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Reconstruction of land cover distribution for mid-twentieth century in Ebro basin

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ABSTRACT
The analysis of historical land use and land cover evolution requires available cartography. In this paper, we provided a reconstruction of land cover distribution for mid-twentieth century of part of the Ebro basin. This reconstruction is carried out using three methods: (i) previously available cartographic sources, (ii) land cover reconstruction by data extrapolation in some areas where land cover surface is like other with land cover data availability, and (iii) manual digitization based on 1956–57 orthophotography. As a result, we provide land cover cartography for 71.7% of the study area and the estimated land cover distribution of data for the rest 28.3%.

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Land cover reconstruction; historical cartography; 1956–57; digitization

Highlights

- There is a lack of historical land cover data for the Ebro basin
- We provide a land cover cartography and distribution data of the mid-twentieth century in the upper and middle Ebro basin
- The reconstruction of land cover data has been made following a mixed methodology based on existing cartography and data contribution, the extrapolation of homogeneous land cover distribution areas and manual digitization

1. Introduction

The knowledge of land use and land cover (LU/LC) change has become increasingly important for the analysis of environmental processes and problems (Jansen, 2006). Spatially detailed LU/LC maps are needed to assess effects on nature and landscape (de Nijs et al., 2004).

Changes in land use and land cover, besides modifying the landscape, impact the runoff (Thornes, 2005) and delivery of water, sediment feeding and connectivity with drainage network (Llena et al., 2019), nutrients, and other materials downstream, and can alter water quality, aquatic habitat, and channel and floodplain morphology (Scorpio & Piégay, 2021) over short to intermediate timescales (James & Lecce, 2013). Land use changes, vegetation changes, agriculture, grazing, urbanization, mining, … are considered indirect human changes over the rivers (Brierley & Fryirs, 2005). Wohl et al. (2015) stated that modern and historical land uses in watersheds should be understood to develop a spatially distributed watershed perspective of the river and a sense of the temporal dynamics of the system, which are important considerations for river rehabilitation and management.

LU/LC analysis requires not only data collection and representation as maps, but also a more dynamic environmental and evolutionary analysis to understand the past, monitor present situation and to predict future trajectories (Dolman et al., 2003).

However, there is few available historical land cover data for Europe and the Iberian Peninsula in particular. The HILDA+ project, the global HIstoric Land Dynamics Assessment, reconstructs global land use/cover change from 1960 to 2019 (Winkler et al., 2020, 2025) at a 1-km spatial resolution for a wide extension of the continents, including the whole of Europe. In Spain, there is a first Forest Map of Spain at a scale of 1:400,000 drawn up by Luis Ceballos and published in 1966. This map was based on field identification work complemented with aerial images from the American Flight of 1956–1957, among other available aerial images (Ceballos, 1966). However, even though this source covers the entire surface of the study area, the comparison of this cartography

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with the aerial photography of the American flight presents important divergences. In Andalucia, the MUCVA (*Mapa de Usos y Coberturas Vegetales del Suelo de Andalucía*) project reconstructed LU/LC historical cartographies at a scale of 1:25,000 based on 1956 black and white, 1 m resolution orthophotography (Gutiérrez-Hernández et al., 2016). Like this we have the Map of Crops and Uses of Navarre (2009), a land use and cover map based on the 1956 orthophotography.

In the context of the Ebro Sediment Observatory project, the need to obtain a cartography of LU/LC for different periods to assess the impact of LU/LC changes of the Ebro basin on the morphological evolution and morphodynamics changes focusing on sediment balance of Ebro mainstream has required the reconstruction of the first LC map based on the 1956–57 aerial images, the oldest ones that cover the whole Ebro basin.

The manual digitization of the different categories of land cover seemed unmanageable in terms of time and resources, so a mixed methodology was proposed, complementing available cartography from previous works carried out in the study area, extrapolations of land cover distributions and, in those areas where the two previous options were not considered viable, manual digitization.

The objective is to reconstruct the land cover data of the upper and middle Ebro basin from the mid-twentieth century. This LC map and data will be useful for an evolutionary analysis of the changes that have occurred in recent decades and to relate them to the changes on the drainage network and especially on the Ebro River morphology and dynamics, but also for other environmental and geographical analyses.

