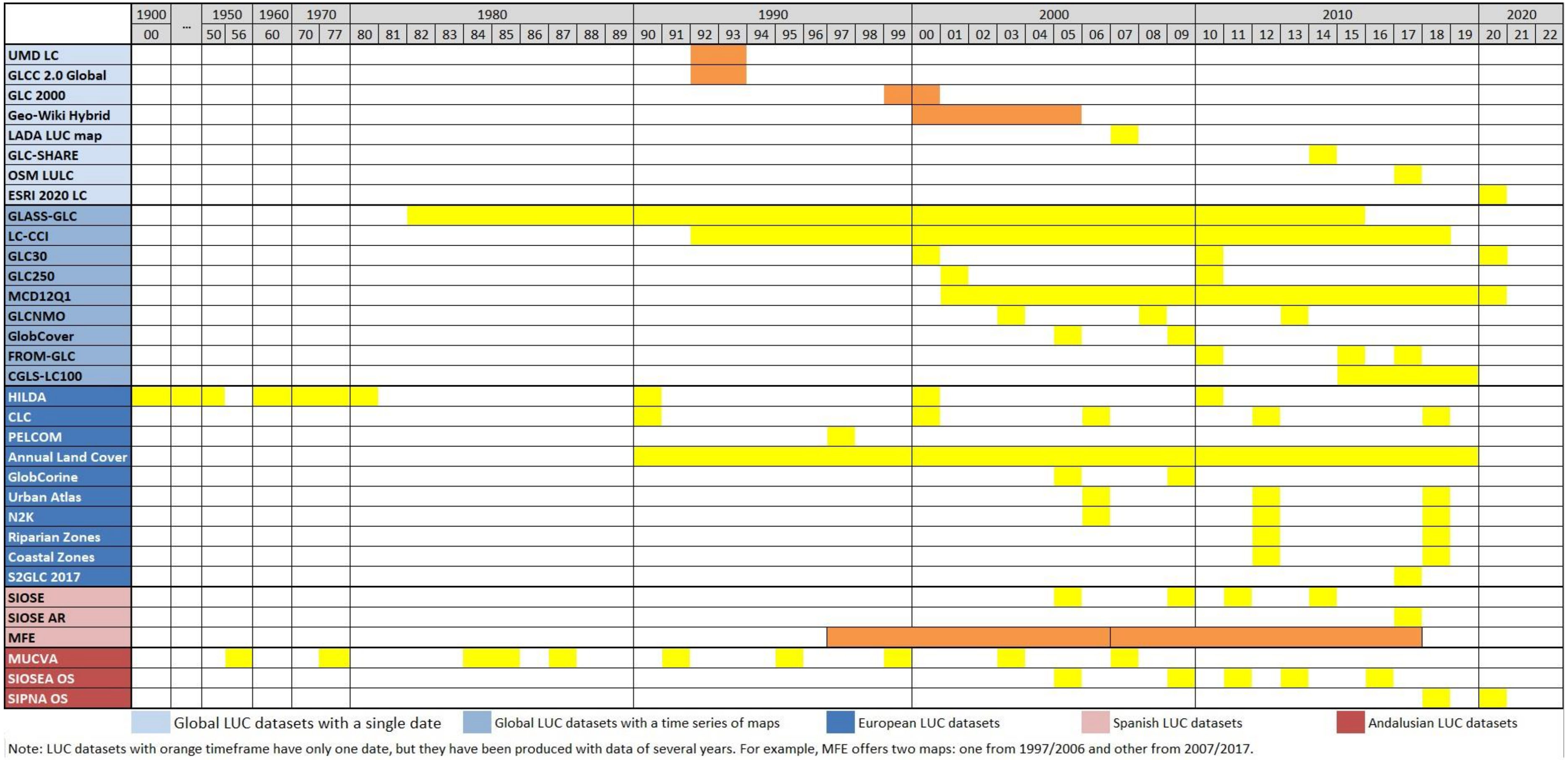

Figure 2. Timeline for the LUC datasets

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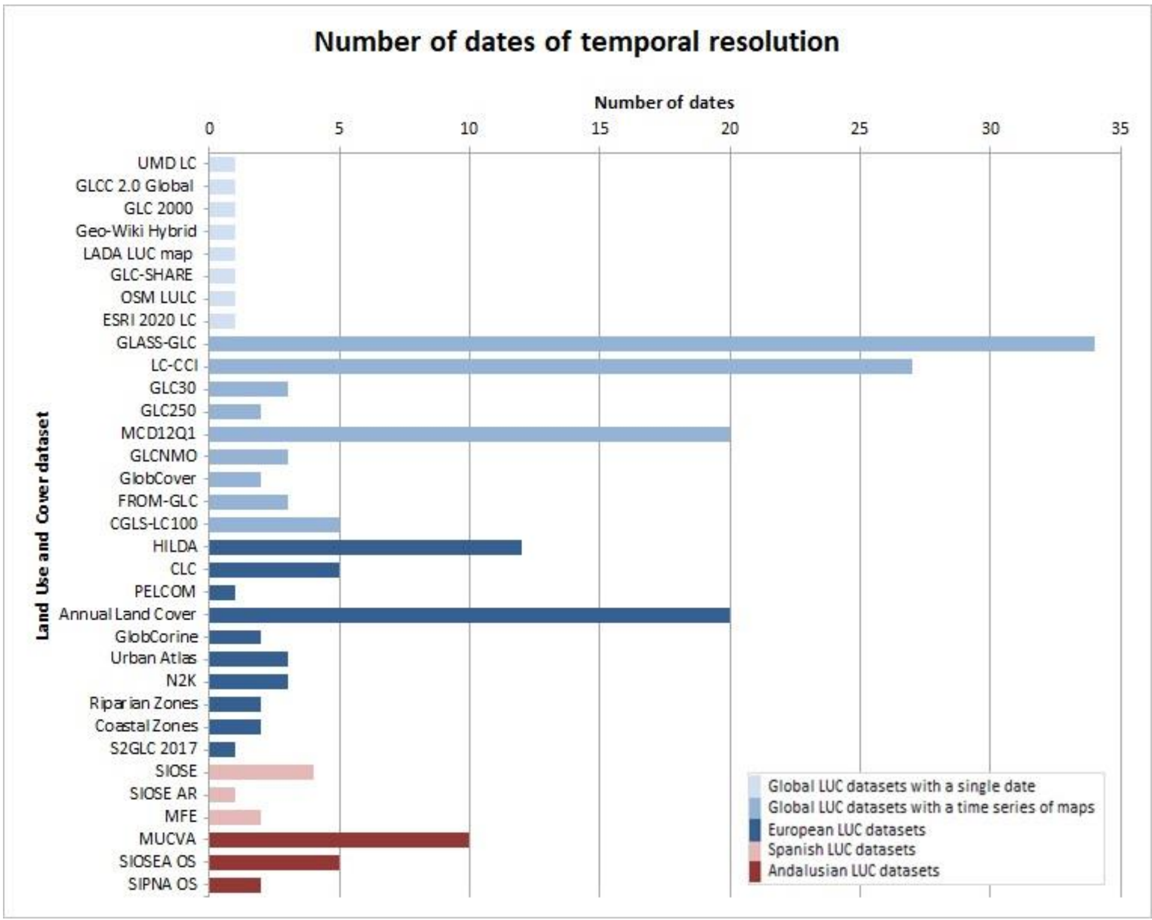

