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August 2021

BC3 WORKING PAPER SERIES

2021-01

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Land use and land cover databases for Mediterranean landscape analysis at the watershed scale

João Pompeu[a], Itxaso Ruiz[a], Antonio Ruano[a], Hugo Bendini[b], María José Sanz[a,c]

Land use and land cover (LULC) information is a key variable in ecosystem services modelling and, thus, for sustainable land management planning at the landscape scale. There is a proliferation of LULC products already available for final users, with a variety of spatial resolution, temporal coverage, level of detail in classification and format. In this context, this working paper aims to compare how different LULC products available for El Mijares watershed, in Eastern Spain depict the landscape, where an assessment of the ecosystem services is foreseen as part of a participatory process for land planning and management. Seven LULC products were evaluated: CORINE (raster), S2GLC (raster), LUCAS (sample points), a LUCAS-based Landsat resolution map (raster), SIOSE (predominant land use from polygons), SIGPAC (polygons) and a CORINE-based Landsat resolution map (raster). Results show that forest and shrublands are the main land cover in the watershed followed by agricultural land uses, but their proportions differ amongst the LULC products with a 45.5 % (+4.8 %) overall spatial consistency of the raster maps. We argue that the integration of statistical products and LULC raster maps enhance the understanding of the land use dynamics in the watershed, and conclude that no single product can inform all of the LULC aspects of the landscape. Lastly, and for the particular case of El Mijares, we consider that extending the Landsat/CORINE to the entire Landsat series results in more suitable raster maps for the long-term analysis of the watershed.

Keywords: CORINE, Sentinel, LUCAS, Landsat, remote sensing, ecosystem services

Cite as: Pompeu J., I. Ruiz, A. Ruano, H. Bendini and M.J. Sanz (2021) Land use and land cover databases for Mediterranean landscape analysis at the watershed scale. *BC3 Working Paper Series 2021-01.* Basque Centre for Climate Change (BC3). Leioa, Spain.

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1. Introduction

Reliable land use and land cover (LULC) data is needed to better understand ecosystem dynamics, provision of its services and management of environmental trade-offs with human activities. LULC maps are a basic source of information for studying the impact that economic activities, natural processes and climate change have on land cover and on the Earth system. These maps are important for policymaking, sustainable development and resource management decisions, such as in the field of agriculture, forestry, water management, urban planning, environmental protection, and practices fostering human well-being without compromising the natural resources. However, land use and land cover are commonly not clearly distinguished in most land classification schemes (FISCHER et al., 2005). Land cover is determined by direct observation, while land use requires socio-economic interpretation of the activities that take place on the surface of the Earth.

Most projects that involve modelling of climate, land dynamics and ecosystem services nowadays rely on LULC maps (Jacobs et al., 2015). Amongst the several tools for ecosystem services modelling (such as ARIES - ARtificial Intelligence for Environment & Sustainability, InVest - Integrated Valuation of Ecosystem Services and Tradeoffs, and SWAT – Soil and Water Assessment Tool), land use is a key input parameter (Vigerstol et al., 2011). Until a few years ago, mapping large extensions of land was very time and labour consuming. The increased availability of remotely sensed images from satellites and airborne sensors at planes or unmanned aerial vehicles (UAV), along with the higher capacity of both local and on-cloud data processing, has increased the availability of LULC products at various scales. These products are ready to end users without the need to collect field data and to process large amounts of remote sensing images. However, they vary in extent, spatial resolution, temporal coverage, number of LULC classes and type of spatial data (raster or vector). Hence, given the characteristics of the information, each product is more prone to certain applications than others. According to García-Alvares et al. (2019), who tested two Spanish LULC products for land use modelling, the choice of the product strongly affects the modelling results.

The quality of the input information is critical for science-based policymaking towards sustainable land management, especially in highly diverse landscapes with long human occupation and a variety of environments, such as the Mediterranean landscapes. The western Mediterranean basin constitutes an especially outstanding environment for the implementation of adaptation actions at watershed scale aimed at combating the accumulated effects of historical land use and climate change. In particular, at the headwaters of el Mijares watershed, these changes may have led to modifications in the local precipitation, affecting the regime of summer storms (Millán et al., 2005), whereas at the river mouth they have resulted in the intensification of anthropogenic activities. The progressive decrease of orographic summer precipitation in form of local storms, which are the main source of water in summer, along with an increase in water demand and longer periods of droughts followed by extraordinary events of heavy rains, is predicted to trigger a feedback cycle towards drought and desertification. In this line, several projects[1] are ongoing in the Mijares watershed to assess ecosystem services and co-produce with the regional authorities and the local stakeholders the best combination of sustainable land practices, in particular forest and natural ecosystems restoration, that can increase

[1] RESH2O and MASBIO projects study how sustainable land management practices and in particular, the restoration of forest ecosystems, can increase resilience to climate change and other ecosystem services in the Mediterranean basins, using el Mijares as a pilot example to be replicated elsewhere. RESH2O (Restauración de servicios ambientales y ciclo del agua en un contexto de adaptación al cambio climático en Cuencas Mediterráneas) aims to identify the key elements for the articulation of comprehensive plans restoration programs that increase resilience to climate change while promoting a long-term recovery of the water cycle. MASBIO (Prácticas de MAnejo Sostenible de la tierra para la preservación de la BIOdiversidad y otros servicios eco-sistémicos en la cuenca del Mijares) seeks to implement adaptation practices that generate synergies to the hydrosphere, the atmosphere, and the biosphere while promoting sustainable rural development.

the resilience of the territory to climate change while promoting other ecosystem services such as water cycle recovery, protecting biodiversity and sequestering carbon.

In this context, this working paper aims to compare different sources of land use and land cover data for landscape analysis in El Mijares watershed. The evaluation presented here will contribute to the choice and/or integration among LULC databases, depending on the suitability of each information to the desired outcomes of different research objectives. In practice, this evaluation will subside not only the ongoing projects, but can also provide useful information for future projects relying on LULC data at the continental Spanish territory and/or the Mediterranean basin.

2. Study area

El Mijares is a watershed 4045 km² large, with elevation ranging from 0 to 2008 m.a.s.l. (Figure 1). It is located on the Eastern Spanish coast, in Valencia, and it offers an ideal environment for studying the challenges posed by the management of Mediterranean land and water resources. This is due to several reasons, the first of which is its landscape heterogeneity.

Broadly, landscapes of el Mijares watershed range from coniferous and broadleaf forests together with sclerophyllous vegetation zones in the upper and middle course of the watershed, to intensive fruit tree plantations along with urban areas and industry at the river mouth. Their use has changed over millennia, with an increased transformation during the second half of the 20th century. Industrial growth, urban and peri-urban spread, and cropland intensification have dominated the trend at the lower course of the river, while rural abandonment and agro-pastoralism loss have taken place in the highlands (Generalitat Valenciana, 2018). Because changes in the land are considered among the major direct drivers of environmental change worldwide, and on account of climate models pointing at a trend towards a warmer and drier environment for the basin (MedECC, 2020), it is of key importance to accurately map the different land uses and land covers of El Mijares.

