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Saline wetlands fate in inland deserts: an example of eighty years decline from Monegros, Spain

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ABSTRACT

Wetlands inventory is one of the goals of conservation plans on a national and a global scale. Inventories are needed for long-term monitoring or for identifying lost wetlands and those where restoration is feasible. In this article we present an updated inventory of the saline wetlands of Southern Monegros, Spain. We depict the evolution of these saline wetlands, locally named 'saladas' with a unique long term retrospective study based on aerial photographs from 1927. Their inventory has been accomplished through a map analysis based on a GIS using aerial photographs and orthophotographs, topographic maps, unpublished local studies, and field surveys. Remaining vegetation, changes in soil moisture and colour, and geomorphology have been the key features in identifying the saladas. Their changes in number, size and shape have been driven by human pressure, the main modifier of landscape in the last 80 years. The information gathered will contribute to the awareness of stakeholders and decision makers for their conservation as natural resources. Moreover, our large retrospective approach is a consistent base from which to propose the inclusion of the saladas of Monegros in the Ramsar List of Wetlands of International Importance.

KEYWORDS: photointerpretation; salinity; halophytes; landscape evolution; Natura 2000.

INTRODUCTION

Arid wetlands fate: values and threats

The wise use of wetlands is advocated by the Ramsar Convention (Ramsar Convention Secretariat, 2006), through national initiatives and international cooperation, like Medwet (http://www.medwet.org) or GlobWetland projects (www.globwetland.org). The Convention highlights the interest of wetland inventories in order to design policies and measures for their conservation and wise use, and establishes the List of Wetlands of International Importance on the basis of ecological, biological, limnological and hydrological criteria. Worldwide, around 50% of wetlands have been converted and lost during the 20th century (Dahl and Johnson, 1991; Davis and Froend, 1999; Tiner, 2002), mainly by agricultural intensification (OECD, 1996), and the remaining wetlands also face further changes and destructions. Avoiding or minimizing wetlands lost requires suitable information and primarily an up-to-date inventory for their effective management.

The arid and semiarid areas contain some of the world's largest rivers and important wetlands though this is not reflected in their knowledge and conservation (Jolly *et al.,* 2008). Many arid lands are unpopulated or located in developing countries, they are poorly mapped (Finlayson *et al.,* 1999) and little or no information about them is available. The frequent lack of cadastral information is associated to the low agricultural value of these lands, and their scorn by the traditional rural society.

Continental dry areas host unique geomorphological processes producing a great variety of desert wetlands (Thomas, 2000). The new focus on dry lands by the United States and international environmental programs (Reynolds *et al.,* 2007) supports the consideration of playa-lakes as hot-spots for nature conservation. Spain is the only European country containing inland saline wetlands. They are frequently small, ephemeral, and non-vegetated, with local importance based on hydrological, chemical, biological and ecological properties (Montes and Bifani, 1991). The saline wetlands scattered across the desert of Monegros, NE Spain, have attracted attention from scientists and environmental authorities because of the rarity and isolation of these habitats. Their uniqueness depends on their biogeographic setting, hosting endemisms, extremophile microbes and invertebrates, as well as plants included in the Habitats Directive (Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora), the cornerstone of Europe's nature conservation policy.

Arid wetlands delineation and inventory

The available techniques for the study and monitoring of wetlands in humid countries are barely useful for arid zones, as reviewed by Tooth and McCarthy (2007). Inland wetlands in arid areas are complex and very changeable environments due to their irregular dry-wetting cycles and require specific delineation protocols (Lichvar *et al.,* 2004; 2006; 2008). Distinguishing their boundaries in the field is particularly difficult (Pressey and Adam, 1995), and field surveys guided by aerial photographs from different dates are advisable tools for wetland delineation. The development of GIS makes the task of gathering information and producing inventories easier.

As examples of wetland inventories in arid zones, the U.S. Fish and Wildlife Service classifies isolated playas and salt flats (Tiner *et al.,* 2002), and the U.S. Environmental Protection Agency (2010) has included them in its system of classification of wetlands used in the National Wetlands Inventory (Cowardin and Golet, 1995). Endorheic systems have been added to the South African National Wetland Inventory (Dini *et al.,* 1998) in recognition of the significant ecological role played by pan ecosystems in southern Africa. Wetlands which can be dry for decades are included in the functional classification of wetland types of the Northern Territory of Australia for their recognition at the local, national and international level (Duguid *et al.,* 2002).

Earth observation (EO) technologies are well suited for updating the inventories needed for wetland management (Davidson and Finlayson, 2007; Mackay *et al.,* 2009), reducing expensive and time consuming field work. As most inland saline wetlands are in cloud-free regions, historical archives of satellite images, mainly from the continuous Landsat programs, are a primary source of data. Their main practical shortcoming for historical reconstructions is the EO existence only for the last decades. On the basis of aerial photography, our study makes available the largest observation time-lag of inland saline playa-lakes in dry regions, as illustrated by the applications compiled in Table I. Moreover, satellite imagery can have spatial limitations to separate wetlands (Ozesmi and Bauer, 2002) compared to the detailed information of aerial photography.