Figure 3. Temporal resolution of the LUC datasets - Number of dates

The European LUC dataset with the oldest information is the 1900 HILDA map. Several products issued between 1990 and 2019 are available, although more recent, updated products have not been issued since then. Of the two European datasets with a single date, PELCOM was compiled with information from 1997, with no updates since then, while the S2GLC 2017 is expected to be updated in the future. GlobCorine has two dates[5], the most recent in 2009. As regards the other Copernicus datasets (CLC, Urban Atlas, N2K, Riparian Zones and Coastal Zones), which have between two and five dates, regular future updates of the time series are planned. CLC, with five dates, is one of the most widely used LUC datasets for temporal analysis, due to the regular distribution of these dates over three decades. A special mention should go to HILDA, with 12 dates (one per decade) from 1900, and Annual Land Cover, with 20 dates (one per year) from 1990. HILDA is the dataset with the longest timespan and the oldest LUC information, although it has a low level of spatial and thematic detail. It is also important to bear in mind that this dataset was created from a combination of historical data and the modeling of past territories from a reference provided by a current LUC layer (Fuchs *et al*., 2015).

As regards the Spanish LUC datasets, the MFE products are available for two dates, but, as commented in Figure 2, they were produced with data gathered over several years (from 1997/2006 and 2007/2017). Due to changes in the production methodology between the dates, they are not

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comparable. The four SIOSE products are more recent, from 2005 to 2014. An updated version, SIOSE AR, is currently only available for eight Spanish regions (Asturias, Cantabria, Castilla-La Mancha, Extremadura, Galicia, Islas Canarias, La Rioja, and Murcia) and two autonomous cities (Ceuta and Melilla), but is expected to become the LUC map of reference for Spain as a whole. Although SIOSE AR is a "direct descendant" of SIOSE, the two datasets are not compatible, and it will therefore be impossible to compare the new data with the historical series.

As for the Andalusian LUC datasets, the MUCVA presents a long series of ten dates starting in the 1950s, although the most recent is 2007. SIOSEA OS has a temporal resolution of five dates, from 2005 to 2015. SIPNA OS, with two dates, 2018 and 2020, is the most recent, most updated Andalusian LUC dataset, and uses a production method similar to the new SIOSE AR. The same compatibility issues referred to in the national datasets also apply to those focused on Andalusia. Despite having systems for classifying categories that are compatible with each other, the datasets were obtained using different production methodologies and cannot therefore be used for comparison purposes when undertaking studies on land use and land cover change. A major problem associated with the production of highly detailed LUC datasets has been the creation of consistent historical data series, with which researchers can conduct reliable studies of land use and land cover change easily (Lambin & Geist, 2006; Brown *et al*., 2012; Gallardo & Martínez-Vega, 2016). MUCVA achieved this quite successfully in Andalusia until 2007, when it stopped being updated and was replaced by SIOSEA. Until then, it had been an exemplary dataset due to its enormous detail and the fact that it had been developed from photo-interpretation work. There were no other similar datasets with those characteristics (Moreira Madueño, 2007).

LUC datasets with longer time series have become more common in recent decades, with the availability of more sensors, methodological improvements in remote sensing techniques and open access to the historical archive of satellite imagery. Likewise, the development of cloud computing devices, such as Google Earth Engine, which can manage tons of information at any one time, has fostered the development of new, more consistent time series of LUC data.

LUC datasets obtained by photointerpretation are usually available for just a few dates, due to their high cost in terms of human and economic resources. However, they have been traditionally one of the most trustworthy methods for producing consistent time series of LUC data. Nowadays, the development of new, more complex remote sensing techniques has made it possible to create very rich time series of LUC data, which, however, still show important technical inconsistencies and variations when carrying out temporal analyses between dates.

The availability of a time series of LUC maps does not mean that this series is fully comparable or that they can be used as a basis for LUC change analyses without first treating the data in some way so as to make them comparable. Thus, most of the available time series of LUC maps, including those obtained using traditional photointerpretation techniques, involve important sources of uncertainty and technical changes that all users must bear in mind. In this sense, when assessing the practical utility of these datasets, it is important to understand their purpose and their production methodologies. On many occasions, the year-on-year comparison of the different layers of these datasets involves high levels of uncertainty, due to problems or changes of a methodological nature, which prevent undertaking, with a minimum level of reliability, studies of the changes in land use and cover (Sulla-Menashe *et al*., 2019). The production of consistent LUC datasets, with minimum sources of error and uncertainty, in which all the technical changes are explained transparently, is therefore one of the main challenges facing researchers in the field of LUC mapping.

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3.3. Thematic parameters

The third criterion of analysis is one of the most important parameters when deciding whether a LUC dataset is fit for our particular purpose or not. These parameters refer not only to the number of classes or categories, but also to their nature and how they are defined.

The thematic parameters show a very wide panoply of situations, with even greater contrasts than the spatial and temporal ones. As discussed in previous sections, the spatial and temporal parameters can contribute to the uncertainty of LUC datasets, although different pixel sizes or, more importantly, different dates do not necessarily imply different types of LUC maps. However, when it comes to thematic parameters, the specific number of classes, whether they focus more on land cover or land use, and whether they follow a compatible legend, can lead to an almost unlimited number of different characterizations, compounded by the fact that some datasets, such as for example GLCC 2.0 Global and MCD12Q1, offer different types of classified LUC products, as commented in section 2.1. Following the most recent and comprehensive classification of each dataset, the Figure 4 reveals how the same pixel can be classified through different categories and at different levels of detail depending on the dataset, and its corresponding spatial and thematic resolution.