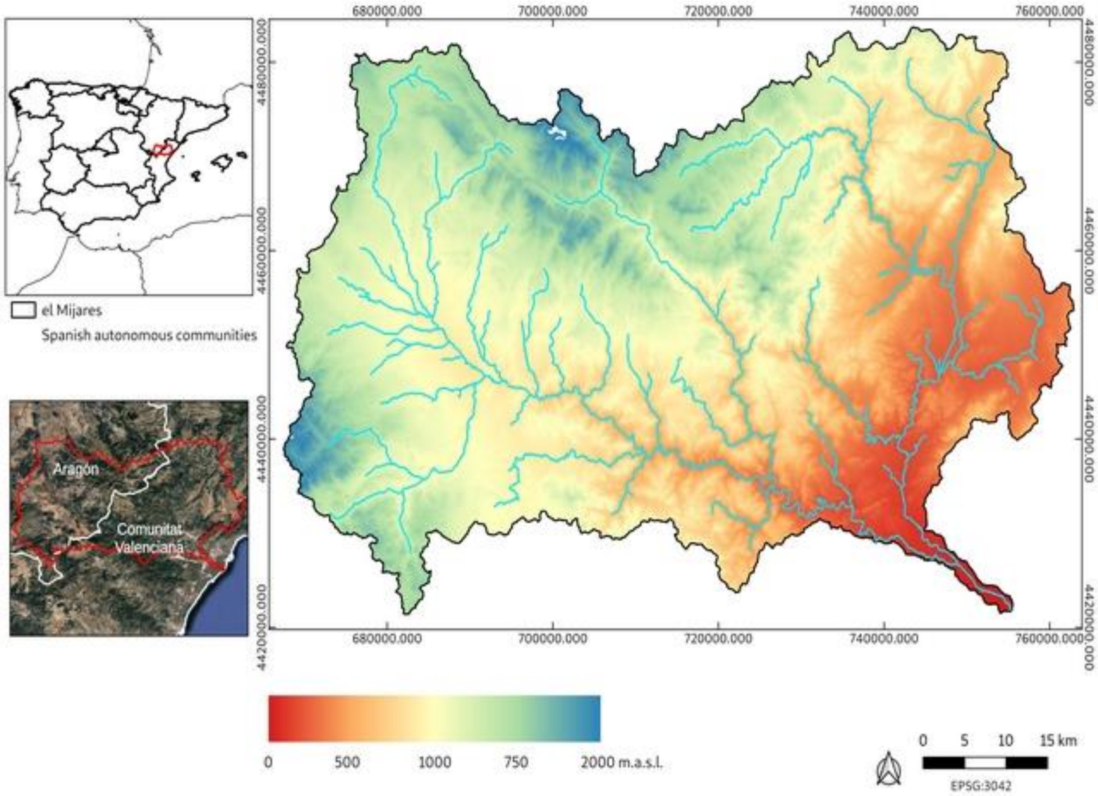

Figure 1: Elevation map of El Mijares watershed derived from 30 m SRTM

In addition to its land use change history, the watershed includes multiple water needs that entangle the disposition of its resources, ranging from agriculture (72 % of the total water use), to urban consumption (16 %) and industry (4 %) (Confederación Hidrográfica del Júcar, 2019). There is, moreover, a fragile balance between available water resources (335.7 hm^3/year) and water demands (268.23 hm^3/year), which is often compromised by sporadic torrential floods and periodic droughts, overall challenging the planning and management of its hydrological budget

3. Land use and land cover products

A series of LULC products are publicly available at various scales, from the whole globe to small portions of the landscape (e.g. watersheds and municipalities), including subnational regions, countries and continents.

Pérez-Hoyos et al. (2017) compared nine global land cover datasets for monitoring croplands worldwide: FAO-GLCshare (FAO Global Land Cover Network), Geowiki IIASA-Hybrid (Hybrid global land cover map from the International Institute of Applied System Analysis), GLC2000 (Global Land Cover, 2000), GLCNMO2008 (Global Land Cover by National Mapping Organizations), GlobCover, Globeland30, LC-CCI (Land Cover Climate Change Initiative) 2010 and 2015, and MODISLC (MODIS Land Cover product). The authors report a huge variety in spatial resolution (from 30 m to 1 km), periods of data acquisition, sensors, classification methods and number of classes (10 to 22 LULC types). The overall accuracy of the products analysed ranged from 68.5 % to 87.9 %. Their results revealed a substantial variation among the maps, highlighting that the main discrepancies are related to the intrinsic factors of both the dataset and complexity of the landscapes worldwide. In this sense, Hua et al. (2018) tested for spatial consistency five out of the nine global land cover datasets from Pérez-Hoyos et al. (2017). The authors concluded that the consistency of these five datasets is relatively low, despite the slightly higher overall consistency for Europe, when compared to other continents. Given the properties of these global land cover maps, with low suitability for very local scale analysis, as reported by previous research, they were not considered in the context of El Mijares.

At the continental scale, there are four main available LULC products especially developed for land classification in Europe: (1) CORINE, (2) S2GLC, (3) LUCAS, and a third European map based on (4) LUCAS samples and Landsat imagery.

1. CORINE, the European reference map, is obtained by generalizing more detailed national maps or by photointepretation at the scale 1:100.000 (Büttner, 2014). Each mapped feature in CORINE is at least 25 ha large, with a spatial resolution of 100 m, for the years 1990, 2000, 2006, 2012 and 2018. The legend is a 3-level hierarchical classification, composed of 44 homogeneous classes, i.e. >75 % of the pattern has the characteristics of a given class from the nomenclature. A set of generalisation rules were defined to deal with small non-homogeneous areas (<25 ha), such as the class 242, named “complex cultivation pattern”. The level 1 reports five broad land cover classes (Artificial surfaces, Agricultural areas, Forests and semi-natural areas, Wetlands and Water bodies). From the third level, it is possible to extract some specific information on land use, e.g. mining, vineyards, olives, agroforestry etc.

2. Despite the broad spatial and temporal extent of CORINE, the European Space Agency (ESA) funded the Sentinel-2 Global Land Cover (S2GLC) project, which aimed to develop a methodology for operational automated global land cover classification (Malinowski et al., 2020), in order to provide rapid yearly maps with high spatial resolution. This methodology consists of using the Random Forest classifier to Sentinel-2 images, with 10 m of spatial

resolution, based on CORINE and other high-resolution layers for sampling collection. At the present, there is only one product available, for the European continent with images acquired during 2017 and representing 13 land cover classes. The S2GLC platform does not inform whether new maps will be available in the near future.

3. In the year 2000, the European Parliament implemented the Land Use/Cover Area frame Survey (LUCAS) to provide statistical information on LULC, as well as soils and agro-environmental variables (D'Andrimont et al., 2020). Data is collected over a regular grid of points, located 2 km far from each other. The points are first assessed by photointerpretation and then a random set of points is visited in the field. In the period of 2006 to 2018, a total of 651,780 unique points was surveyed every three years, totalling 1,351,293 observations. This database is useful for extracting statistical information on a certain region and it was harmonized for the first time in 2020 by D'Andrimont et al. (2020).
4. The last pan-European dataset considered here was developed by Pflugmacher et al. (2019) and consists of a LULC map for the year 2015. The authors used the LUCAS as samples of LULC classes across the whole continent as input for the Random Forest algorithm. Spectral and temporal Landsat-8 indices were used for mapping 12 classes. Despite the authors consider two types of agriculture as land uses (seasonal and perennial croplands), the classes describe general land cover types, as S2GLC does.

Three other products have been here considered for the LULC characterization of El Mijares watershed: (5) SIOSE, (6) SIGPAC, and (7) own build-up Landsat-based LULC map

5. Since 2012, the Spanish CORINE is based on the generalization of the more detailed Spanish mapping system called SIOSE (García-Alvárez et al., 2017). SIOSE is a particular land use database produced by photointepretation aimed at objects and, unlike CORINE, not homogeneous classes. Each polygon drawn in SIOSE represents an area of at least 15 m in length and its minimum mapping unit range from 0.5 to 2 ha. The polygons are labelled with the percentage of a certain number of land uses and land cover types inside it, e.g. a single polygon can represent 30 % of forests, 20 % of vineyards, 15 % of olives, 15 % of build-up area, 10 % of water bodies and 10 % of roads and infrastructure. This way, it is possible to infer some land uses from the composition of the polygons, although translating these composite polygons of SIOSE into discrete LULC maps is not a simple task (Hernándes, 2016), and most studies with SIOSE adopt the predominant land cover of each feature. A new high-resolution SIOSE map for 2017 is under production.
6. Another Spanish vector database useful for land use investigation is the SIGPAC (Geographic Information System for Agricultural Plots), which consists in the interpretation of very high-resolution imagery and fieldwork to define agricultural plots in the whole country. In this database, each agricultural parcel is identified and labelled according to 30 categories defined by the Spanish government. It is a very detailed source of agricultural land uses, however, given the objectives of this database, for example, coniferous broad-leaved forests or non-forested areas (Shrublands and open woodlands) are not distinguished and are classified in the same category (Forest), except if it is used as pastureland when then it is classified in three classes depending in its type of cover. Anyway, if a forest parcel is reported inside the farm, the classification will infer forestry land use, regardless of the forest type.
7. Finally, a Landsat-based LULC map was developed for El Mijares in this paper. LULC training samples were collected from no-change areas of all the CORINE maps (since 1990). All the samples were individually evaluated for trends in their vegetation indices (NDVI and EVI)

Sentinel/Landsat time-series, using the QGIS plugin GEE Time Series Explorer (Rufin et al., 2021), to ensure they were representative of no-change areas in the landscape. This step aimed to provide a unique sampling dataset for the entire time frame of the Landsat imagery, starting in 1984, with 13 LULC types. This task was proceeded to allow the production of annual LULC maps of El Mijares with 30 m of spatial resolution. Then, spectral-temporal metrics (mean and standard deviation) were derived from the six reflective bands of cloud-free Landsat 8 images for both winter and summer seasons of 2018, and classified with the Random Forest algorithm (Breiman, 2001) with 500 trees. Despite under development and evaluation, this approach will be useful for tracking long term (~40 years) landscape changes in El Mijares.