[Table I]

In this sense, the first inventory of the Monegros saline wetlands (Castañeda *et al.*, 2005a) was limited to some degree by the spatial resolution of the available images. At present, the ongoing irrigation works and the resulting change in the wetlands hydric regime threaten the present saline habitats, as stressed by Castañeda and Herrero (2008), and may well result in the disappearance of a unique set of saline wetlands in Western Europe. Their inventory, retrospective study, and knowledge of the evolutionary trends are keystones for maintaining the equilibrium between agriculture and environmental protection. For this purpose, the integration of aerial photographs from different dates, together with topographic maps and field observations, are crucial.

Hypothesis and aim of this research

The saladas of Monegros are an example of habitats traditionally scorned by the local population and the decision makers, as shown by our historical reconstruction. This frequent situation around the world is illustrated by the irrigation of Monegros, intended in 1915 as a way to overcome hunger, without considering saladas conservation. In the 1990's, some saladas and surrounding lands were excluded from irrigation after the blockage of European Union funds because of the pressure of scientists and ecology activists. Now, the challenge is to preserve the hydrological regime in the protected saladas, in spite of the new irrigation schemes, avoiding the false positive effect of supplanting the natural saline habitats by an artificial more "green" landscape.

The aim of this article is to give an integrated overview of these saline wetlands explaining the present landscape components by means of historical milestones. For this purpose, we establish two partial objectives: (i) historical reconstruction and updating of the inventory of saladas, and (ii) identification and assessment of spatial-temporal changes from 1927 until now. Our main tools are photointerpretation and GIS to analyze the landscape components and to obtain maps illustrating the landscape changes.

STUDY AREA

Setting

The saline wetlands, or saladas, are scattered across the desert of Monegros, NE Spain. They form a constellation of endorheic depressions developed on a Tertiary structural platform in the center of the Ebro valley (Figure 1), between 320 and 417 m above sea level. The continental Mediterranean climate is the most arid in the valley (Herrero and Snyder, 1997), with 350 mm of mean annual precipitation in the last 20 years. Rain is irregular both interannually and seasonally, with maximums in spring and autumn, and minimums in summer and winter. The mean annual reference evapotranspiration (ET_0), calculated using the FAO Blaney-Cridley method by Martínez-Cob *et al.* (1998), is 1183 mm. The dry NW wind, very frequent during the winter, contributes to the water deficit.

[Figure 1]

The geology of Monegros is characterized by horizontal Miocene strata of alternating limestone, gyprock and lutites. The carving of these horizontal strata by karstification and aeolian erosion results in a landscape with flat-bottomed valleys (local name 'val', plural form 'vales') and closed depressions hosting the saladas. They behave as groundwater discharge areas, but infiltration processes cannot be ruled out due to the brine's density (García-Vera, 1996). Clay and silt-sized Quaternary sediments at the floor of the saladas can reach several meters in depth, and contain gypsum and more soluble salts.

No soil survey of the saladas is available. The cultivated soils are poor in organic matter and not saline except in the vicinity of the saladas, where salinity can reach 30 dS m^{-1} (Castañeda *et al.,* 2010); their depth ranges from 30 to > 125 cm. Soil depth has been managed by the use of heavy machinery; boulders brought to the surface are stocked in piles, and more recently dumped in the escarpments and at the saladas floor of the saladas, or sometimes crushed on site. Soils at the floor of the saladas are very saline, with few or no stones, and rich in organic matter, because of the accumulation of insect, pollen, and algae remains together with extremophile microbes.

González (2002) distinguishes two kinds of saline wetlands depending on their hydrological regime: 'clotas' or round depressions that are occasionally cultivated, and playa-lakes that are temporarily brine-flooded. These flat-bottomed temporary lakes, which are bigger than clotas, are often covered by algal-microbial mats and salt efflorescences. In this article we use the generic term 'salada' and the specific terms 'lakes' and 'clotas' (Castañeda, 2002); particular terms found in the topographic maps and photomaps are also incorporated and discussed.

The interest of natural vegetation, today restricted to the escarpments and the floors of saladas, was stressed by Braun-Blanquet and Bolòs (1958) and by Molero *et al.* (1989), among others. The wet and saline floors of clotas are dominated by *Arthrocnemum macrostachyum* and *Suaeda vera*, arranged in bands related to topography, soil composition, and moisture; they are bare in the often-flooded saline lakes (pans, mudflats). The escarpments, which are lighter in color, bear gypsophilous plants.

Landscape

Dryland agriculture is the outstanding feature of the Monegros landscape, a broad plain with smooth undulations, depressions and vales with longitudinal slopes between 2% and 5%. The growth of winter cereal in the plain —barley and durum—, plus the saladas' hydric regime and the associated facies (Castañeda *et al.,* 2005b), results in a distinct seasonality marked by drastic changes of landscape color, mainly between spring and summer.