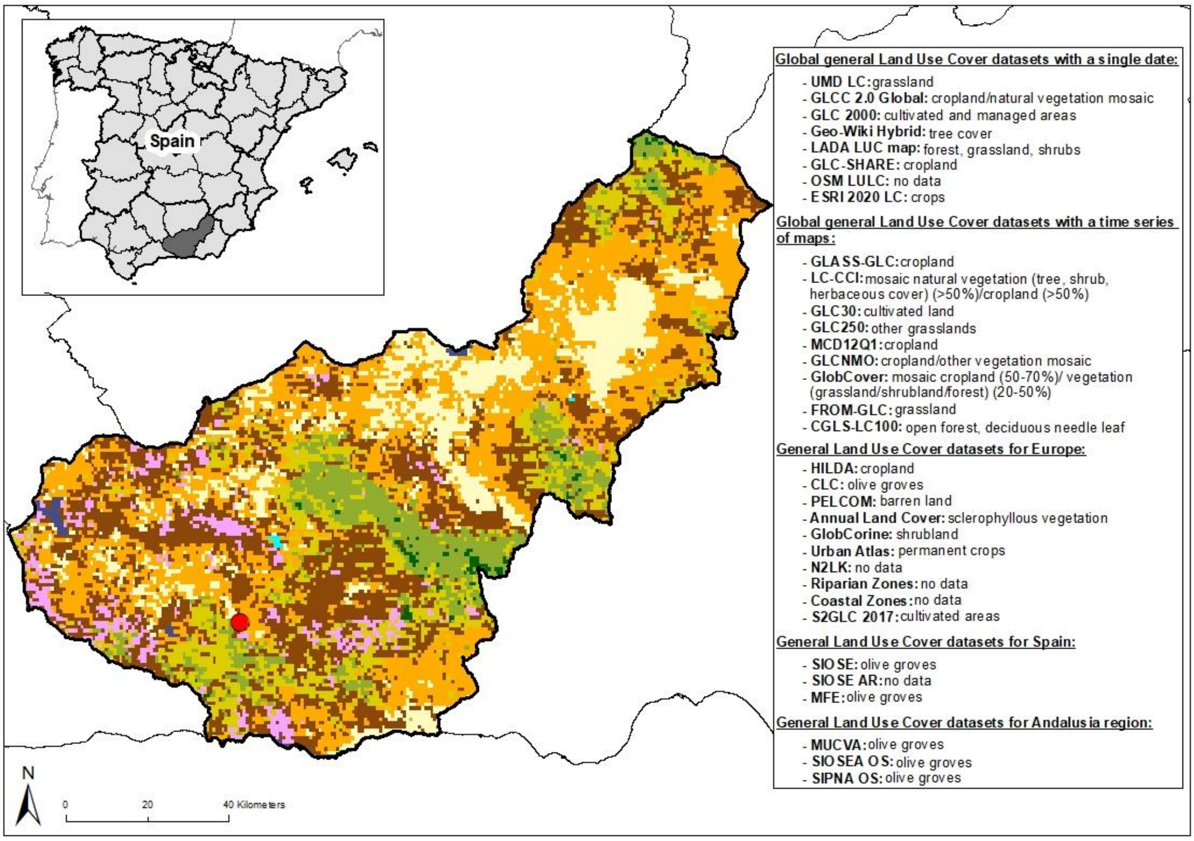

Figure 4. The map shows the classification of a random pixel (red point) through different LUC categories in all the analyzed datasets for Granada (Andalusia)

Regarding to the *nature of classes* (Table 3), most global datasets show Land Cover (LC) rather than Land Use (LU) categories, although the names of several of these datasets suggest that they are

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based on Land Use Cover (LUC) data. One exception is the LADA LUC dataset, which is not a standard LUC map. It defines itself as a Land Use Systems (LUS) map that was created specifically for the purposes of the LADA project, *i.e.*, to study land degradation (Nachtergaele and Petri, 2013). OSM LULC, which is compatible with the CLC level 2 legend, also includes some artificial categories that can be identified as LUC.

In the case of European datasets, some are focused on LC, but most of them mix both types of classes, without differentiating them. This is the case of CLC, Urban Atlas, N2K, Riparian Zones and Coastal Zones. The LU is represented above all in artificial categories (such as "Industrial or commercial units" or "Sport and leisure facilities"), but also in other types such as "Intensively managed fish ponds", which falls within the water bodies group.

Table 3. Nature of classes and compatible legends of the LUC datasets

Land Use Cover datasets	**Nature of classes: Land Use (LU), Land Cover (LC), Land Use Cover (LUC), Differentiated (LU/LC), Land Use Systems (LUS)**	**Compatible legends**
Global general Land Use Cover datasets with a single date		
UMD LC	LC	✓ International Geosphere-Biosphere Programme (IGBP)
GLCC 2.0 Global (IGBP)	LC	✓ IGBP
GLC 2000	LC	✓ FAO-Land Cover Classification System (FAO-LCCS) ✓ IGBP
Geo-Wiki Hybrid	LC	✓ FAO LCCS
LADA LUC map	LUC LUS	
GLC-SHARE	LC	✓ FAO LCCS
OSM LULC	LUC	✓ CLC level 2
ESRI 2020 LC	LC	
Global general Land Use Cover datasets with a time series of maps		
GLASS-GLC	LC	✓ FROM-GLC
LC-CCI	LC	✓ Plant Functional Type (PFT) ✓ FAO LCCS
GLC30	LC	✓ GLC30
GLC250	LC	✓ FROM-GLC ✓ FAO LCCS ✓ IGBP
MCD12Q1 (IGBP)	LC	✓ IGBP
GLCNMO	LC	✓ FAO LCCS
GlobCover	LC	✓ FAO LCCS
FROM-GLC	LC	
CGLS-LC100	LC	✓ FAO LCCS
General Land Use Cover datasets for Europe		
HILDA	LC	✓ Intergovernmental Panel on Climate Change (IPCC) ✓ FAO LCCS
CLC	LUC	
PELCOM	LC	
Annual Land Cover	LC	✓ LUCAS ✓ CLC
GlobCorine	LC	✓ CLC ✓ FAO LCCS
Urban Atlas	LUC	✓ CLC
N2K	LUC	✓ Urban Atlas ✓ Riparian Zones ✓ Coastal Zones
Riparian zones	LUC	✓ Urban Atlas ✓ N2K ✓ Coastal Zones
Coastal Zones	LUC	✓ Urban Atlas

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		✓ N2K ✓ Riparian Zones
S2GLC 2017	LC	✓ CLC
General Land Use Cover datasets for Spain		
SIOSE	LU/LC	
SIOSE AR	LU/LC	
MFE	LUC	
General Land Use Cover datasets for Andalusia region		
MUCVA	LUC	
SIOSEA OS	LUC	✓ MUCVA ✓ SIOSE AR
SIPNA OS	LUC	✓ SIOSE AR ✓ SIOSEA OS ✓ Hábitats de Interés Comunitario (HIC) ✓ Vegetation ✓ Biogeography ✓ Sistema de Información Geográfica de Parcelas Agrícolas (SIGPAC)

The only datasets that differentiate between the LU and LC (LU/LC) categories are the Spanish datasets SIOSE and SIOSE AR. Unlike the global and European datasets, SIOSE and SIOSE AR have a high level of detail, and use production methodologies that are not based exclusively on automatic or semi-automatic remote sensing techniques. In this way, they can clearly differentiate between land uses and land covers, so solving one of the great problems that has traditionally arisen in the production of LUC maps (Comber, 2008). Table 4 shows the LU categories used in SIOSE, which follow the Hierarchical INSPIRE Land Use Classification System (HILUCS) and can be applied to existing and planned land use. The LC categories follow the CODIIGE classification (Consejo Directivo de la Infraestructura de Información Geográfica de España).