This project focuses on 345 km Ebro River's free meandering channel between Logroño and La Zaida (Zaragoza). This segment includes the upper and middle river basin and encompasses a drainage area of 49,434 km^2, around 58% of the Ebro's total basin (Figure 1). In this area, we find a very wide range of landscapes due to very diverse environmental conditions, from the high mountains in the Pyrenees on the north, Atlantic conditions in the upper basin, to Mediterranean in the southeast and semi-arid in the Ebro Depression.

2. Methodology

2.1. Collection of existing LC cartography and data, and aerial orthophotography

The reconstruction of mid-twentieth century LC for the studied area is carried out using different three different sources (Table 1):

(i) GIS format map layers:

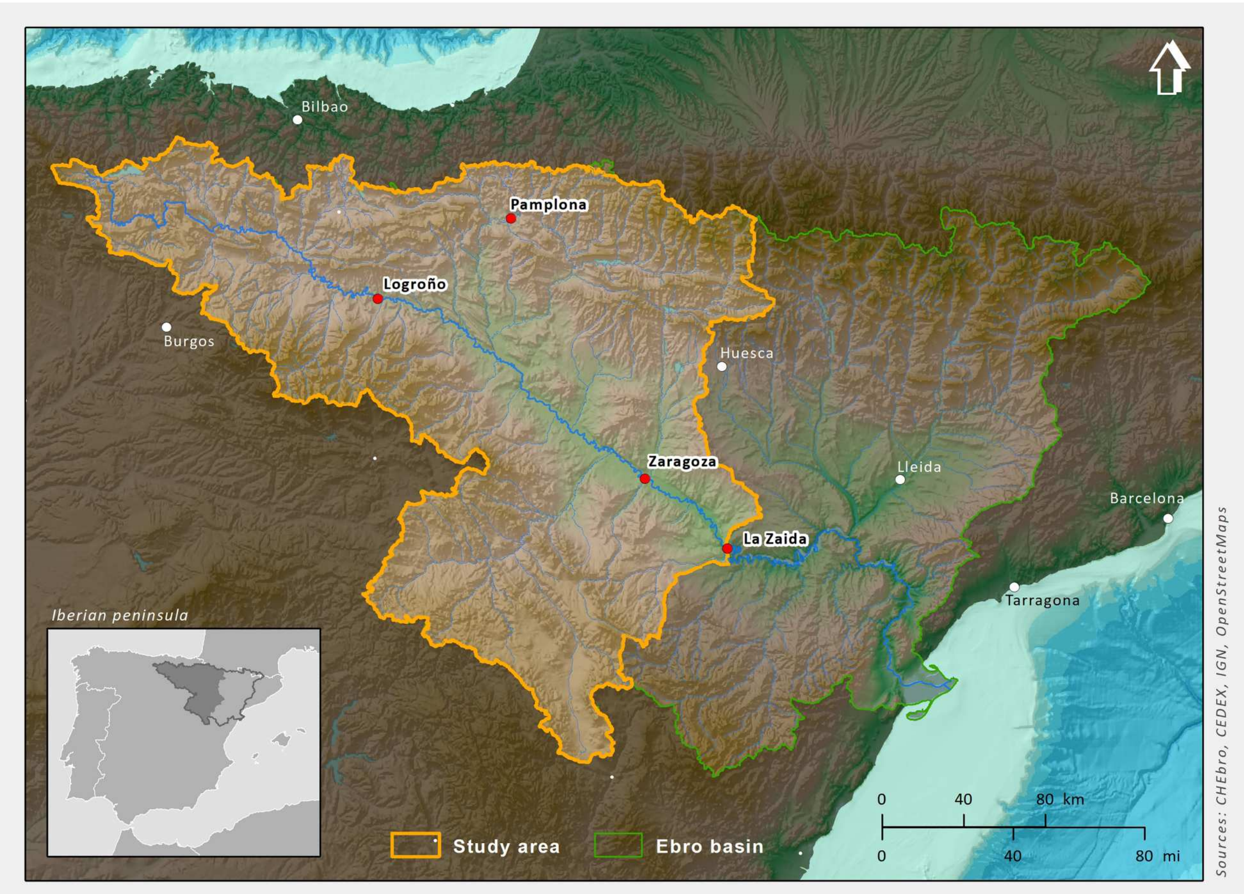

Figure 1. Study area of the Ebro basin.

Table 1. Available cartography, aerial images, and data sources used.