New irrigation districts have been developed on these dry lands, and works for others are in progress. Since the mid-1990s, pressurized irrigation in the north of our study area has maintained alfalfa, corn, and other irrigated crops, allowing for new agro-industries around the urban area of Bujaraloz. Intensive farms and alfalfa dehydration factories are very conspicuous buildings in this horizontal landscape.

The grain-growing dry steppe is characterized by light colors because of the abundance of gypsum and calcium carbonate, and the low contents of soil organic matter. Trees are absent, but idle and scrub lands are frequent, interspersed with small, isolated dry stone buildings or 'mases'. Most of them are ruined, but are now considered important for the survival of protected birds.

The landscape color and patterns changed between the introduction of agricultural machinery in the mid-20th century and the land systematization prior to irrigation. Many saladas were invaded by cultivation, and much land was plowed and leveled. For years, the floors and escarpments of saladas have been used for stone dumping, and the new linear infrastructures are producing more modifications.

Plot merging and leveling for irrigation, plus other work on pipe networks, drainage ditches, pumping stations and minor service roads, modify the relief. This fact, plus the return flows from irrigation, may lead to the disappearance of the protected halophytes, with a false positive effect of increasing biomass and birds, as has already happened at Lake Sariñena, 30 km to the north of our study area.

MATERIAL AND METHODS

Material

For recognizing, drawing and inventorying saladas, we used topographic maps, aerial photographs and orthophotographs, unpublished documents, and data bases from previous studies referenced in Castañeda (2002, page 33).

The main documents were: (i) the 1927, 1929, 1950, 1952, and 2004 editions of the sheets 413-Gelsa and 414-Bujaraloz of the National Topographic Map of Spain at a scale of 1:50 000; (ii) black and white photomaps from the 1927 flight by the Ebro Basin Water Authority (the Confederación Hidrográfica del Ebro, or CHE); contact prints from flight B from 1956 and 1957 by the US Air Force; and from the photogrammetric flight of the Instituto Geográfico Nacional between 1981 and 1984; (iii) color orthophotographs from the 2006 flight by the National Aerial Orthophotography Plan (PNOA, by its Spanish name). Moreover, photographs from the 'Interministerial Flight' (1977-1979), even though incomplete for our study area, allowed some verification.

The 1927 flight was intended to cover all lands dominated by the projected irrigation canal network distributing irrigation water from the dams due to be built in the Pyrenean rivers to the mouth of the River Ebro into the Mediterranean. The Ebro Basin Water Authority contracted the flight and the related works to the Compañía Española de Trabajos Fotogramétricos Aéreos (CETFA) in one of the earliest non-military applications of aerial pictures. CETFA used a Zeiss 24 × 30 cm camera with a focal distance of 50 cm flying at 2500 m elevation, each shot covering 1 km^2. Tilt was corrected with a restitution instrument. The contact prints and negatives are not available, only the photomaps at a scale of 1:10 000, digitized by CHE.

The 1956-57 aerial photographs were taken by the US Air Forces flying over Spain. Each sheet of the National Topographic Map (about 500 km^2) is covered by 4 or 5 tracks with 12-19 photographs each; the scale of the contact prints is about 1:33 000.

The 1981-1984 flight at a scale of 1:30 000 was intended to produce a map of crops and land use for Spain. Each sheet of the National Topographic Map is covered by 4 or 5 tracks with 12 to 14 photographs each. Most photographs of our study area were taken in 1981, except for the 413 sheet.

The orthophotographs by the PNOA at a scale of 1:30 000 were taken with a differential GPS, obtaining digital orthophotographs with a 0.5 m pixel and 2 m altimetric accuracy (Arozarena and Villa, 2004).

We used as a reference the saladas' inventory of Balsa *et al.* (1991) and their location sketch. We also used the georeferenced database of the saladas' vegetation (Domínguez *et al.,* 2006) at scales from 1:2000 to 1:6000.

Technical procedures

We used a digital mosaic georeferenced at the University of Lérida from 46 photomaps from 1927. Fixing the deformations detected in the 1927 photomaps was possible during the georeferencing process thanks to the short range of elevations (from 320 to 417 m above sea level) in the platform hosting the saladas.

The 44 contact prints from the 1957 USAF flight at a scale of 1:33 000 were scanned with 800 dpi resolution and georeferenced maintaining their original dimensions. The smaller saladas are represented by a minimum of 4 pixels. We produced digital copies with a 1 m pixel as a compromise to avoid both information losses and inflating the data processing. For each contact print, we used from 6 to 12 control points for georeferencing on the PNOA orthophotograph. The technical parameters for orthorectification were not available; fiducial marks were never visible, and often the same applies to the flight altitude; only the flight direction was used. A second degree polynomial was applied to achieve an allowable adjustment correcting the linear patters of the scanner; resampling was done using the nearest-neighbor technique.