Table 4. Land Use (LU) categories applied in SIOSE

Code	Land Use (HILUCS)	Code	Land Use (HILUCS)
110	1_1_Agriculture	410	4_1_TransportNetworks
120	1_2_Forestry	430	4_3_Utilities
130	1_3_MiningAndQuarrying	500	5_ResidentialUse
140	1_4_AquacultureAndFishing	610	6_1_TransitionalAreas
200	2_SecondaryProduction	620	6_2_AbandonedAreas
310	3_1_CommercialServices	631	6_3_1_LandAreasNotInOtherEconomicUse
330	3_3_CommunityServices	632	6_3_2_WaterAreasNotInOtherEconomicUse
340	3_4_CulturalEntertainmentAndRecreational Services	660	6_6_NotKnownUse

The Spanish MFE and the Andalusian MUCVA datasets focus on LUC categories, without differentiating between LU and LC. In the first versions of MUCVA, terms such as "forms of use" or "types of use" tried to establish a different way of identifying LUC categories. However, most of the categories focused on vegetation covers and uses. The term "*Ocupación del suelo*" (land occupation) mentioned in the titles of the SIOSEA OS and SIPNA OS datasets covers both LU and LC. In addition, SIPNA OS includes the LUC categories of SIOSEA OS and the information from the HIC (*Hábitats de Interés Comunitario* – Habitats of Interest for the Community) database, vegetation, biogeography and the SIGPAC (*Sistema de Información Geográfica de Parcelas Agrícolas* - Agricultural Parcels Geographic Information System).

If we turn to the *compatible legends* in each dataset (Table 4), most of the global datasets legends follow standard LUC classifications to ensure that they are compatible with other LUC datasets. One of the most common is the International Geosphere-Biosphere Programme (IGBP), which as mentioned earlier, is used in one of the GLCC 2.0 global and one of the MCD12Q1 products. In other cases, the legend is compatible with (although not exactly the same as) the IGBP legend, such as in UMD LC, GLC 2000 or GLC250. Maps based on the IGBP legend distinguish around 17 categories.

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The FAO-Land Cover Classification System (LCCS) (Di Gregorio and Jansen, 1998) is, perhaps, the most standard classification in use today, since its legend is hierarchical and comparable, making it easily adaptable to the different scales used around the world. The GLC2000, Geo-Wiki Hybrid, LC-CCI and GLC250 legends, among others, are compatible with this flexible classification.

Other classifications include the FROM-GLC legend, which is compatible with the legends used in GLASS-GLC and GLC250, because all three datasets were produced by the same group of researchers. Similarly, one of the products of MCD12Q1 takes the legend used in UMD LC as a reference, while the OSM LULC legend is based on that of CLC level 2.

For European datasets, the FAO LCCS, the Intergovernmental Panel on Climate Change (IPCC), the Land Use/Cover Area frame Survey (LUCAS) and the CLC are the most common legends. Other Copernicus Land Monitoring program products, such as Urban Atlas, N2K, Riparian Zones and Coastal Zones have legends that are mutually compatible, in that they all take the CLC legend as a reference. The Spanish SIOSE is also compatible with the CLC legend. In fact, the CLC information for Spain is currently updated via a geometric and thematic simplification of SIOSE (García-Álvarez & Camacho Olmedo, 2017). For its part, MFE follows its own classification system, which is not compatible with any other legend. Great efforts have been made to combine the Andalusian products as far as possible by using compatible legends. The SIOSEA OS legend is compatible with that used in MUCVA, and since 2016 it has been part of SIPNA OS, which has a similar production method to the new SIOSE AR.

As regards the *number of classes* (Fig. 5)[6], at first glance, there appears to be a relationship between the number of classes and the area covered by the datasets. Global datasets tend to be coarser (fewer classes), while continental, national and, above all, regional datasets offer increasingly detailed information (more classes). As a result of the number of classes, the 33 datasets offer a total of 40 different products/maps.

The thematic resolution of the global datasets ranges from 7 to 40 classes: 2 of the datasets (ESRI 2020 LC and GLASS-GLC) have a resolution of less than 10 classes, while 2 others (LC-CCI and LADA LUC map) have between 30 and 40. The rest have between 10 and 29 classes. There is no difference between global data with a single map or with a time series.

As regards the European datasets, the number of classes varies greatly. HILDA has just 6 classes, while S2GLC 2017 has 13 and PELCOM has 14. At the other end of the scale, Riparian zones dataset has 56 classes (Level 3) while Coastal Zones has 71 (Level 5). These wide differences are due to the different level of spatial detail in each dataset, as well as to their different production methodologies. HILDA is produced using very imprecise, limited historical data sources and modeling techniques (Fuchs *et al*., 2015). The Coastal Zones dataset, on the other hand, is made with high-detail remote sensing and photo-interpretation techniques and in very specific areas (European Environment Agency, 2021).