A summary of the seven main LULC databases useful for landscape analysis in El Mijares is shown in Table 1. Their respective analysis and discussion on the suitability of each map is presented in the next section.

Table 1: Summary of the main characteristics of the products considered in this analysis

Source	Extent	Spatial resolution	Minimum Mapping Unit	Periods of data acquisition	# of classes	Classification scheme	Method
(1) CORINE	Europe	100m	25ha	1990, 2000, 2006, 2012, 2018	3 levels with 5, 15 and 44 classes	Homogeneous nomenclature for dominant patterns (>75% of the area)	Generalization of national maps or photointerpretation.
(2) S2GLC	Europe	10m	10 x10m	2017	13	Pixel-based homogeneous classes	Random Forest classification of Sentinel-2 images based on CORINE and other high resolution layers.
(3) LUCAS	Europe	-	-	2006, 2009, 2012, 2018	77 at the third level	Sampling grid with 2x2km over the continent.	Photointerpretation of all points and fieldwork at random points.
(4) Landsat/LUCAS	Europe	30m	30x30m	2015	12	Pixel-based homogeneous classes	Random Forest classification of Landsat-8 images of 2015, based on LUCAS samples.
(5) SIOSE	Spain	15 m	0.5-2ha	2005, 2009, 2011, 2014	85	Proportion of various LULC types inside a single polygon	Single or composed polygons based on photointerpretation
(6) SIGPAC	Spain	0.5 m	100 m² or less	2008 onwards (2020 used here)	30	Classification of individual agricultural parcels	Photointerpretation

(7) Landsat/CORINE	El Mijares	30 m	30x30m	2018 (possibly extended to all Landsat series)	12	Pixel-based homogeneous classes	Random Forest classification of all available Landsat images with samples collected at no-change areas from CORINE.

3.1 Comparison of the raster products

The four land cover raster maps (CORINE, S2GLC, Landsat/LUCAS and Landsat/CORINE) were compared for spatial consistency of their land cover classes. The maps were resampled to the best resolution (10 m) using the nearest neighbour method, in order to preserve the information of all layers. Then, the maps were harmonized to a common 9 classes legend (Table 2), based mainly on S2GLC due to its more limited land cover distinction. A pixel-wise comparison was processed with the "raster" package in R environment and both the local and overall agreement of the maps are reported in the next section. Where pixels of all the maps agreed, they were classified into a "high agreement" class, where three maps had the same LULC, it was considered as "good agreement"; where only two maps corresponded, it was assigned a "low agreement" class.

Table 2: Common land cover classes for comparison of the products

Common legend	CORINE	S2GLC	Landsat/LUCAS	Landsat/CORINE
Artificial surface	Artificial surface (level 1)	Artificial surfaces and construction	Artificial land	Artificial surface
Agriculture	Agricultural areas (level 1)	Cultivated areas; Vineyards	Cropland, seasonal; Cropland, perennial	Non-irrigated arable land; Irrigated arable land; Fruit trees and berry plantations; Olive groves
Broad-leaved forest	Broad-leaved forest	Broadleaf tree cover	Forest, broadleaved	Broad-leaved forest
Coniferous forest	Coniferous forest	Coniferous tree cover	Forest, coniferous	Coniferous forest
Mixed forest	Mixed forest	-	Forest, mixed	Mixed forest
Grassland	Natural grasslands (Level 3)	Herbaceous vegetation; Moors and heathland	Grassland	Grassland
Shrubland	Sclerophyllous vegetation (level 3); Transitional woodland-shrub (level 3)	Sclerophyllous vegetation	Shrubland	Sclerophyllous vegetation; Transitional woodland-shrub
Natural non-vegetated	Open spaces with little or no vegetation (level 2)	Natural material surfaces	Barren	Beach, dune and sand
Water	Water bodies	Water bodies	Water	Water bodies

4. Results

This section is divided in two subsections to show 1) how each specific product represent El Mijares landscape according to their LULC schemes; 2) the comparison of the products in terms of land cover and landscape analysis for the watershed.

4.1 Land use and land cover from different products in El Mijares watershed

4.1.1 LULC changes from CORINE

Amongst all the available LULC products evaluated for El Mijares watershed, CORINE has the longest time-frame, allowing for tracking landscape changes since 1990. However, this data has the lowest spatial resolution (100 m) and minimum mapping unit (25 ha). According to CORINE, the most expressive land cover is "forest and semi-natural areas", occupying more than 70 % of the landscape, with an increasing trend since 1990 (Table 3). This trend is mainly driven by the expansion of coniferous and mixed forests. Conversely, the decrease in the agricultural land cover is due to the decrease in "non-irrigated arable lands" and "complex cultivation" classes. More drastic landscape changes occurred between 2000 and 2006.

The major individual land covers are "coniferous forests" and "sclerophyllous vegetation", distributed all over the landscape (Figure 2). Arable lands are mainly concentrated in the highest portion of the landscape, while "fruit trees" (citrus plantations), "complex cultivation" and most "artificial surfaces" are found in the lower part of the watershed.

4.1.2 S2GLC land cover

S2GLC has the highest spatial resolution for a continental-scale mapping (10 m). However, the product is only available for 2017, constraining temporal analysis. Also, the classification scheme is divided into 13 major land cover classes, being a suitable map for investigations focused on land cover. As CORINE, S2GLC also points to "coniferous tree cover" as the major individual land cover in El Mijares (Table 4), with 26.1 % of the landscape in 2017. A similar pattern is observed for the association of scrub and herbaceous vegetation, which sums 35.1 % from "natural grasslands", "moors and heathland" and "sclerophyllous vegetation".

The distribution of the classes on the landscape is similar to the pattern found in CORINE, with its central portion covered mainly with forests and herbaceous vegetation in the highest portion (Figure 3). Cultivation in the lower parts of the watershed is also found in S2GLC, however the citrus plantations are classified as vineyards. Indeed, amongst the agricultural land uses, only vineyards are classified in S2GLC, which is not a suitable representation in El Mijares landscape.

Table 3: Land use and land cover in El Mijares from CORINE classification (%)