The 46 digital photographs from 1981-1984 were georeferenced on the PNOA orthophotographs with more than 20 control points in each photograph.

The georeferenced mosaics of the photomaps from 1927, the photographs from 1957 and 1981, and the PNOA orthophotographs from 2006, were photointerpreted on screen. This interpretation was based on geometric criteria, plus image texture, grey level, and color.

The geometric criteria were shapes clearly associable with saladas, in general elongated (playa-lakes) or subcircular (clotas or hoyas), and aligned with a preferred NW-SE orientation. The minimum accepted map delineation is one that allows the detection of small saladas in the cartographic documents, working with a scale better than 1:30 000. The main textural criteria were the occurrence of natural vegetation on escarpments and floors, and the dumping of boulders. The color or tonal criteria give an account of the occurrence of salt efflorescences and soil moisture in changing irregular surface patches of variable extent and shape. Only the PNOA orthophotographs contain chromatic information.

These observations were checked and completed by photointerpretation of stereoscopic pairs of contact prints from 1957. The sketch by Balsa *et al.* (1991) made it possible to locate in the mosaics of 1957 and 1927 those saladas that cannot be seen in the most recent orthophotograph. The delimitation of saladas derived from the vegetation data base of Domínguez *et al.* (2006) has been used to draw a reference map on the PNOA orthophotograph.

The presence of 'old' saladas in the PNOA orthophotographs has been checked, also using field observations on the occurrence of halophytic vegetation, geomorphic features such as depressions or escarpments, or color changes at the soil surface.

A geodatabase has been created incorporating the toponymy from historical and present sources and inventories. We assign to each salada the name given in Balsa *et al.* (1991); if this author did not name or recognize a salada, we use the name of a nearby site, well or road appearing on the oldest available photomap or topographic map.

Each of the four resulting maps is one layer of the geodatabase. These layers are arbitrarily named M1927A, M1957A, M1984A, and M2006A, because updating can be foreseen if better photograms from the same or other flights become available, or documents from any other source are exhumed. Those saladas detected at one date but not at another later date are qualified as having disappeared between these two dates, while those not detected at one date but detected at some later date are qualified as recovered. Of course, these qualifiers can change if new cartographic documents or other information become available.

RESULTS AND DISCUSSION

The saladas in 1927, 1957, 1984, and 2006

The detailed information and planimetry provided by the aerial photographs have been invaluable for the retrospective study of saladas and their surrounding landscape. The studied dates are good bench marks for relevant landscape changes: the year 1927 was prior to agricultural mechanization; 1957 was at the end of the famine following the Spanish Civil War (1936-39) and the beginning of agricultural mechanization; the years 1984 to 2006 display the changes associated with agricultural intensification, the Common Agricultural Policy (CAP), and the introduction of irrigation.

From the four maps of saladas, M1927A contains 136 saladas; M1957A contains 115; M1984A contains 101; and M2006A contains 96 saladas, the lowest number from the four dates. It must be stressed that the most recent inventory is the most detailed because of the possibility of checking in the field, the available vegetation map (Domínguez *et al.,* 2006), and the color and resolution of the orthophotographs from 2006. The total number of different detected saladas is 140, including those coincident and those exclusive to each date.

The quality of the cartographic documents hampered recognition of shapes and textures denoting saladas. Delineation was conditioned by the differences in scales and the geometric deformations of the historical cartographic documents, mainly in those from 1927 and 1957; for this reason, the saladas' borders on the four layers (M1927A, M1957A, M1984A, and M2006A) cannot be used for the automatic measuring of changes in extension. This kind of problem in comparing flights from different times has been pointed out by other authors (Cardenal *et al.,* 2008), even for more recent documents or aerial photographs.

Layer M2006A contains 88 of the 99 saladas inventoried by Balsa *et al.* (1991); the difference may be due to the disappearance of some of them but also to the field recognition criteria. The textural and grey level criteria plus the toponymy found in the photomaps from 1927 produced layer M1927A. Of the 136 saladas of this layer, 82 are coincident with the saladas of Balsa *et al.* (1991); of the remaining 54, only 16 were not recognized at any other date. The 21 saladas recorded by these authors with the generic name 'clota', plus the 54 new saladas, have been designated with the toponym of the older document, i.e., the photomaps of 1927.

Layer M1957A results from classical photointerpretation based upon textural and tonal criteria. The 115 saladas of this layer include 78 of those inventoried by Balsa *et al.* (1991); three of these saladas —Hoya de Correo, Balsa de Gros, and Hoyo de Benamud— were not identified in M1927A. Moreover, 85 of the saladas inventoried by these authors have been recognized among the 101 saladas contained in layer M1984A.