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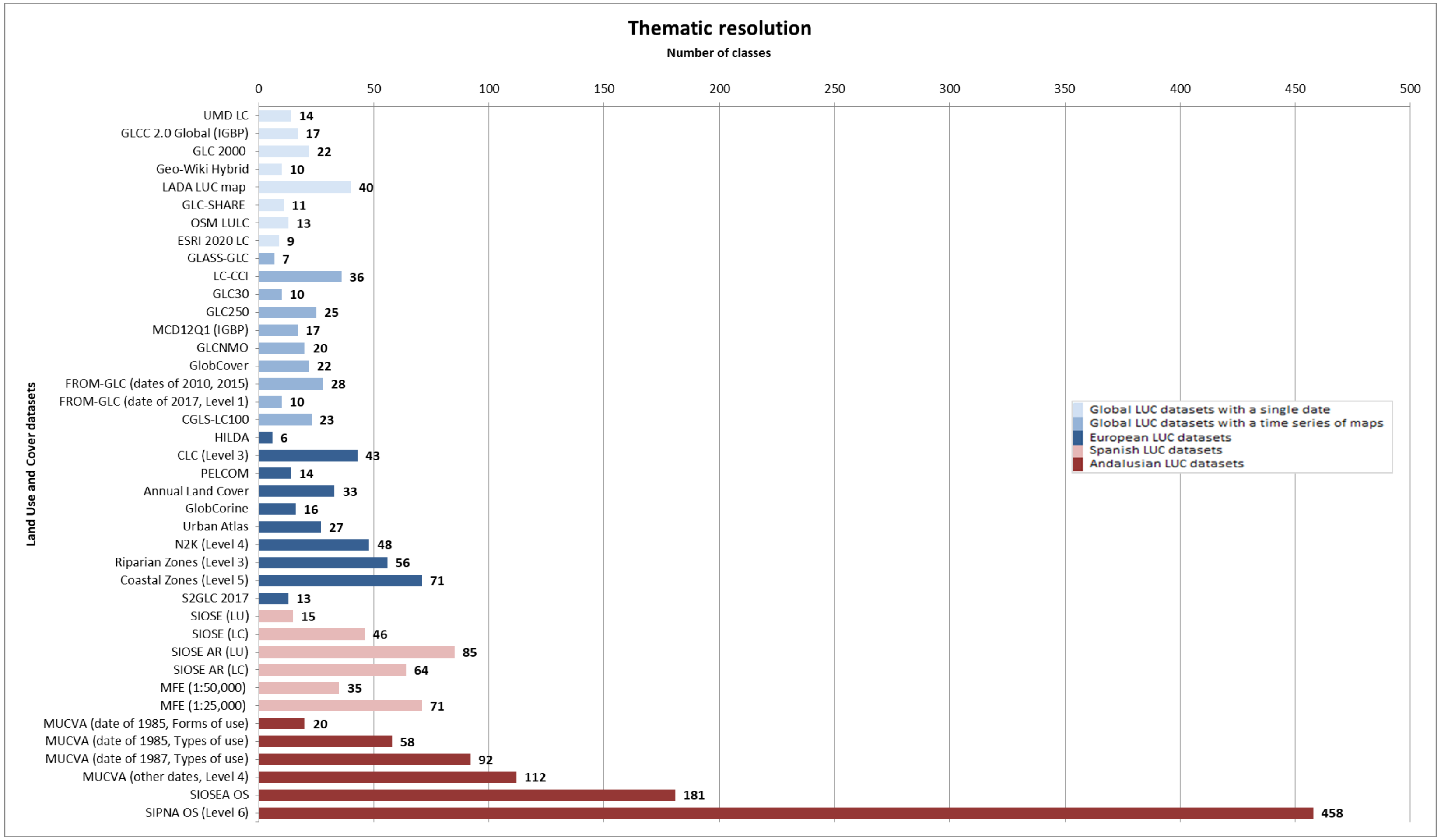

Figure 5. Number of classes in the LUC datasets

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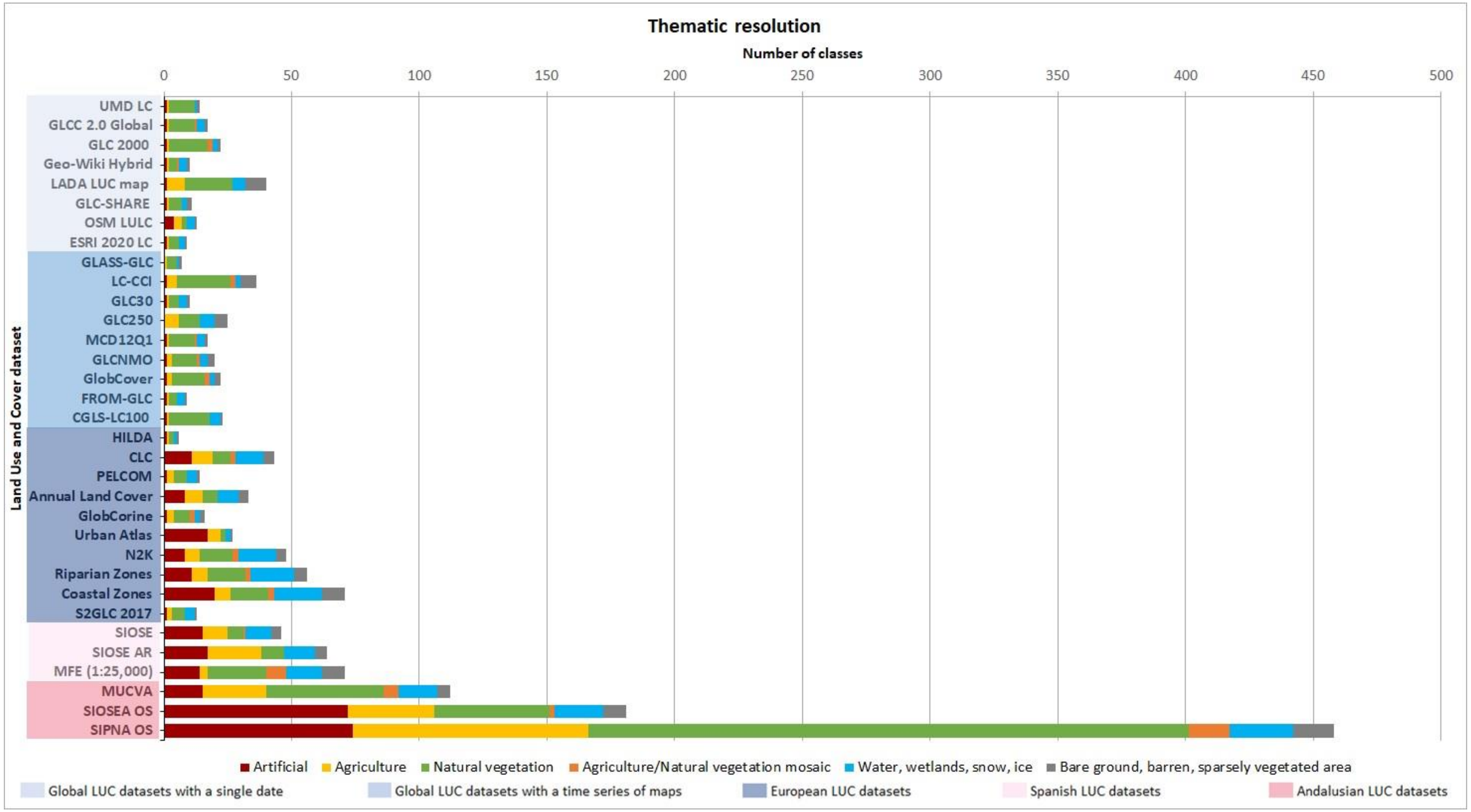

Figure 6. Number of classes, divided by groups, in the LUC datasets

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In the case of the Spanish datasets, SIOSE has a thematic resolution of 15 Land Use (LU) and 46 Land Cover (LC) classes, while the new SIOSE AR has 85 LU and 64 LC classes. As commented earlier, these are the only datasets that differentiate LU categories from LC. The most detailed version of the Spanish MFE has 71 classes. The number of classes increases considerably for the Andalusian datasets, in that the different spatial and temporal datasets of the MUCVA have 20, 58, 92 and 112 classes respectively, while SIOSEA OS has 181 classes and SIPNA OS has 458. The fact that the different editions of the MUCVA have different thematic resolution is due to the technical restrictions imposed by the fact that historical sources of information were used to obtain the first editions of this dataset (Moreira Madueño, 2007).