Level 1	1990	2000	2006	2012	2018	Level 2	1990	2000	2006	2012	2018	Level 3	1990	2000	2006	2012	2018
ARTIFICIAL SURFACES	0.27	0.51	1.14	1.09	1.11	Urban fabric	0.13	0.16	0.50	0.46	0.46	Continuous urban fabric	0.07	0.07	0.07	0.09	0.09
												Discontinuous urban fabric	0.06	0.08	0.42	0.37	0.37
						Industrial, commercial and transport units	0.96	0.25	0.34	0.48	0.50	Industrial or commercial units	0.09	0.25	0.32	0.39	0.41
												Road and rail networks and associated land	0	0	0.01	0.02	0.02
												Airports	0	0	0	0.06	0.65
						Mine, dump and construction sites	0.02	0.08	0.29	0.13	0.13	Mineral extraction sites	0.02	0.07	0.10	0.12	0.12
												Dump sites	0	0	0.01	0.01	0.01
												Construction sites	0	0	0.17	0	0
						Artificial, non-agricultural vegetated areas	0	0.01	0.01	0.01	0.01	Sport and leisure facilities	0	0.01	0.01	0.01	0.01
AGRICULTURAL AREAS	27.9	27.7	20.1	20.3	20.3	Arable land	9.10	9.13	6.45	6.03	5.99	Non-irrigated arable land	8.50	8.54	5.96	5.63	5.59
												Permanently irrigated land	0.59	0.58	0.49	0.40	0.40
						Permanent crops	5.06	4.95	5.73	5.81	5.83	Vineyards	0.02	0.02	0.11	0.11	0.11
												Fruit trees and berry plantations	4.37	4.25	5.08	5.15	5.19
												Olive groves	0.67	0.67	0.53	0.54	0.52
						Pastures	0.18	0.01	0.42	0.52	0.52	Pastures	0.18	0.01	0.42	0.52	0.52
						Heterogeneous agricultural areas	13.7	13.6	7.54	8.01	8.02	Complex cultivation patterns	8.88	8.75	3.05	3.37	3.38
												Land principally occupied by agriculture, with signifi cant areas of natural vegetation	4.85	4.85	4.49	4.63	4.64
FOREST AND SEMI NATURAL AREAS	71.6	71.6	78.5	78.3	78.3	Forests	29.9	29.8	39.2	39.0	38.9	Broad-leaved forest	4.23	4.18	5.92	6.03	6.03
												Coniferous forest	22.8	22.7	27.0	26.7	26.7
												Mixed forest	2.86	2.88	6.26	6.21	6.21
							41.3	41.4	38.6	38.7	38.7	Natural grasslands	3.03	3.03	10.9	10.9	10.9

Level 1	1990	2000	2006	2012	2018	Level 2	1990	2000	2006	2012	2018	Level 3	1990	2000	2006	2012	2018
						Scrub and/or herbaceous vegetation associations						Sclerophyllous vegetation	23.7	23.7	21.0	20.9	20.9
												Transitional woodland-shrub	14.5	14.6	6.58	6.87	6.89
						Open spaces with little or no vegetation	0.25	0.25	0.65	0.59	0.59	Beaches, dunes, sands	0.18	0.18	0.25	0.24	0.24
												Bare rocks	0.01	0.01	0.02	0.03	0.03
												Sparsely vegetated areas	0.05	0.05	0.31	0.31	0.31
WATERBODIES	0.17	0.16	0.17	0.19	0.19	Inland waters	0.17	0.16	0.17	0.19	0.19	Water bodies	0.17	0.16	0.17	0.19	0.19

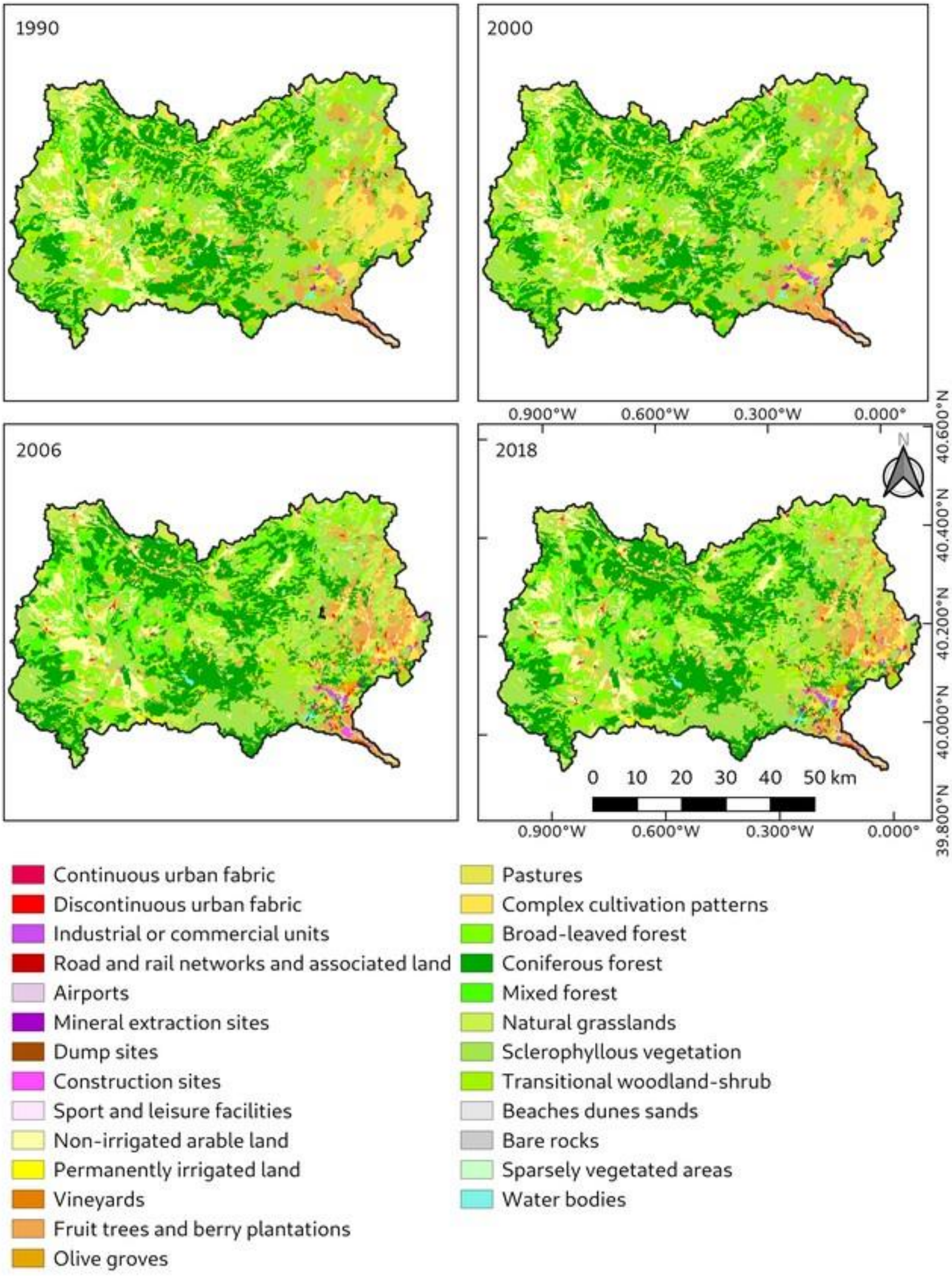

Figure 2: CORINE maps of El Mijares in 1990, 2000, 2006 and 2018. For improving the visualization, the map of 2012 was omitted in the figure

Table 4: El Mijares land cover from S2GLC (%)

Land cover	S2GLC (2017)
Artificial surfaces and construction	1.15
Cultivated areas	9.06
Vineyards	6.41
Broadleaf tree cover	17.4
Coniferous tree cover	26.1
Herbaceous vegetation	18.3
Moors and heathland	5.93
Sclerophyllous vegetation	10.8
Marshes	0.63
Natural material surfaces	3,83
Water bodies	0.19