If the four maps are compared, 11% of the saladas occur at only one date, most of them in the photomaps from 1927; 24% occur at two dates; 62% at three dates. Only 55% occur at the four dates: those of bigger size, or playa-lakes, and hoyas or clotas greater than 20 ha. Moreover, those clotas < 10 ha with closed escarpments also occur at the four dates.

Extent, shape, and confinement of saladas

The location and toponymy of the saladas were contrasted for all the sources consulted, and both ambiguities and discrepancies between sources recorded. The reference documents were the inventory and sketch by Balsa *et al.* (1991), but all the names of saladas found in the topographic maps and photomaps were incorporated into the GIS. We recorded eight different terms used to designate the saladas: balsa, clota, hoya, hoyo, laguna, saladar, salina, and pozo. These are usually accompanied by a second word which frequently refers to the owner's family name, alias or job; for this reason some of them differ between dates. The generic terms refer to the morphology and confinement of the depression (clota, hoya, hoyo), the size and occurrence of water (laguna), their use as a saltern (saladar, salina), and the proximity of a water supply (balsa, pozo), key for the survival of humans and livestock. In the map M2006A, the names of 36% of the saladas incorporate terms such as hondonada, clota, hoya, or hoyo referring to a depression, while 16% evoke the occurrence of water or salts, such as laguna or salina.

Figure 2 displays the extent of saladas grouped according to the qualifiers of Balsa *et al.* (1991), or M2006A for those not inventoried by these authors. The size ranges from 1.2 to 29.8 ha for clotas, and from 5.2 to 56.2 ha for hoyas, suggesting that these names refer more to the shape and the confinement by escarpment than to the size. Commonly, the escarpments of clotas are more abrupt and closed than in hoyas; clotas are often located in the SE of the study area, while hoyas are more common in the SW. The terms 'hoya' and 'hoyo' are used for depressions with smooth borders that are in general drier than the others. No relationship was found between the size of clotas and their geographical location or the preservation of their escarpment, but invasion by crops is more frequent at hoyos and hoyas because of the open morphology of their escarpments.

The laguna, saladar and salina types are the largest saladas, their sizes being similar in range if we exclude La Playa. While not abundant, these are the most persistent types. Many suffer degradation over time, much more often due to the dumping of boulders or debris than as a result of agricultural invasion. The terms 'pozo' (well) and 'balsa' (artificial pond), related to landscape elements close to the salada, are not represented in Figure 2.

[Figure 2]

Persistence and disappearance of saladas

The analysis of qualitative changes shows frequently alternating land uses. This fact, plus the limitations of photointerpretation due to the low quality of old documents, explains the appearance of new saladas in maps M1957A, M1984A, and M2006A (Table II).

The number of saladas that have disappeared would be, at the minimum, the difference between those detected at the earlier date and those concurrent with them at the following dates. When talking about saladas that have disappeared or recovered, it must be stated whether we are referring only to the concurrent saladas or to all the saladas detected at each date. The following two tables show both numbers. Table II displays the number of saladas detected at each date, and how many of them persist at each later date. Table III displays the recovered saladas and the net differences; all are negative and account for saladas that have disappeared.

[Table II]

[Table III]

Some saladas that appear to be plowed or cultivated at one date appear with natural vegetation at a later date. Irrespective of surface area, we qualify these saladas as recovered; if the contrary happens, we consider the salada to have disappeared.

From 1927 to 2006, at least 47 saladas were lost; 50% in 1957 and 37% since the introduction of CAP. The greatest number of saladas was detected in the photomaps from 1927 (Table II); the 16 saladas identified only in the 1927 photomaps are located mainly in the south of the study area. Of the 136 saladas detected in 1927, 111 were also seen in 1957; of these, 84 persisted in 1984, and of these 77 persisted in 2006. The number of saladas in M2006A is 29% lower than in M1927A.

Of all the time intervals under consideration, the greatest decrease in the number of saladas happened between 1927 and 1957 (Table II). Most of the saladas recognized in 1957 are coincident with those of 1927, except Hoyo de Benamud, Hoya de Correo I, Yesera I, and Balsa de Gros. These four saladas are regarded as recovered, subject to the discovery of new maps or other documents with additional information.

Between 1957 and 1984, 27 saladas disappeared, 26 of which were identified on the aerial photomaps of 1927. In 1984, 13 saladas were recovered. Hoya de Correo II was recognized for the first time in the photographs of 1984.

Even though the most intense landscape changes happened from 1984 to 2006, the number of saladas that disappeared is the lowest (Table III). Moreover, 3 saladas (Corral Nuevo I, Corral Nuevo III, and Saladar de Don Roque) that were plowed or cultivated in 1984 were recognized in 2006.

If we look at the net differences between the saladas that disappeared and recovered between the dates (Table III), the disappearance of saladas has decelerated in recent years: 21 from 1927 to 1957, 14 from 1957 to 1984, and 5 from 1984 to 2006 (Table III). These figures include the balance of disappeared and recovered saladas, such as Hoya del Correo and Balsa de Gros, which were cultivated in 1927 and recovered in 2006; or, by contrast, Hoyo de Botones, Hoyo del Lugar, or Clota del Saso, which were visible in 1927 and cultivated in 2006.