As regards the *groups of classes* (Fig. 6)[7], except for artificial (a) and agriculture/natural vegetation mosaic (m), all the groups are present in all the datasets we analyzed.

The thematic resolution by category groups is highly dependent on the methods used in the production of the LUC datasets. In addition, the spatial resolution, cartographic scale and extent of the LUC datasets are very closely related with the LUC legends. Datasets obtained by supervised/unsupervised classification of satellite images are incapable of detailing different artificial (a) or agriculture (ag) classes, which is only possible through photo-interpretation and with the help of auxiliary data. Similarly, global datasets are limited when several artificial (a) classes are differentiated, whereas regional datasets usually map these classes at higher levels of thematic detail.

In other cases, the nature and type of the LUC legend is dependent on the purpose of the datasets. One example is the Spanish MFE datasets. Although the legend of these datasets includes all the groups of categories, it is more focused on the types of natural vegetation (v). SIPNA OS also includes a detailed legend of natural vegetation and biogeographic classes. Other datasets are more focused on artificial (a) legends, such as Urban Atlas or SIOSEA OS. In the new SIOSE AR, the agriculture (ag) classes are very specific because detailed information about the different types of crops is obtained from the Agricultural Parcels Geographic Information System (*Sistema de Información Geográfica de Parcelas Agrícolas* - SIGPAC) and the Farmers' Declarations (*Declaración de Agricultores*).

This wide variety of legends in the LUC datasets increases the uncertainty when users have to decide which dataset is most appropriate for their purposes, as many datasets are not fully inter-comparable. There has recently been a move to standardize legends and make them more compatible. The LUC datasets of the European Copernicus program, which use the CLC legend as a reference, have compatible legends. In the Autonomous Community of Andalusia, great efforts are being made to integrate the different legends: the SIOSEA OS legend is compatible with the MUCVA legend, and since 2016 it has been integrated into SIPNA OS, which has a similar production method to the new Spanish SIOSE AR.

Even though this variety, the large amount of categorical information is also a valuable source of reference data (training areas), which properly managed and filtered, can serve to generate new and more reliable LUC maps series. Examples of the use of different datasets for classification purposes can be found (Vidal-Macua *et al*., 2017; Gonzalez-Guerrero *et al*., 2020; Padial Iglesias *et al*., 2021).

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3.4. Comparison of the spatial, temporal, and thematic parameters

Of all the parameters analyzed in sections 3.1., 3.2. and 3.3., a simple comparison on a 3D figure of the spatial resolution/cartographic scale, and the temporal and thematic resolution for the raster (Fig. 7) and vector (Fig. 8) LUC datasets confirmed the great diversity and large number of situations. It is important to remember that some datasets are produced and/or distributed in both raster and vector formats, which is why they appear in both Figure 7 and Figure 8. In addition, some of the datasets have various spatial resolutions or cartographic scales. As regards the thematic resolutions, we only include the most detailed legend for each dataset. This means that in addition to the group of LUC datasets shown, more hierarchical legends could be added, except in those cases in which the different temporal, spatial, temporal and spatial, or thematic versions have different legends.

As discussed in their respective sections, the 33 datasets analyzed offer a total of 30 different products/maps due to different spatial resolution, 16 due to different cartographic scales, 187 due to temporal resolution (datasets with several maps for different dates) and 40 due to thematic resolution. The combination of these three types of resolution gives rise to 53 types of products—represented in Figures 7 and 8—, and a total of 217 different products/maps—if we count the time series. Also, as discussed earlier, more hierarchical legends would result in more maps being added. As a result, users are faced with a myriad of products that make it difficult to decide which dataset best suits their purposes.

At first glance, the raster LUC datasets (Fig. 7) show some degree of regular distribution. However, if we look closer, behavior is very diverse in the total datasets and also in each group, especially in the European datasets. In addition, the specificity of some datasets due to their low spatial resolution (such as the LADA LUC map), or their high temporal (GLASS-GLC, LC-CCI, Annual Land Cover), or thematic (MUCVA) resolution tends to skew the 3D figure, hiding what is really quite a heterogeneous distribution. In any case, this 3D figure is useful for highlighting the panoply of situations and also for finding clusters of datasets that share the same spatial, temporal or thematic resolutions, even though they belong to different groups of extent, such as the Global ESRI 2020 LC and the European S2GLC 2017.

The 3D representation of the vector LUC datasets (Fig. 8) is more heterogeneous with respect to the total of datasets. By groups of extent, the European datasets are the most homogeneous group, except for the CLC (level 3) due to its smaller cartographic scale. The Spanish and Andalusian groups show great diversity in terms of both spatial and temporal resolution in the first case, and in terms of spatial and, above all, thematic resolution in the second. This great diversity is due in part to the very high number of classes in SIPNA OS (level 6), which distorts the 3D figure to some extent.