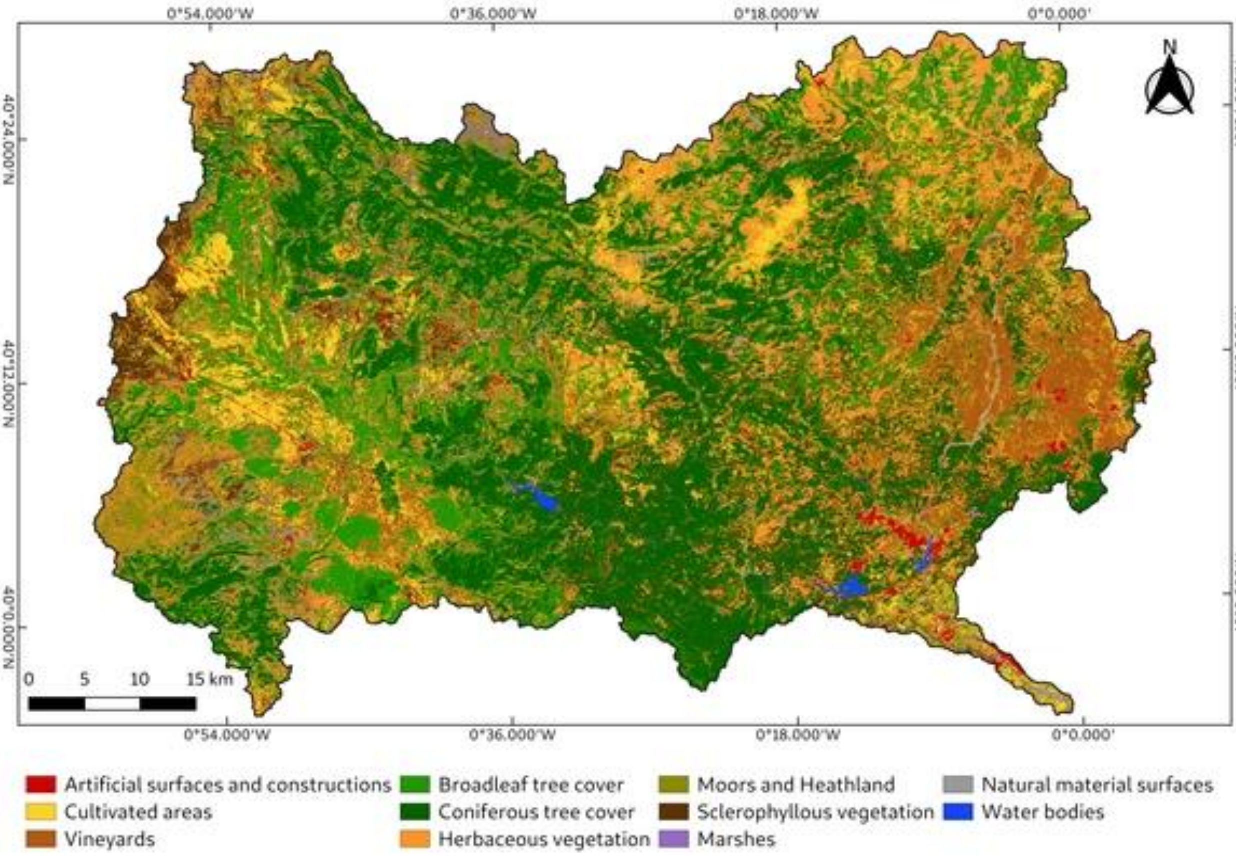

Figure 3: S2GLC 10 m land cover of El Mijares for 2017

4.1.3 LUCAS samples

The proportion of land use and land cover from LUCAS surveys for the years 2006, 2012 and 2018 are shown in Table 5. In the following years, there were 178, 238 and 344 points sampled in El Mijares. Although it is not a raster map that could be used as input in modelling platforms such as ARIES, LUCAS depicts the land use among each land cover in more detail than any other product. For example, in 2018, a third of the broadleaf land cover and a half of the pines were used for forestry, a piece of information not available in any other product. LUCAS also points to the decrease of agricultural areas, especially "nuts trees", which were mainly replaced by pines plantations for forestry. On the other hand, LUCAS indicates that most shrublands are mainly natural or semi-natural areas without a clear predominant land use, but with minor agricultural and recreational activities. Grasslands are also shrinking, with some agricultural land use that might be related to grazing, despite this information is not explicit in LUCAS.

Table 5: Land use and land cover from LUCAS in the years 2006, 2012 and 2018

Land cover category	2006 (%)	2012 (%)	2018 (%)	Land cover class	2006 (%)	2012 (%)	2018 (%)	Land use class	2006 (%)	2012 (%)	2018 (%)
Artificial land	2.24	5.04	1.74	Buildings with 1 to 3 floors	1.12	1.68	0.29	Residential	1.12	0.84	0.29
								Abandoned areas	0	0.84	0
				Non built-up area features	0	1.68	0	Chemical and allied industries and manufacturing	0.56	0	0
								Commerce, financial, professional and information services	0	0.84	0
								Residential	0	0.84	0
				Non built-up linear features	0.56	1.68	1.45	Road transport	0.56	1.68	1.45
Cropland	30.8	18.9	8.15	Common wheat	0.56	0.84	1.16	Agriculture (excluding fallow land and kitchen gardens)	30.8	18.9	8.15
				Barley	3.93	3.36	1.74				
				Oats	1.68	0.42	0.29				
				Tomatoes	1.12	0	0				
				Cherry fruits	0.56	0.42	0				
				Other leguminous and mixtures for fodder	0	1.26	0.29				
				Nuts trees	16.8	8.40	2.61				
				Olive groves	4.49	2.52	0.58				
				Oranges	0.56	0.42	0				
				Other citrus fruit	1.12	0	0				
				Vineyards	0	0.42	0.29				
				Permanent crops	0	0.84	0.58				
Woodland	23.6	41.5	58.9	Broadleaved woodland	1.68	12.2	11.3	Agriculture (excluding fallow land and kitchen gardens)	0.56	0	0.29
								Forestry	1.12	2.52	3.77
								Other primary production	0	0	0.29
								Semi-natural and natural areas not in use	0	9.66	6.97
				Pine dominated coniferous woodland	1.12	13.8	33.1	Forestry	1.12	2.52	15.1
								Semi-natural and natural areas not in use	0	11.3	18.0
					4.49	2.94	5.51	Forestry	4.49	2.10	2.03

				Other coniferous woodland				Semi-natural and natural areas not in use	0	0.84	3.48
				Pine dominated mixed woodland	0	7.98	4.35	Forestry	0	0.84	1.74
								Semi-natural and natural areas not in use	0	7.14	2.61
				Other mixed woodland	16.3	4.62	4.64	Agriculture (excluding fallow land and kitchen gardens)	0	0	0.29
								Forestry	16.3	1.26	1.16
								Semi-natural and natural areas not in use	0	3.36	3.19
Shrubland	16.2	18.1	19.7	Shrubland with sparse tree cover	9.54	12.6	7.55	Agriculture (excluding fallow land and kitchen gardens)	1.12	2.10	0.29
								Forestry	0	0	0.29
								Abandoned areas	0	0	0.29
								Semi-natural and natural areas not in use	8.42	10.5	6.68
				Shrubland without tree cover	6.73	5.46	12.2	Agriculture (excluding fallow land and kitchen gardens)	0.56	1.26	0.29
								Amenities, museums, leisure	0	0	0.29
								Forestry	0	0	0.87
								Road transport	0	0	0.29
								Semi-natural and natural areas not in use	6.17	4.20	10.4
Grassland	21.3	12.8	10.1	Grassland with sparse tree/shrub cover	8.41	5.46	2.61	Agriculture (excluding fallow land and kitchen gardens)	4.49	1.68	0.58
								Abandoned areas	0.56	0.42	0.29
								Fallow land	0.56	0	0
								Forestry	2.80	0	0
								Semi-natural and natural areas not in use	0	3.36	1.74
				Grassland without sparse tree/shrub cover	12.9	1.68	3.77	Agriculture (excluding fallow land and kitchen gardens)	5.05	0.84	1.16
								Fallow land	6.17	0	0
								Forestry	0.56	0	0
								Holiday camps	0.56	0	0
								Residential	0.56	0	0
								Abandoned areas	0	0.84	0.87
								Semi-natural and natural areas not in use	0	0	1.74
				Spontaneously vegetated surfaces	0	5.04	3.77	Agriculture (excluding fallow land and kitchen gardens)	0	0	0.58
								Fallow land	0	3.78	2.03
								Other abandoned areas	0	1.26	0.87

								Semi-natural and natural areas not in use	0	0	0.29
Bare land and lichens/ moss	3.92	2.94	1.45	Bare land	3.92	0	0	Abandoned areas	1.68	0	0
								Fallow land	2.24	0	0
				Rocks and stones	0	1.68	0.87	Semi-natural and natural areas not in use	0	1.68	0.58
								Waste treatment	0	0	0.29
				Other bare soil	0	1.26	0.58	Agriculture (excluding fallow land and kitchen gardens)	0	0	0.29
								Fallow land	0	1.26	0.29
Water	1.68	0.84	0	Inland running water	1.68	0.42	0	Semi-natural and natural areas not in use	0	0.42	0
								Water transport	1.68	0	0
				Inland water bodies	0	0.42	0	Water supply and treatment	0	0.42	0

4.1.4 Pan-European Landsat/LUCAS-based map

This map from Pflugmacher et al. (2019) reports 11 land cover classes as S2GLC, with a quite similar pattern of class distribution, as shown in Table 6. The most expressive land cover, however is “Shrubland” (41.7 %), followed by “coniferous forest” (32.9 %). The same pattern would be found in S2GLC if “Herbaceous vegetation”, “Moors and heathland” and “Sclerophyllous vegetation” were also classified into a single shrub land cover, but with different values. This, however, differs from CORINE, in which forests and shrublands occupy nearly 38 % of El Mijares landscape each.