Many saladas have been lost over the 80 years covered by our study. Moreover, their identification has been difficult because of the great variability in their conservation status. In spite of the low level of agricultural mechanization during the first 30 years, the saladas were modified and their number decreased due to the strong agricultural pressure. The pressure continued in the following 50 years, increasing the cultivated surface through the elimination of natural vegetation. However, some saladas have recovered. As an illustration, in the last 20 years only 8 saladas have disappeared, and 3 were recovered, as against 25 that disappeared and 4 that recovered between 1927 and 1957. The increase in recovered saladas may be a false impression produced by the quality of the more recent documents.

Figure 3 shows an example of the change in land use between 1927 and 1957. Bare soils and brush in 1927 (Figure 3a) located among cultivated lands were broken up (Figure 3b). The increase in low-productivity cultivated surfaces preceded the disappearance of many saladas by the plowing of their escarpments, and sometimes also the floors, to earn subsidies.

Superimposing our maps on the Spanish Farming Land Geographical Information System (SIGPAC), and from the 2005-2006 alphanumerical data from the GIS for Herbaceous Crops of the Spanish Ministry of Agriculture, Fisheries and Food, we ascertained that the 31 saladas that disappeared from 1957 until 2006 formed part of 137 farming plots (belonging to 17 farming polygons) with a total surface area of 1373 ha. Of this surface, 133 ha belonged to saladas: 22 clotas, and 9 hoyos or hoyas. SIGPAC qualifies 93% of the surface of these saladas as arable land, and the remaining 7% as idle land, roads, or water bodies. About 44% of the arable surface of the saladas was fallow in 2005-2006; 34% is of unknown use; and 11% is cultivated with durum or barley. Set-aside is a requirement in order to earn the single CAP payment only for 4% of the surface area occupied by the 31 saladas that have disappeared. The remaining arable land (7%) is alfalfa and voluntary set-aside lands.

[Figure 3]

Landscape assessment

Historical documents note the landscape changes in Monegros, referring to the elimination of vegetal cover (De Asso, 1789). In 1927, rainfed winter cereal crops were the main landcover (Figure 4a). De los Ríos (1982) reports that on the small terraces, easily recognized in photomaps, the irregular yield becomes nil in the drier years. Both cultivated and idle lands show uniform textures and light colors in the aerial photographs, but agricultural fields can be recognized by their elongated and rectangular shapes. Fields and small roads were adapted to the gentle reliefs and to the slopes of vales, and the escarpments of clotas and hoyas remain unplowed.

Agricultural intensification in Spain started around 1950, but mechanization, the introduction of the moldboard plow, and fertilizers were late coming to Monegros (Castelló, 1984). No relevant changes in the fields' morphology or in the escarpments of saladas can be seen in 1957 (Figure 4b). Only some fields at the bottom of the vales were plowed. Other fields contain aligned points corresponding to vineyards or to trees such as olive or almond, which are now very rare in the study area.

The texture and grey level in the aerial photographs are very similar for fallow and winter cereals in Monegros. If the day of the flight is unknown we only have an idea about the general status of the landscape, but it is impossible to ascertain whether a particular field was cultivated. Figure 4b is dominated by homogeneous textures and light grey tones related to the flight date (28 July 1956) just after the harvest, finishing before 15 July in this area. Dark tones at the bottom of saladas are due to moisture. The absence of whitish spots representing salt efflorescences can be attributed to a wet season or occasional rain. The vegetation of the saladas shows an irregular mottled texture, and seems undisturbed. The roads, which are quite straight and light in tone, have not changed.

During the 1960s and 1970s the human pressure increases. The fields are more regular and bigger in extent; the relief is smoothed to gentle slopes, close to plain (Figure 4c). Heavy machinery extensively brings pieces of limestone and gyprock strata to the surface. The boulders are stocked either in piles spread in the fields, or at the borders of the fields; if a salada is close, the boulders are dumped at the floor. More recently, surface stones are crushed. Some saladas close to the urban area of Bujaraloz have disappeared, filled up with debris and earth, or their vegetation has changed from halophilous to nitrophilous under the influence of animal farm leachates or other residues.

In the 1980's the irrigation canal reached our study area. A complaint from ecological activists filed in Brussels stopped the irrigation works for 11 years and reduced to a half the surface of the study area to be irrigated. The land systematization process prior to irrigation lasted until 2005. Now the main landscape alterations come from the works for irrigation water distribution and drainage ditches (Figure 4c). Moreover, the new roads are much broader than the old ones, and make a more orthogonal network. The old network is still partially existent. Some saladas interrupt the network of field borders and roads. The surface occupied by saladas decreased (Figure 4c), and the escarpments of some saladas became vestigial. Natural vegetation is often confined to the steeper escarpments and the bottoms, where plowing is difficult. At times, moisture or low productive spots suggest a salada that has disappeared, as is the case with Hoyo del Lugar (Figure 4).