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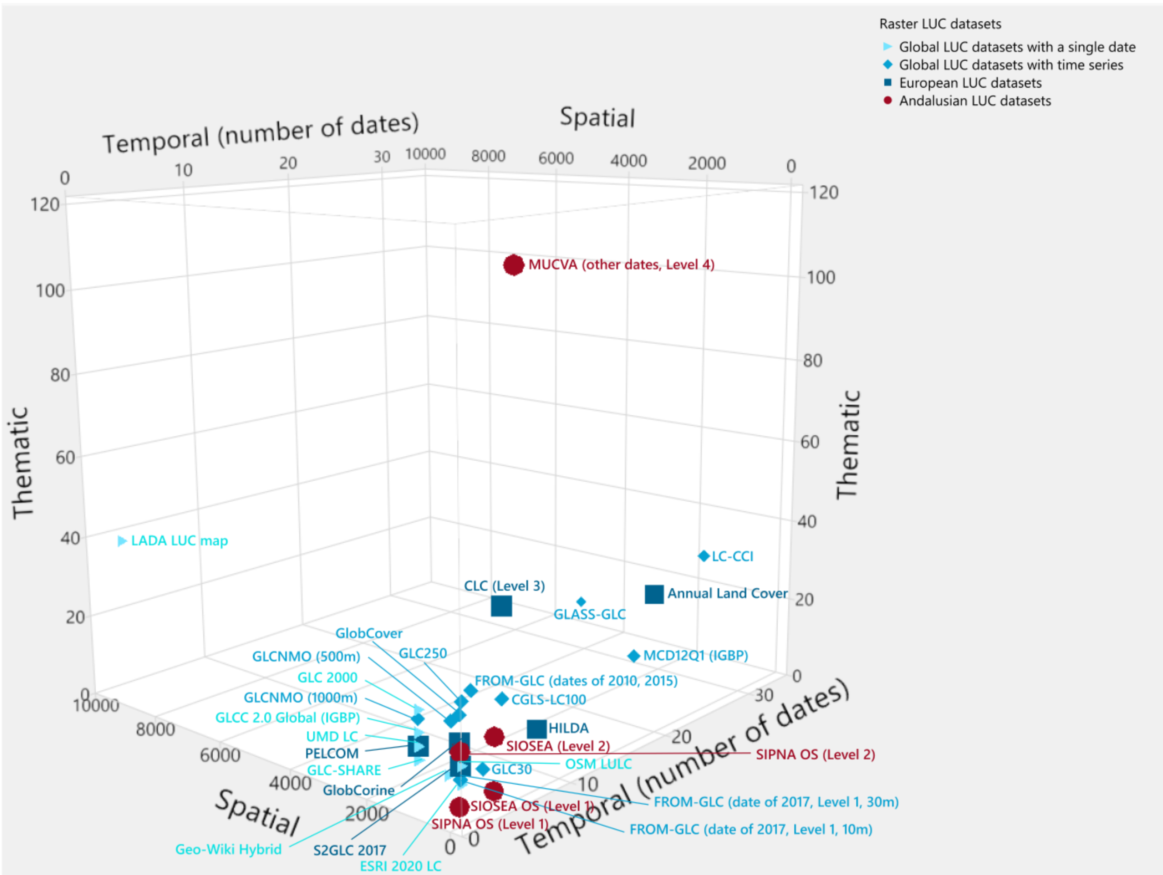

Figure 7. Spatial, temporal and thematic resolution in the raster LUC datasets

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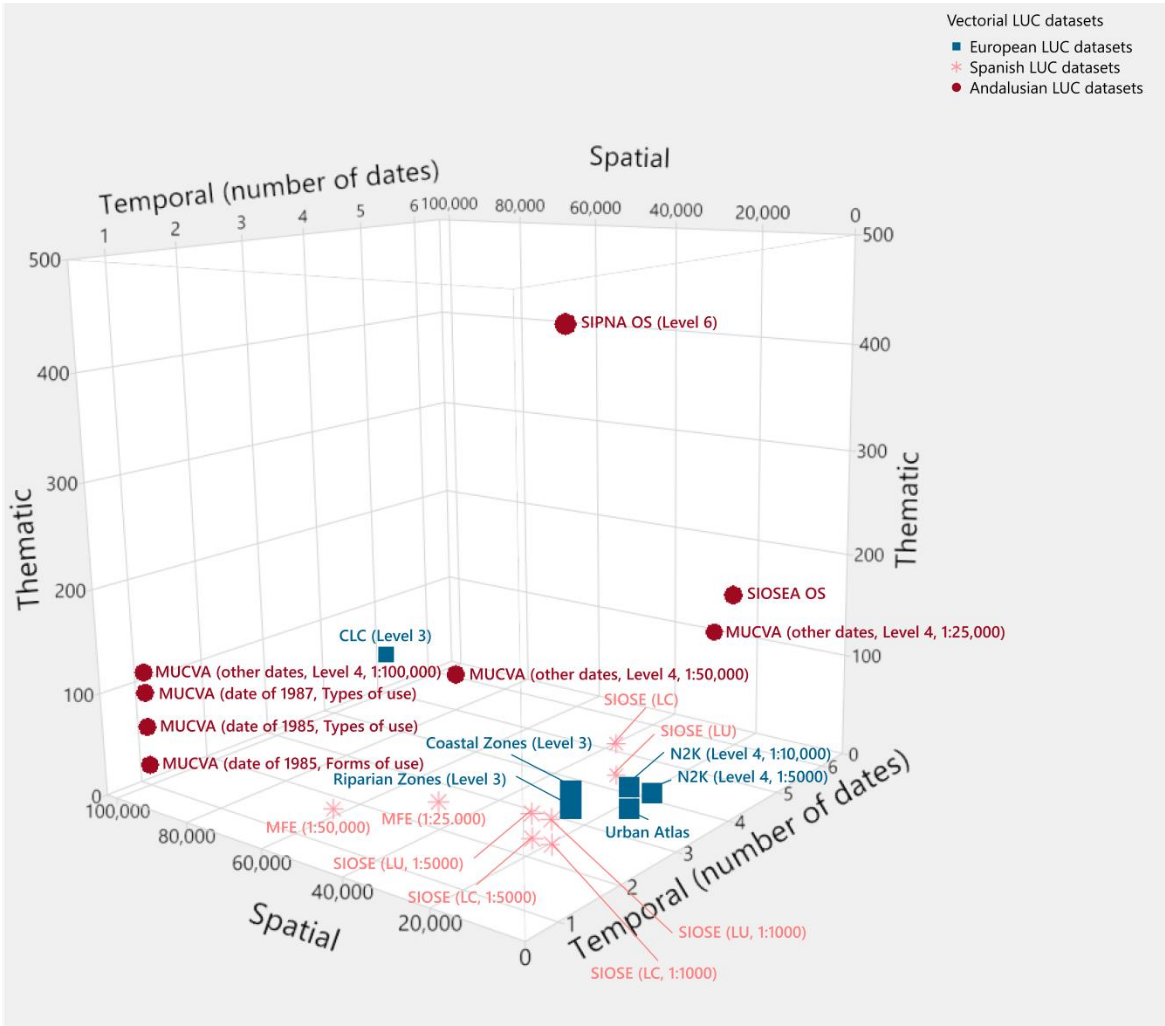

Figure 8. Spatial (cartographic scale), temporal and thematic resolution in the vector LUC datasets

4. Conclusion

The spatial, temporal and thematic parameters of 33 general LUC datasets at global, European, Spanish and regional scales (Andalusia) have been reviewed and characterized. The results show a considerable variety of datasets with highly diversified but complementary characteristics. This comparative analysis shows that from these 33 datasets, users can obtain at least 217 different layers, with different characteristics and at different scales, and with different spatial, temporal and thematic resolutions. This wide variety of maps makes finding the most suitable LUC dataset a real "obstacle course" for users, so creating additional significant sources of uncertainty for their studies and analyses.