Table 6: Pan-European Landsat-based land cover from 2015 in El Mijares (%)

Land cover	%
Artificial land	1.05
Cropland, seasonal	4.24
Cropland, perennial	8.66
Forest, broadleaved	6.45
Forest, coniferous	32.9
Forest, mixed	0.03
Shrubland	41.7
Grassland	4.57
Barren	0.06
Water	0.18
Wetland	0.01

Despite the intermediate spatial resolution and time-frame, older than the S2GLC and the latest CORINE, the overall distribution of the classes is similar to those previous maps (Figure 4). Unlike S2GLC, the citrus plantations in the lower portion of the watershed are mainly classified as perennial croplands and not “vineyards”, which agrees more with CORINE’s classification of “tree plantation”.

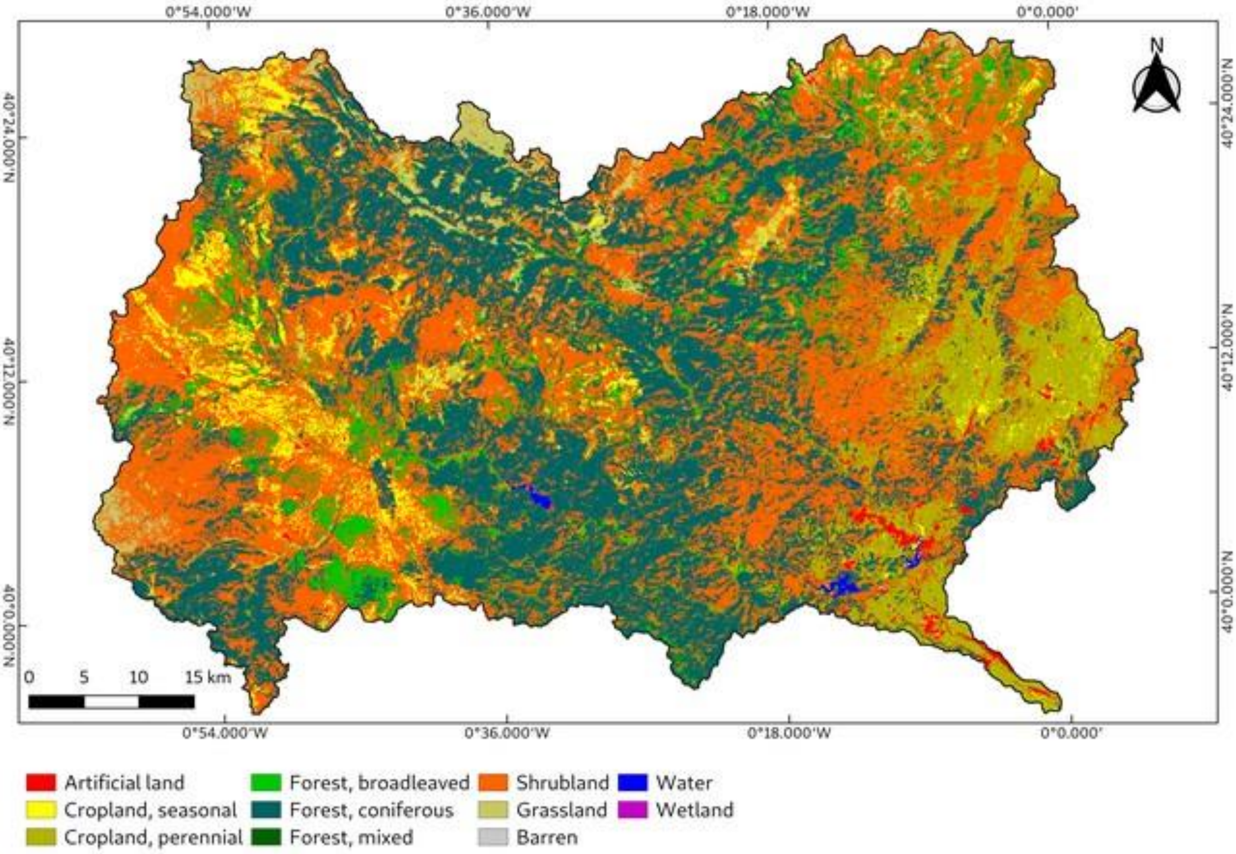

Figure 4: Land cover map of El Mijares for 2015 based on Landsat imagery and LUCAS samples

4.1.5 Predominant LULC from SIOSE

As the official LULC from Spain, and the basis for CORINE, SIOSE reports a high number of land use and land cover classes, mainly those related to urban and infrastructure networks. It reports the association of agriculture and vegetation as the main individual agricultural land use, followed by herbaceous croplands fruit trees and fruit trees (Table 7). Indeed, SIOSE has the highest proportion of agricultural lands when compared to all the other six LULC products. This is mainly due to the association of agriculture and vegetation, which is difficult to classify with remotely sensed data and requires human interpretation of the images. Regarding the Level 1 classification, "natural vegetation" has the highest share of the landscape, with six major land covers in the more detailed level, with no information on land use.

Table 7: Predominant LULC from SIOSE polygons

Level 1 (CLC)		LULC (SIOSE)	COD	2014 (%)
		Casco	111	0.14
		Ensanche	112	0.18
		Discontinuo	113	0.31
Artificial land	2.02	Zona verde urbana	114	0
		Instalación agrícola y/o ganadera	121	0.08
		Extración mineral	123	0.17
		Industrial	130	0.43

		Servicio dotacional	140	0.04
		Asentamiento agrícola y huerta	150	0.01
		Red viaria o ferroviaria	161	0.53
		Aeropuerto	163	0.05
		Infrastructura y suministro	171	0.03
		Infrastructura de residuos	172	0.05
Agriculture	23.2	Cultivo herbáceo	210	4.20
		Invernadero	220	0
		Frutal cítrico	231	1.70
		Frutal no cítrico	232	2.31
		Viñedo	233	0.01
		Olivar	234	0.43
		Combinación de cultivos leñosos	236	1.15
		Prado	240	0.17
		Combinación de cultivos	250	1.69
		Combinación de cultivos con vegetación	260	11.5
Natural vegetation	72.89	Bosque de frondosas	311	4.74
		Bosque de coníferas	312	29.3
		Bosque mixto	313	7.12
		Pastizal o herbazal	320	11.4
		Matorral	330	9.03
		Combinación de vegetción	340	11.3
Bare land	1.37	Playa, duna o arenal	351	0.01
		Roquedo	352	0.21
		Teporalmente desarbolado por incendios	353	0.05
		Suelo desnudo	354	1.10
Water	0.47	Curso de água	511	0.33
		Embalse	513	0.13
		Lámina de água artificial	514	0.01

4.1.6 Agricultural parcels from SIGPAC

In turn, SIGPAC, another country-wide high-resolution land use system, has the lowest proportion for forest cover amongst all the studied databases, with no distinction between broadleaved, coniferous and/or mixed forests (Table 8). Moreover, it also reports the highest water coverage of 1.5 %, which is, on average, tenfold the water classes of the other products. As a database developed for agricultural purposes, this might be related to the inclusion of small features of dams and weirs for irrigation. Another substantial difference of SIGPAC to the other products is the prevalence of shrubby pastures and silvopasture (36.1 % and 15.6 %, respectively), possibly indicating the use of the shrublands in El Mijares for grazing.