Source	Type of source	Available source (km^2)	Used source (km^2)	% of the basin
Ceballos (1966)	Cartography	49,430*	4015	8.12
Navarre Government (2009)	Cartography	9207**	9207	18.68
Heredia-Laclaustra (2011)	Cartography	27.21	17.50	0.04
Berger (2022)	Cartography	311.40	311.40	0.63
Errea et al. (2023)	Cartography	96.02	93.10	0.19
American Flight 1956–57	Aerial orthophotography	49,430	25,802.46	52.2
Arnáez et al. (2008)	LC quantitative data	1318.2	1318.2	2.16

*Area corresponding to the study area of the Ebro basin. **Area corresponding to Navarre within the Ebro basin.

– The first Forest Map of Spain (Ceballos, 1966) at a 1:400,000 scale.
– The Map of Crops and Uses of Navarre produced by the Government of Navarre (2009) through the photointerpretation of the orthophotography of the American Flight (series B, 1956–57) at a 1:50,000 scale.
– Academic literature with cartography covering small portions of different areas of the Ebro basin. In the Iberian system, the basin of the Linares River (Berger, 2022), in the Pyrenees the headwaters and middle of the Estarrún River basin (Aisa Valley) (Errea et al., 2023), and in the pre-Pyrenees the work of Heredia-Laclaustra (2011) corresponding to the municipality of Santa Cilia.

(ii) Aerial orthophotography of 1956–57 generated from the American Flight (series B) photograms. This orthophoto is in black and white at a scale of 1:33,000.
(iii) LC quantitative data. The work by Arnáez et al. (2008) without GIS mapping, but with LC distribution data of the Iregua, Leza, Jubera and Cidacos valleys, quantifies the evolution of vegetation cover between 1956 and 2001.

All the vector data, except for the first Forest Map of Spain, based their data on the photointerpretation of the orthophotography of the American Flight series B, conducted between 1956 and 1957. The U.S. Army Map Service carried out this flight. The resulting orthophoto represents one of the most valuable sources due to its high quality and complete coverage of the study area; therefore, in areas where no previous LC cartography is available, we used this flight as reference source.

The map of crops and uses of Navarre, the mapping of the Linares Valley, Santa Cilia and the middle and upper basin of the Estarrún River (Aisa Valley) are incorporated directly into the cartography of our project.

Even though the first Forest Map covers the entire surface of the study area, the overlay of this cartography with the orthophotography of the American flight presented important divergences, so it was decided not to make direct use of the cartographic layer. However, despite the cartography, after comparing results between the distribution data extracted from the cartographic layer by Ceballos and the cartography produced by the Government of Navarre (2009), the results of LC proportions by classes were very similar. The correlation of the Ceballos (1966) data with LC distribution of the shared areas with the Government of Navarre (2009) was consistent (around 0.84), therefore, a methodology was developed to use Ceballos's data to determine the distribution of land cover in the mid-twentieth century in some areas.

2.2. Definition of classes for LC reconstruction

The reconstruction of LC was done by classifying it into the following classes: active channel, forest, shrub, grassland-herbaceous, bare soil, crop, artificial and impounded water (water surface of lakes, wetlands and reservoirs). These classes are selected according to the differentiated role of each of them in the processes of sediment production and runoff. In the case of the cartography available from other sources, it has required the reclassification of the classes to resemble the defined categories (Annex 1). We paid special attention to those classes that represent the fluvial landscape itself, active channel, surface that includes water and bare sediment bar (Surian & Rinaldi, 2003), or with an important effect on its dynamics, such as the bare soil, for the role in providing sediment. The category of active channel was not included in most of the available cartography, so it was digitized manually to have an accurate representation of this category for the year 1956–57 in all the studied area.

2.3. Land cover reconstruction process

Due to the available cartographic diversity and the existence of extensive unmapped areas within the study area, it was decided to adopt a landscape similarity criterion to assign LC distribution data from mapped areas to unmapped areas. To this end, the landscape units defined by the *Atlas de los Paisajes de España* – Spanish Landscape Atlas (Ministry of the Environment, 2003) was used. Landscape Units are spatial divisions of a territory that have homogeneous internal characteristics that distinguish them from other neighboring units. The study area is comprised of 189 landscape units, with a very wide range of surfaces, mean of 262.6 km^2, and minimum of 6.6 km^2 and maximum of 1117.2 km^2.