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The different parameters analyzed here are closely related to each other. As a general rule, the larger the area covered by the dataset, the lower its level of spatial and thematic detail, and therefore the smaller its scale. Accordingly, the spatial and thematic resolutions are progressively higher the smaller the area covered by the different datasets. The cartographic scale, Minimum Mapping Unit (MMU), Minimum Mapping Width (MMW) all vary in the same direction in vector LUC datasets.

Most of the datasets collect information on similar time periods, which basically extend between the end of the 20th century and the beginning of the 21st. Only a limited number of datasets offer a time series and, those that do, do not usually guarantee comparison of the different dates with acceptable levels of uncertainty. In this way, despite the progress that has been made, and despite the existence of many datasets –some with numerous editions–, the study of LUCC from these sources still entails significant challenges and uncertainties for the user.

Finally, most of the datasets include quite a high variety of LUC categories. However, the thematic resolution of those at global scale tends to be much more limited and becomes increasingly complex as the area covered by the datasets becomes smaller. In this way, the highest level of detail is reached in the Spanish datasets and, above all, in those centering exclusively on the Autonomous Community of Andalusia.

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APPENDIX 2. Main website of the LUC datasets

Analyzed LUC datasets	Website
UMD LC	https://daac.ornl.gov/ISLSCP_II/guides/umd_landcover_xdeg.html
GLCC 2.0 Global	https://www.usgs.gov/centers/eros/science/usgs-eros-archive-land-cover-products-global-land-cover-characterization-glcc?qt-science_center_objects=0#qt-science_center_objects
GLC 2000	https://forobs.jrc.ec.europa.eu/products/glc2000/glc2000.php
Geo-Wiki Hybrid	https://www.geo-wiki.org/
LADA LUC map	http://www.fao.org/land-water/land/land-governance/land-resources-planning-toolbox/category/details/en/c/1036360/
GLC-SHARE	http://www.fao.org/land-water/land/land-governance/land-resources-planning-toolbox/category/details/en/c/1036355/
OSM LULC	https://data.osmlanduse.org
ESRI 2020 LC	https://www.arcgis.com/home/item.html?id=d6642f8a4f6d4685a24ae2dc0c73d4ac
GLASS-GLC	http://data.ess.tsinghua.edu.cn/
LC-CCI	https://www.esa-landcover-cci.org/
GLC30	http://www.globallandcover.com/
GLC250	http://data.ess.tsinghua.edu.cn/
MCD12Q1	https://lpdaac.usgs.gov/products/mcd12q1v006/
GLCNMO	https://globalmaps.github.io/glcnmo.html
GlobCover	http://due.esrin.esa.int/page_globcover.php
FROM-GLC	http://data.ess.tsinghua.edu.cn/
CGLS-LC100	https://land.copernicus.eu/global/products/lc
HILDA	https://www.wur.nl/en/Research-Results/Chair-groups/Environmental-Sciences/Laboratory-of-Geo-information-Science-and-Remote-Sensing/Models/Hilda.htm
CLC	https://land.copernicus.eu/pan-european/corine-land-cover
PELCOM	http://www.geo-informatie.nl/projects/pelcom/
Annual Land Cover	https://medium.com/swlh/europe-from-above-space-time-machine-learning-reveals-our-changing-environment-1b05cb7be520
GlobCorine	http://due.esrin.esa.int/page_project114.php
Urban Atlas	https://land.copernicus.eu/local/urban-atlas
N2K	http://land.copernicus.eu/local/natura
Riparian Zones	https://land.copernicus.eu/local/riparian-zones
Coastal Zones	https://land.copernicus.eu/local/coastal-zones
S2GLC 2017	http://s2glc.cbk.waw.pl/extension
SIOSE	https://www.siose.es/web/guest/inicio
SIOSE AR	https://www.siose.es/siose-alta-resolucion
MFE	https://www.miteco.gob.es/gl/biodiversidad/temas/inventarios-nacionales/mapa-forestal-espana/default.aspx
MUCVA	https://www.juntadeandalucia.es/medioambiente/portal/landing-page-%C3%ADndice/-/asset_publisher/zX2ouZa4r1Rf/content/distribuci-c3-b3n-de-los-usos-y-coberturas-vegetales-en-andaluc-c3-ada/20151
SIOSEA OS	https://www.juntadeandalucia.es/medioambiente/portal/landing-page-%C3%ADndice/-/asset_publisher/zX2ouZa4r1Rf/content/siose-andaluc-c3-ada-sistema-de-informaci-c3-b3n-de-ocupaci-c3-b3n-del-suelo-de-espa-c3-b1a-en-andaluc-c3-ada/20151
SIPNA OS	https://www.juntadeandalucia.es/medioambiente/portal/landing-page-%C3%ADndice/-/asset_publisher/zX2ouZa4r1Rf/content/sistema-de-informaci-c3-b3n-sobre-el-patrimonio-natural-de-andaluc-c3-ada-sipna-/20151

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[1] GLCC 2.0 Global databases include seven classified products: Global Ecosystems, International Geosphere-Biosphere Programme (IGBP), U.S. Geological Survey Land Use/Land Cover System – level 2 (USGS LULC – level 2), Simple Biosphere Model (SiB), Simple Biosphere 2 Model (SiB2), Biosphere Atmosphere Transfer Scheme (BATS) and Vegetation Lifeforms.

[2] MCD12Q1 include six classified products: International Geosphere-Biosphere Programme (IGBP), University of Maryland (UMD), Leaf Area Index (LAI), BIOME-Biogeochemical Cycles (BGC), Plant Functional Type (PFT) and FAO-Land Cover Classification System (FAO-LCCS).

[3] Curiously, "Gibraltar" is an excluded category in SIOSEA OS and SIPNA OS.

[4] Formats: .tif (Tagged Image File), .adf (ArcView ARC/INFO Coverage Data Format), .img (Disk Image File), .bil (ESRI BIL Format), .nc (NetCDF4), .hdf (Hierarchical Data Format), .gdb (Geodatabase), .gpkg (Geopackage), .shp (Shapefile).

[5] Unfortunately, only the 2005 version was available for download at the time of this research.

[6] When multiple levels of legends are available, as in the case of hierarchical legends, we only include the most detailed legend for each one (such as for example in CLC, N2K, Riparian Zones, Coastal Zones or SIPNA OS). However, in those cases in which the different temporal (as in FROM-GLC), spatial (MFE), temporal and spatial (MUCVA) or thematic (SIOSE, SIOSE AR) versions of the dataset have different legends, we show all of them.

[7] We only show the most detailed legend for each dataset.