Table 8: LULC from SIGPAC

LULC	%
Agua	1.50
Viales	3.41
Cítricos	0.75
Edificaciones	0.01
Elemento del paisaje	0.01
Frutal de Cáscara-Olivar	0.15
Forestal	23.2
Frutal de cáscara	2.91
Frutal	2.74
Improductivo	1.57
Olivar	1.44
Pasto arbolado	15.6
Pasto arbustivo	36.1
Pastizal	1.73
Tierra arable	7.64
Viñedo	0.11
Zona urbana	1.13

4.1.7 Landsat/CORINE-based land cover for El Mijares

We have developed this map especially for El Mijares. Because it is based on samples collected from CORINE, and CORINE uses an automated supervised classification, this map also reports mainly land cover, as S2GLC and the pan-European map from Pflugmacher et al. (2019). The advantage of this product over the other ones is that the temporal resolution can be extended to the whole Landsat series, assuming that the no-change samples from CORINE are representative of the landscape. Thus, it allows a more detailed 30 m time series analysis of the land cover dynamics in El Mijares. It is worth noting that this product is still under evaluation and some further enhancement to the processing is still needed.

Unlike all the other raster products, here the "mixed forests" is the most common land cover (Table 9), followed by "sclerophyllous vegetation" and "coniferous forests". This might be caused by the spectral confusion of mixed and coniferous forests, which is subject to improvement in the classification. As shown in Figure 5, fruit tree plantation (citrus) is mainly located in the lower portion of the landscape, while the arable lands and shrublands are mainly found in the higher part, with forests occupying the central/upper watershed, as found in the other databases.

Table 9: Land cover (%) from Landsat/CORINE map of El Mijares

Land cover	%
Artificial surface	1.06
Non-irrigated arable land	6.19
Irrigated arable land	1.96
Fruit trees and berry plantations	4.88
Olive groves	4.33
Broad-leaved forest	6.65
Coniferous forest	15.8
Mixed forest	17.8
Grassland	9.46
Sclerophyllous vegetation	17.5
Transitional woodland-shrub	12.8
Beach, dune and sand	1.21
Water bodies	0.14

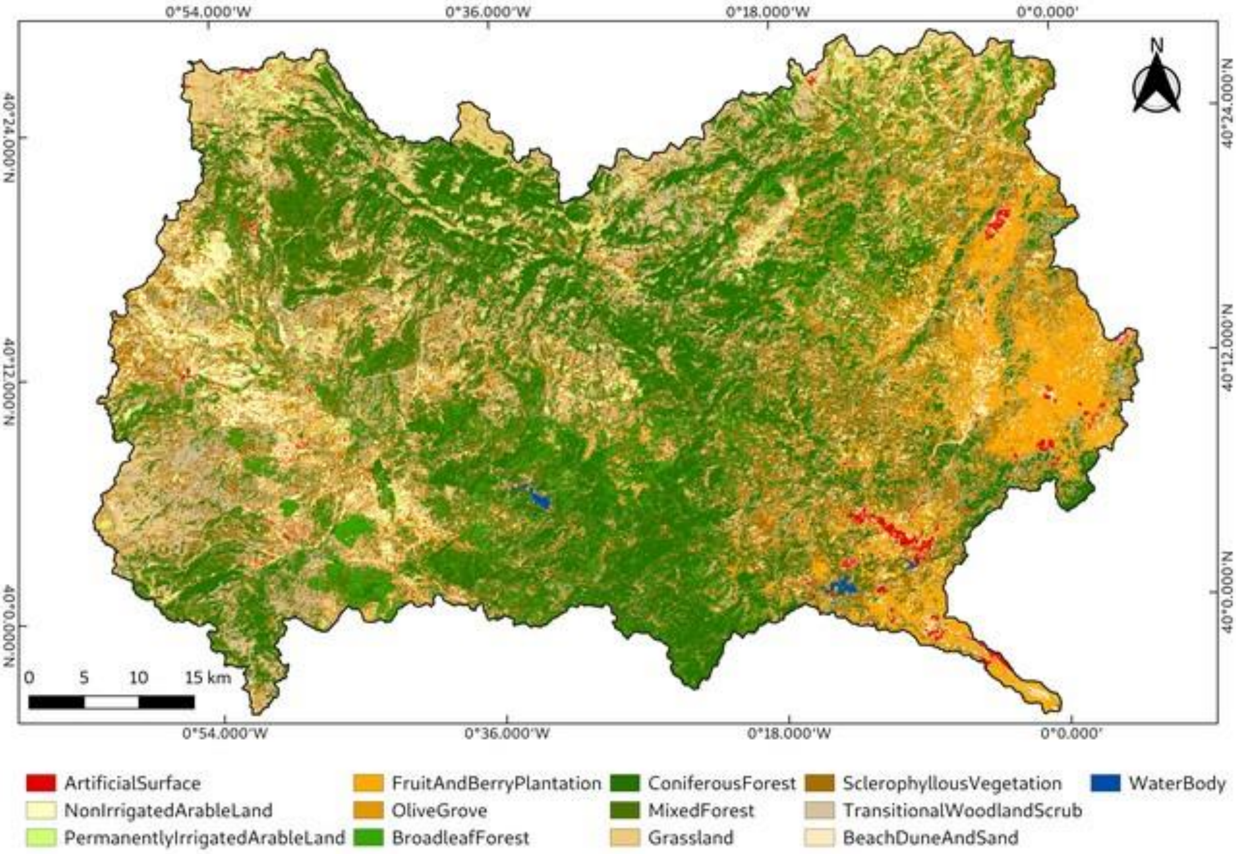

Figure 5: Land cover map of El Mijares derived from Landsat (2018) and CORINE no-change samples

4.2 Raster products comparison

Considering a common legend of 9 land cover classes and assuming that no significant landscape changes occurred during the reference years of the maps (2015, 2017 and 2018), the overall spatial consistency of the maps is 45.5 % (+4.8 %). The highest agreement is found amongst the Landsat-based maps, as shown in Table 10.

Table 10: Overall spatial agreement (%) among the products

	CORINE (2018)	S2GLC (2017)	Landsat/LUCAS (2015)
S2GLC (2017)	41.5	-	-
Landsat/LUCAS (2015)	48.7	47.2	-
Landsat/CORINE (2018)	39.3	39.3	49.6

The local agreement of the maps is shown in Figure 6. A 6.13 % of the landscape had no agreement between the maps (dark red in Figure 6), while the classification in the four maps was the same in 20 % of the landscape (dark green in Figure 6). Intermediate results, i.e. low and good agreement (light red and light green in Figure 6), meaning that two or three maps classified a pixel with the same land cover, is 32.6 % and 41.2 % of the landscape, respectively.