In our case, the landscape unit is not the object of study but the spatial delimitation through which we have mapped and reconstructed LC data using three different methods. All the workflow is shown in Figure 2.

In the first phase, existing cartography was directly included after legend reclassification (Annex 1). This is the case of the cartography of Navarre (2009), Berger (2022), Errea et al. (2023) and Heredia-Laclaustra (2011). In the same way was proceed with the LC distribution data of Arnáez et al. (2008) with limits that coincide with four landscape units. In the case of the LC data from Ceballos (1966), LC data were directly applied to only those landscape units in which, based on expert criteria, the data corresponded to the visual inspection of the orthophotography (Figure 3).

In a second phase, involving data extrapolation, similarities in landscape were sought by reviewing orthophotography, and based on expert criteria, 42 landscape units were selected that could be extrapolated from other units already mapped (Figure 4). Two types of extrapolations have thus been carried out: (i) in some units, partially mapped, after checking that the area not covered has a homogeneous distribution, the LC percentages have been extrapolated to the landscape unit as a whole, (ii) in other cases, no LC mapping is available but these units are very similar to other mapped units, or with LC distribution data, so the data of LC distribution have been extrapolated after an exhaustive analysis of visual verification.

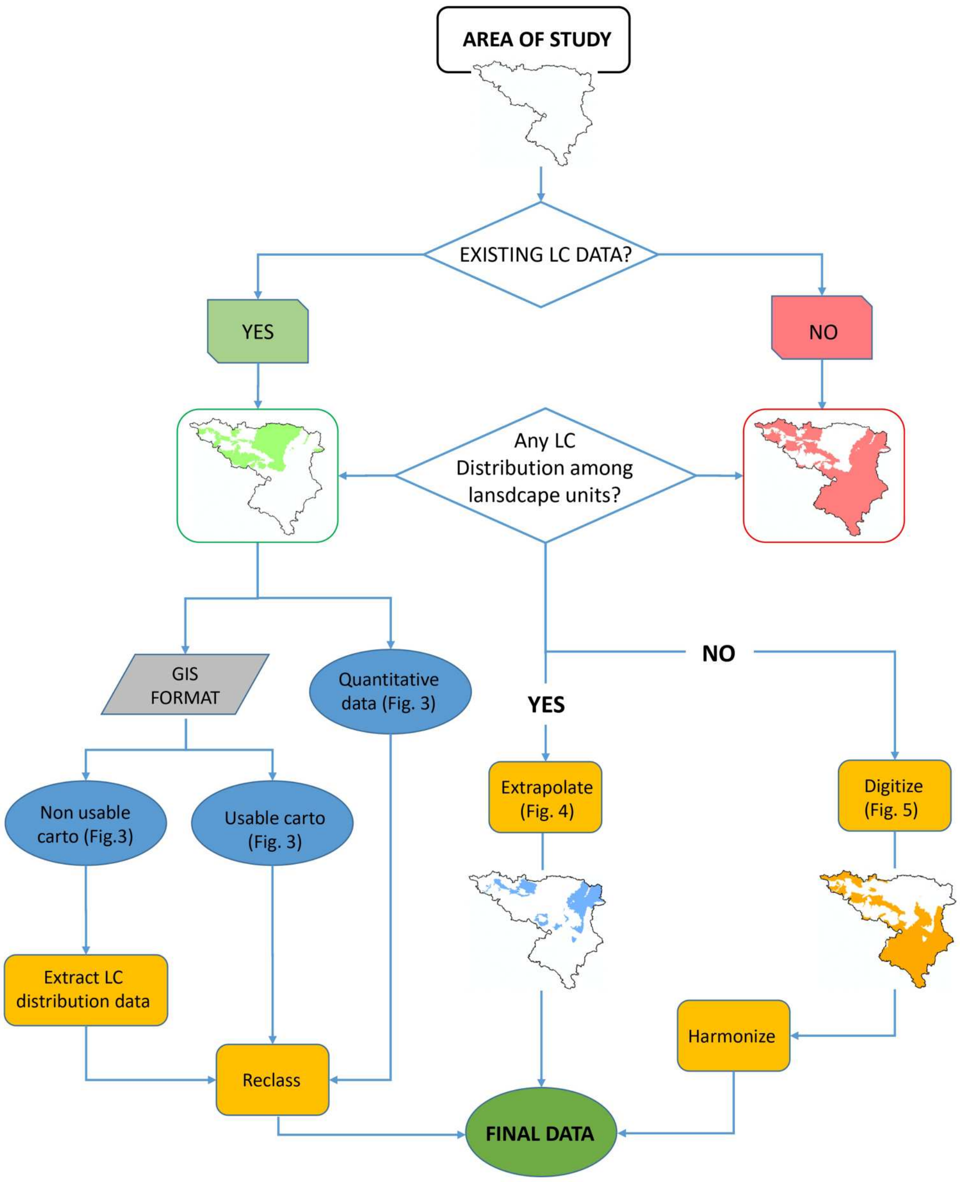

Figure 2. LC reconstruction workflow process.

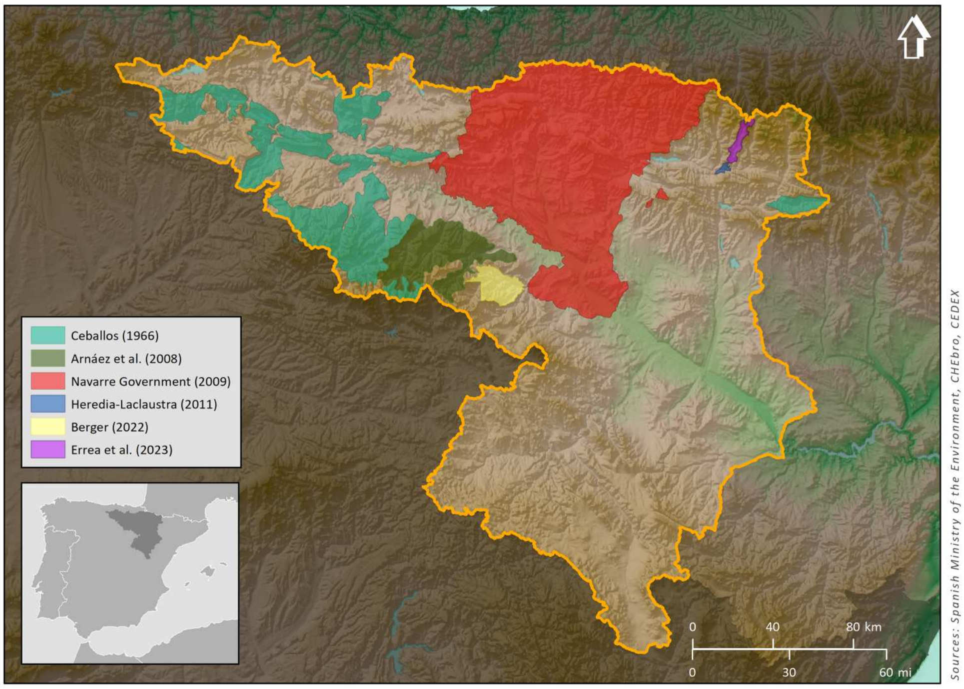

Figure 3. Available LC cartography and quantitative data directly used.

The area where it has not been considered appropriate to apply this method has been photo-interpreted and digitized manually by the work team, which means a total area of 26,849 km^2 and 52.2% of the study area (Figure 5). This task has been carried out by the authors using Geographic Information Systems (GIS). The polygons have been drawn at an approximate scale of 1:10,000, using the orthophoto generated from the American Flight photograms. This scale has been upscaled in those classes that play a crucial role in sediment production and transport, such as bare soil, and active channel. As well, the minimum mapped area has generally been 20 ha for vegetation cover, with greater detail for the rest, as this has a greater effect on river morphology. To ensure consistency across trained team members, a set of interpretation guidelines was developed, and collaborative review sessions were held to harmonize