[Figure 4]

Most saladas that disappeared as a result of agricultural pressure were located at the south of the study area, where saladas were more abundant. Not all saladas have disappeared, but most of them have had their borders altered with time. Borders and floors of saladas have undergone on-and-off cultivation and abandonment because of their low profitability, even though subsidies provide incentives for plowing.

Most changes became more intense from the 1950s following the introduction of machinery for plowing more land. Many saladas disappeared after changes in relief as a result of movements of earth to merge small fields. Figure 5 shows the changes undergone by Salobral, a salada close to the urban area of Bujaraloz. Most of the natural vegetation was preserved in 1956 (Figure 5a), as shown by mottled textures in the west of the salada. The eastern escarpment still has terraces, and the salada is crossed by minor roads. The bare bottom is dry and probably has salt efflorescences. In the east of the salada field limits fade due to the monotonous grey colors; the texture in some fields could be due to vineyard or olive trees. The orthophotograph from 2006 (Figure 5b) shows evidence of major alterations. The salada is flooded by effluents from the surrounding intensive animal farm and irrigated lands, and the roads have disappeared. Dumped debris covers the natural vegetation and half the bottom.

[Figure 5]

Some outstanding changes are the direct destruction of saladas by roads and water pipes associated with the introduction of irrigation, as is the case with Hoyo Garra (Figure 6), which disappeared between 1984 and 2006. In Figure 6a the salada is surrounded by fallow and recently plowed fields of winter cereal crops. The borders of the salada are outlined by natural vegetation that is dark grey in color, while the soil is bare in the central area. Figure 6b shows the new field pattern after land systematization and the complete disappearance of the salada after the construction of the drainage ditch. The color and texture of the sprinkler-irrigated fields to the north of the ditch are very different from the rainfed fields to the south.

[Figure 6]

The inverse evolution is rare. As an example, the floor of Benamud is occupied by several cultivated fields in 1927 (Figure 7a), whereas in 2006 there is bare soil and natural vegetation (Figure 7b). The proximity to the urban area of Bujaraloz and easy access may have fueled cultivation, with subsequent abandonment because of low profitability due to soil salinity. The traces of cultivation, still visible in 1956, have disappeared by 2006, and the natural vegetation is in the process of recovering. However, other saladas not plowed in 1956, such as Hoyo Botones, are plowed in 2006 (Figure 7).

[Figure 7]

The intermittence of agricultural use and abandonment has transformed the mosaic landscape of 1927. The great diversity of textures produced by traditional agriculture, evident in aerial photographs, denotes different kinds of habitats contrasting with the homogeneity of winter cereal crops. The mosaic has been reorganized into big plots suitable for the mechanized cultivation of winter cereals. Now these plots are being put under sprinkler irrigation.

On the other hand, agriculture in Monegros has been revolutionized since the 1980s (García, 2006) by CAP subsidies permitting cultivation in spite of the low yields. This policy does not help the conservation of saladas. The artificial conditions imposed by the new irrigation schemes will drive both the landscape evolution of the arid lands of Monegros and the fate of the saladas. This semi-desertic landscape and the saladas, as unique European inland saline wetlads, deserve monitoring and inclusion in European initiatives like the Long-Term Biodiversity, Ecosystem and Awareness Research Network (Metzger *et al.,* 2010).

CONCLUSIONS

We have inventoried 140 saladas at four dates within an eighty-year span. In the earliest year, 1927, we identify 136 saladas; others have been identified in 1957, 1984, and 2006. Our map of 2006 contains 96 saladas, most of them surrounded by or very close to irrigated or irrigable lands.

The changes in land use have resulted in an increase in plowed land, changes in the cultivation patterns, and the alteration of saladas. The maximum decrease in the number of saladas happened between 1927 and 1957, due to the plowing of new land; the overall landscape morphology was unaltered however. Agricultural mechanization and intensification have been modifying the landscape since 1957, with many of the saladas' escarpments smoothed and then cultivated, as well as some bottoms. Some saladas have later been abandoned because of low profitability.

Photointerpretation allows an understanding of the landscape changes over the 80-year span studied, and provides depictions of landscape patterns and their past and present relationships with the saladas. The old photographic flights have been crucial for the retrospective study of saladas; conversely, their usefulness would be increased by restoring the film or paper support and making available the flight date. Data treatment and analysis by GIS have been key to the quantitative analysis.

Our georeferenced data base, with maps from 1927, 1957, 1984, and 2007, has allowed us to reconstruct the evolution of the landscape and its causes. This database can be enlarged with other data layers obtained by photointerpretation, and with biodiversity maps. This would provide basic information supporting the proposal for inclusion in the Ramsar list.