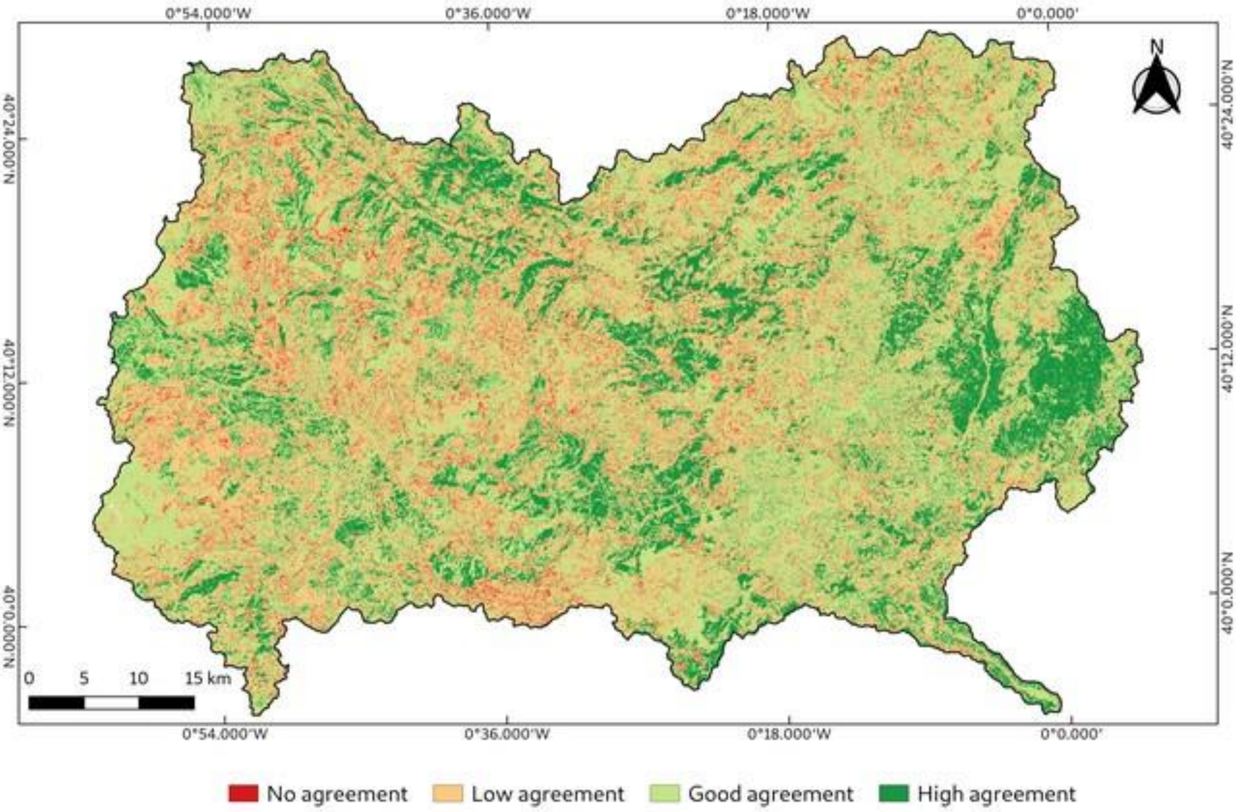

Figure 6: Agreement between the raster products according to the common land cover

Regarding specific land cover, there is little difference in the artificial surfaces and water bodies among all the maps (Table 11). However, the Landsat/LUCAS approach reports the lowest agricultural area and the highest area of both coniferous forests and shrublands, which are the land cover classes that show the highest difference in the maps (from 10.9 % to 41.7 %).

Table 11: Land cover comparison from the four raster products (%) with the common legend

Land cover	CORINE 2018	S2GLC (2017)	Landsat/LUCAS (2015)	Landsat/CORINE (2018)
Artificial surface	1.09	1.15	1.05	1.06
Agriculture	20.3	15.4	12.9	17.3
Broad-leaved forest	6.03	17.4	6.45	6.65
Coniferous forest	26.8	26.1	32.9	15.83
Mixed forest	6.23	-	0.03	17.8
Grassland	10.9	24.2	4.56	9.45
Shrubland	27.7	10.8	41.7	30.4
Natural non-vegetated	0.58	4.46	0.06	1.21
Water	0.19	0.19	0.18	0.14

5. Discussion and conclusions

Despite the inherent differences of the LULC products evaluated here, a general pattern of El Mijares landscape can be learned from them: the highest proportion of forest and/or shrublands, followed by some agricultural activities and minor urban or infrastructure networks coverage. In this sense, the products are more representative of land cover, being LUCAS the most suitable for characterizing their uses. This can be exemplified by the distinct uses of the woodlands, in which half of the pine trees and a third of the broadleaved forests are for forestry. Moreover, SIGPAC indicates the use of shrublands for grazing. As a first conclusion, no single product can inform all of the LULC aspects of the landscape, thus the integration of statistical information with maps more oriented to land cover might be useful for understanding the dynamics of the land uses in the Mediterranean region, especially in El Mijares.

The overall agreement of the raster maps is relatively low (less than 50%), evidencing that the spatial resolution and mapping techniques play an important role in the final land cover classification. The lower agreement is found in the highest portion of the landscape, where transitional woodland-shrub, grasslands and sclerophyllous vegetation occur. A good agreement is observed in the lower parts of the watershed, which are dominated by agricultural land uses, when considering the all the agricultural plots as a single land cover. However, amongst the raster maps, only CORINE and Landsat/CORINE allow to distinguish between citrus plantations (fruit trees class) and other types of agricultural land uses in this part of the landscape. This also highlights the need for a suitable single database, or the integration of products, according to the desired outcome of the research.

Tracking relatively long-term landscape dynamics is only possible with CORINE, beginning in the year 1990 (~30 years). However, its spatial resolution (100 m) can be constraining for some minor land cover classes. So, extending the Landsat/CORINE map to the entire Landsat time series can improve the temporal coverage from 1984/1985 to the present, at a resolution of 30 m. This, however, should be carefully done to avoid spectral confusion, mainly between mixed and coniferous forests, resulting in a possible overestimation of that land cover. Moreover, and despite the miss-categorization within agricultural classes in the S2GLC, especially in the lower watershed, where the citrus plantations are classified as vineyards, and the omission of mixed forests, if new maps are available to the present, they could be useful for present-date land cover information at 10 m of spatial resolution. Both CORINE and LUCAS indicate a temporal trend of coniferous and mixed forests expansion over agricultural areas and grasslands. As explicit from LUCAS, this might be due to the increased forestry activities use mainly of pine trees and, possibly by land abandonment. Thus, future investigation should consider land abandonment and afforestation subsides in the Castellón region as possible contrasting drivers of this forest expansion trend. This is an interesting land use dynamic to be explored by ecosystem services modelling approaches because it can be representative of a trade-off between food production and other economic activities, which in this case is forestry. CORINE also points to the decrease of the class "complex cultivation", which is related to confusing not clear land cover. As the most recent periods have more detailed information on land, the decrease of this class can be attributed to the enhancement of the classification of other agricultural activities.

In this sense, even the products generated by photointerpretation of high-resolution images relate some level of class misinterpretation, as the case of "association of agriculture and vegetation", which is 11.5 % of the land cover in SIOSE. Human interpretation of the images is usually very time consuming and, as in this case, does not necessarily increase the distinction of different complex LULC. To avoid confusion classes, or at least to enhance the classification of complex land patterns, both fieldwork and editing of the existing maps is required. This increases not only the processing time, due to increased labour, but also the travel costs for in situ verification.

Given the comparison of the LULC products, some recommendations can be drawn aiming at the parsimonious use of each one. If only the statistics on land use and land cover are desired, without the need for raster or vector maps (e.g. as required in modelling platforms), LUCAS is a rich source of information that can be extracted at the watershed scale. When a smaller scale is sampled, however, the statistics of the predominant LULC from SIOSE may be a better option. Additionally, SIOSE is a good choice for short-term (decadal) landscape changes at very high spatial resolution. At the parcel scale, SIGPAC becomes the unique database for agricultural land use, for both very small extension of land to the whole country. SIOSE and SIGPAC can also be rasterized with relatively small cell sizes to be used as inputs in models but computational requirements increase exponentially with the increased resolution. In this sense, the three medium resolution raster products (S2GLC, Landsat/LUCAS and Landsat/CORINE) are suitable for an overall evaluation of the watershed land cover. It is important to highlight, however, that there are important differences between these products, evidenced by the relatively low spatial agreement among them.

Landsat/LUCAS, despite based on LUCAS samples, does not distinguish land uses, but a limited number of land cover, and is only available for the year 2015, becoming the least suitable map in the case of El Mijares. In turn, S2GLC presents the best spatial resolution of the three, but also do not classify agricultural land uses properly, particularly the citrus plantations in the lower portion of the watershed, which could be improved if combined with SIGPAC. Landsat/CORINE overestimates the mixed forests, while underestimating the coniferous forests, when compared to CORINE. Thus, an improvement in the classification of these forest types is required. As a second and last conclusion, for the particular case of El Mijares, the option of extending the Landsat/CORINE to the entire Landsat series results in the most suitable output for the long-term analysis of the watershed, benefiting from Landsat's better spatial and temporal resolution at the watershed scale (since 1984/1985) and from CORINE's longer LULC information (1990).

Modelling ecosystem services to propose sustainable land management at the landscape scale, as is the case of MASBIO and RESH2O is not an easy task. Relying on the available LULC maps is necessary to reduce the costs and execution time of landscape characterization. It is thus, of great importance to recognize the limitations and strengths of all the input data and, and more importantly, to choose the better product or combination of products according to its suitability to the context of the project.

Acknowledgments

This research is supported by María de Maeztu excellence accreditation 2018-2022 (Ref. MDM-2017-0714), funded by MCIN/AEI/10.13039/501100011033/; and by the support of the Ministry for the Ecological Transition and the Demographic Challenge, through the Biodiversity Foundation.

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