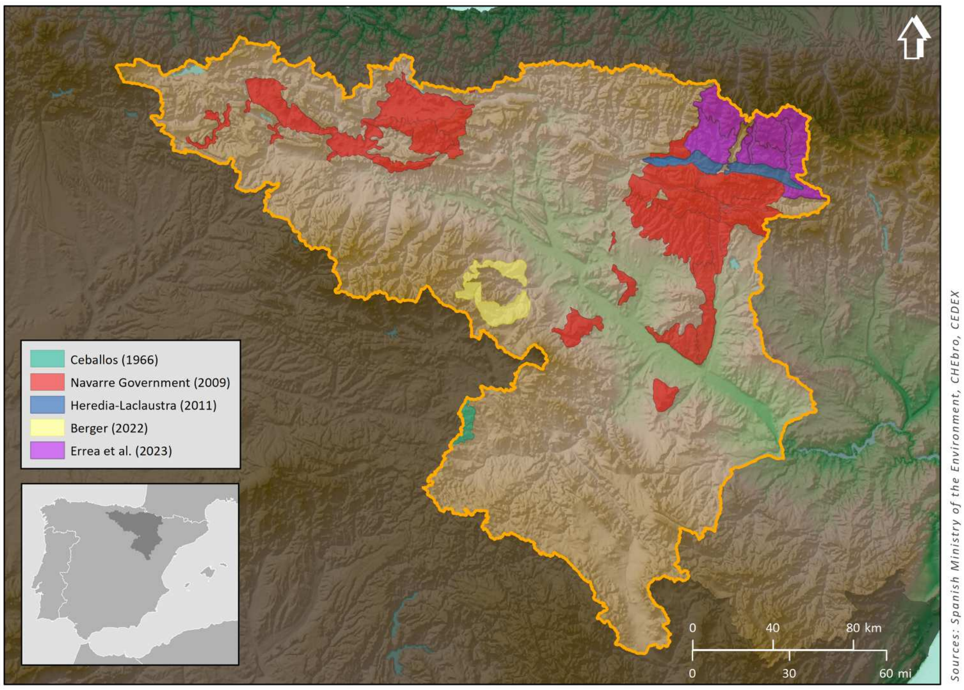

Figure 4. Extrapolated LC cartography and quantitative data from other sources differentiated according to the used one.

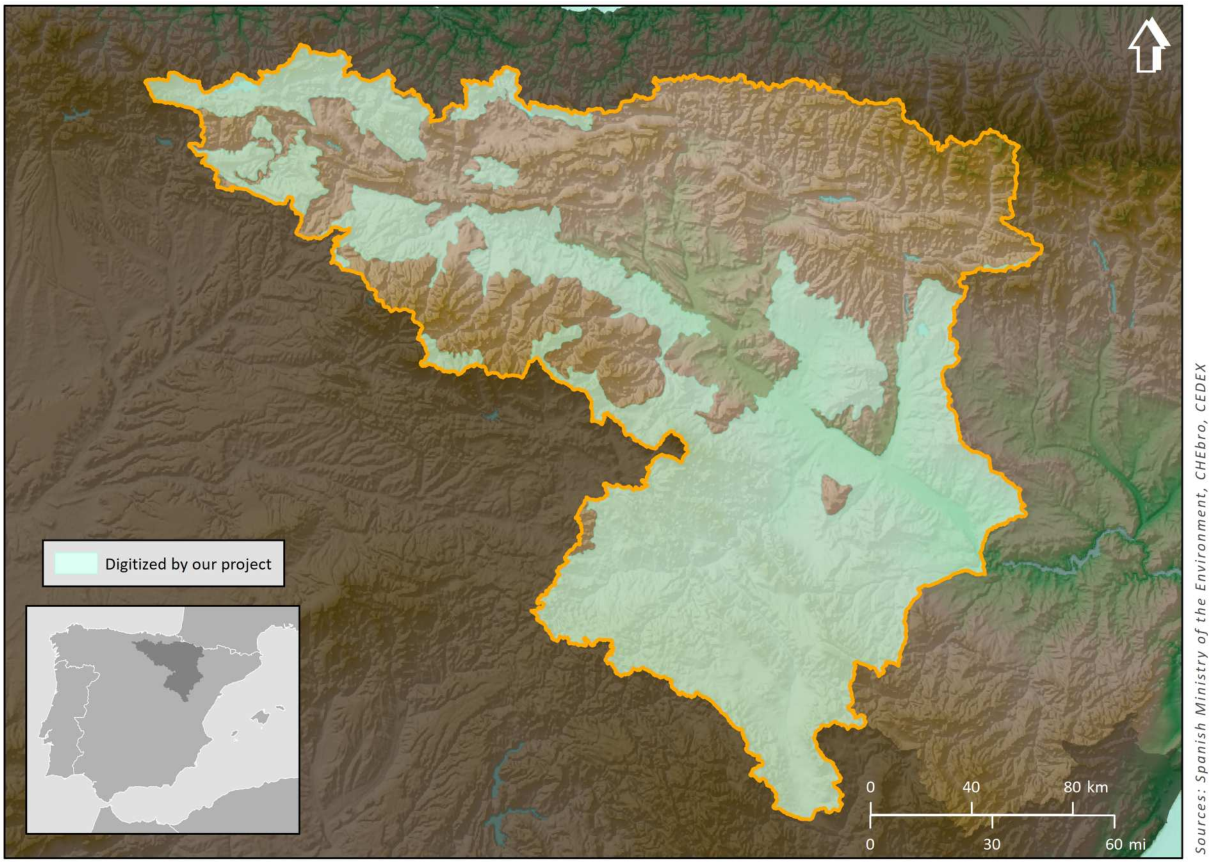

Figure 5. Digitized LC cartography by the project.

criteria and resolve discrepancies. When available, auxiliary data sources – such as LU/LC maps from different dates, their corresponding aerial photos, and complementary geographic information, for example infrastructure networks – were also consulted.

Thus, of the 189 units identified, we have LC distribution mapping for 121 units (32,836.74 km^2), 101 digitized and 20 units from the previously existing cartography, 26 with LC quantitative data and the remaining 42 units have been extrapolated.

3. Results

The use of previously prepared cartographic sources, the extrapolation of LC surface in areas with similar LC distribution from existing cartography or data, and digitization has made it possible to obtain a distribution of LC for the whole study area. Therefore, part of this distribution also has a detailed cartographic representation and in other cases, it is limited to the percentage distribution of LC based in the landscape unit as geographic division unit (see Main maps 1, 2 & 3 in Supplementary Material).

3.1. Cartography and data of land cover

71.7% of the surface of the study area is covered by LC mapping, either obtained from previous sources or digitized (see Main map 1 in Suplementary Material). 19.5% of the mapped area was obtained from the existing maps and 52.2% of the study area was digitized manually. This digitization covers with greater coverage the right bank of the Ebro, the most southeastern area (Jalón and Huerva basins) the upper basin, as well as the left bank of the Gállego and part of the lower basin of the Arba.

10.8% of the study area has LC unmapped data coming from Ceballos (1966), 22 landscape units mainly for the upper Ebro basin, and from Arnáez et al. (2008), which includes the Iregua, Leza, Jubera and Cidacos valleys, coincides with the boundaries of 4 landscape units.

17.5% of the catchment area has been extrapolated from previously available mapping sources (42 landscape units), based on the similarity of the landscape units and expert criteria through visual recognition of each of them. The extrapolation was in this way: 29 landscape units of the sub-Atlantic nature, the Pre-Pyrenees and Pyrenees extrapolated from similar landscape units with cartography of Navarre (2009); 2 landscape units of the high Soria countryside, south-western of the study area, extrapolated from similar landscape units from LC data of Ceballos (1966); 8 landscape units reconstructed from Errea et al. (2023) work in areas of high and medium mountain environments of the Pyrenean valleys; 1 landscape unit of the Berdún Canal reconstructed from the LC distribution of part of it based on Heredia-Laclaustra (2011); 2 adjacent landscape units of the Iberian Range reconstructed from Berger (2022).

3.2. Land cover distribution

The mapping and distribution of land cover data obtained for the mid-twentieth century show that half of the Ebro basin was covered by crops (48.9%), followed by shrubs (24.6%) and forest with almost a fifth of surface (Table 2, Main maps 1, 2 & 3 in Suplementary Material).

This distribution changes depending on the specific site within the study area, as it shows the different LC distribution in the charts corresponding to each extrapolation unit (Main map 2 & 3 in Suplementary Material). The Ebro basin has a very high diversity of landscapes, according to the very different environmental conditions in a transition area among more Atlantic environments on the northwestern part to Mediterranean of the east, high mountains of the Pyrenees in the north, continental of the south and semi-arid environments on the Ebro Depression. We see this diversity in the different landscape images that characterize some of the landscape units for which we have LC distribution (Main map 4 in Supplementary Material). Each of these images correspond to the units with LC distribution charts of Main map 2 in Suplementary Material, with letters as corresponding reference.

4. Discussion and conclusion

This reconstruction provides an LC distribution, georeferenced in a wide part, which is very useful to analyze historical conditions and evolutionary analysis from different perspectives. Digitization of land cover from orthophotography is the closest approximation to reality but also a high time/human resources consuming task (Mboga et al., 2020), especially in large areas (Forster, 2006), and challenging having a homogenized result when different people take part in the process. Potential use of automatic or semi-automatic classification methods was initially proposed. There are specific cases of black and white aerial image applications with promising results on land cover classification based on texture (Caridade et al., 2008). However, the large surface of the study area, the different quality condition of the historical photograms forming the orthophoto (overexposure, blurring, darkness), the relatively extensive legend and the high diversity of geographical environments (high mountains, Atlantic, Mediterranean, semi-arid) made it difficult even the photointerpretation.

Homogenizing thematic land cover data is crucial but it requires careful attention to detail to minimize errors and maintain consistency across datasets due to different spatial resolutions, different legends and proposals of the classifications (Di Gregorio & Jansen, 2000). In our case, the availability of an orthophotography of the same date for the whole area allowed us to guarantee the consistency of the meaning of each category.

The estimated surface, although without spatial reference, gives information of LC distribution for areas that can be used for comparative works. This method has also some limitations and uncertainties associated with the dataset: e.g. the availability of cartography/data sources to apply the extrapolation method or the diversity of the legends. However, the result gives a good approximation of LC reconstruction and to compare with current LC.

Table 2. Distribution of LU/LC in 1956-57 in the whole study area.

Class	Surface (km^2)	%
Active channel	208.2	0.42
Forest	8535.3	17.27
Shrub	12,163.4	24.61
Grassland-herbaceous	2900.1	5.87
Bare soil	991.2	2.01
Crop	24,187.1	48.93
Artificial	318.6	0.64
Impounded water	126.1	0.26
Total	**49,430.0**	**100**

Software

The digitalization of the different land cover classes as well as the map compositions have been carried out using the ESRI's platform software ArcGis Desktop and ArcGis Pro.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The data that support the results of the map series are available from the corresponding author on reasonable request.

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Annex 1. Reclassification of the categories from the cartographic sources used (1956–1957).

Map of crops and uses of Navarre	Original source category (code)				Reclassification category
	Ceballos (1966)	Errea et al. (2023)	Berger (2022)	Heredia-Laclaustra (2011)	
Water		Water courses	Active channel	Sparse vegetation	Active channel
Beeches	Poplar trees	Forest	Forest	Coniferous forest	Forest
Oaks	*Fagus sylvatica*	Forest and shrubs		Hardwood forest	
Holm oaks	*Pinus halepensis* afforested	Forest, shrubs and pastures		Mixed forest	
Riparian vegetation	*Pinus nigra* (=laricio)			Coniferous forest and shrubs	
Reforestation hardwood	Afforested *Pinus nigra*			Hardwood forest and shrubs	
Other hardwood and mixtures	*Pinus pinaster*	Forest and shrubs		Abandoned fields with tree presence	
Scots pine and white spruce	Afforested *Pinus nigra*				
Black pine	Afforested *Pinus pinaster*				
Reforestation coniferous	Afforested *Pinus radiata*				
Coniferous/Hardwood	*Pinus sylvestris*				
	Afforested *Pinus sylvestris*				
	Pinus uncinata	Forest, shrubs and pastures			
	Quercus faginea (=*lusitanica*)				
	Quercus ilex				
	Quercus petraea (=*sessiliflora*)				
	Quercus pyrenaica (=tozza)				
	Quercus robur (=*pedunculata*)				
Shrubs	Shrubs	Shrubs	Sparse shrubs	Shrubs and coniferous forest	Shrub
		Shrubs, pasture and forest		Shrubs	
		Shrubs, pasture and forest		Abandoned fields with Shrubs	
				Sparse vegetation	
Pastures		Pasture	Pastures	Shrubs and coniferous forest	Grassland-herbaceous
High mountain pastures		High mountain pastures		Shrubs	
High mountain pastures		Pastures and shrubs			
		Pasture, shrubs and Forest			
Outcrops		Bare soil and pasture		Sparse vegetation	Bare soil
	Crops	Agricultural area	Crops	Rainfed arable crops mosaic	Crop
				Mosaic of irrigated arable and woody crops	
Urban		Urban area	Urban areas	Urban and infrastructures	Artificial
		Road network			
Water	Water				Impounded water