The acquisition of information from photographs and maps produced during an 80-year span is restricted by flaws in the conservation of the documents, differences in scale, geometric deformations, and the lack of flight data. These flaws have been admissible because our aim was more to locate, identify, and assess the conservation of saladas than to produce accurate delimitation and planimetry. However, in order to improve the accuracy and reliability of the historical inventories, we recommend the restoration of the original paper or film supports and the publication of available flight data such as the date, camera or altitude.

The four maps of saladas and their future updates will help monitoring and management. A sustained loss of these wetlands can be foreseen given the current conditions of the saladas and their location in the face of present and future irrigated lands, their infrastructures and effluents. This is the case with some saladas that are already degraded or destroyed, while low agricultural productivity and the alternation of land uses have allowed the recovery of other saladas.

Overall, in the last 25 years the landscape has changed its appearance. The dryland agricultural fields, scattered with saladas over the course of a secular equilibrium, are becoming bigger fields, often owned by agricultural companies; the backbone of this new landscape is provided by irrigation water.

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Figure captions

Figure 1. The inventory of saladas is drawn over a RGB 432 composition of an ASTER image of Monegros from 5 July 2005. Irrigated land is highlighted in red and future irrigation in blue. *This figure is available in color online at wileyonlinelibrary.com/journal/ldr.*

Figure 2. The qualifier of saladas against the decimal logarithm of their surface extent in ha.

Figure 3. Parts of sheet number 414 of the National Topographic Map, editions from 1929 (a) and 1952 (b). We enclose in a red line the area changed from brush and idle land to rainfed cereal. *This figure is available in color online at wileyonlinelibrary.com/journal/ldr.*

Figure 4. Example of landscape changes in the north, from 1927 to 2006. Photomap from 1927 (a), aerial photograph from 1957 (b), and PNOA orthophotograph from 2006 (c). *This figure is available in color online at wileyonlinelibrary.com/journal/ldr.*

Figure 5. Changes in Salobral from the 1956 aerial photograph (a) to the 2006 orthophotograph (b). *This figure is available in color online at wileyonlinelibrary.com/journal/ldr.*

Figure 6. Aerial photograph from 1981 (a) and orthophotograph from 2006 (b) showing the destruction of Hoyo Garra after the construction of a drainage ditch. Green area in (b) is under irrigation. *This figure is available in color online at wileyonlinelibrary.com/journal/ldr.*

Figure 7. Salada Benamud in 1927 (a), and 2006 (b). Yellow lines encircle cultivated or plowed saladas; red lines mark saladas with natural vegetation at the date the photograph was taken. *This figure is available in color online at wileyonlinelibrary.com/journal/ldr.*

Tables

Table I. Examples of application of remotely sensed data to the specific study of inland saline playa-lakes in dry regions.

Author	Target	Area extent (km^2)	No. of images	Date of study
Marsh and Lyon 1980	Garfield Flat, Nevada	~ 7	1 Landsat 2	1977
Schneider *et al.* 1985	Lake Chad	20000	10 Landsat MSS 16 NOAA	1972-1982
Prata 1990	Lake Eyre	10^6	28 NOAA	1984-1985
Crowley 1993	Death Valley US	500	7 AVIRIS	1990
Drake and Bryant 1994	Chott el Djerid and Tunisian playas	90 to 6000	Monthly NOAA	1985-1987
Harris 1994	Abiyata, Ethiopia	200	55 NOAA, monthly 1 Landsat MSS	1985-1991
Wadge *et al.* 1994	Chott el Djerid	6000	ERS-1	
Bryant 1996	Chott el Djerid	6000	1 Landsat TM	1986
Verdin 1996	Sahel	> 0.10	2 Landsat TM 62 NOAA	1988-1989 1988-1989
Nakayama *et al.* 1997	Aral Sea and Lake Balkhash	66500 and 18000	Landsat MSS NOAA	1970-1990
Oren and Ben-Yosef 1997	Dead Sea	1200	3 Landsat TM	1991 and 1992
Birkett 2000	Lake Chad	26500 and 900	15 NOAA 1 TOPOX/POSEIDON ERS	1993/94-1997/98
Bryant and Rainey 2002	Chott el Djerid	6000	154 NOAA, monthly	1979-2000
Schultz 2001	Owens Dry Lake, California	256	5 Landsat MSS	1977-1992
Krapivin and Phillips 2001	Aral-Caspian Sea	68000 371000	Airborne microwave sensor	1960-1985
Koch *et al.* 2003	La Mancha, Spain	36	1 ASTER 1 DAIS	2002
Mahowald *et al.* 2003	Chotts in Tunisia and Etosha Pan in Namibia	6000 and 6000	NOAA 2-4 images per month TOMS (spectrometer for ozone, UV)	1983-1992 1996-2000
Lichvar *et al.* 2004	3 playas in Edwards AF Base, California	From 5 to 114	80 Landsat	1982-2001
Roshier and Rumbachs	New South Wales and Southern	10^6	1 NOAA	1997

2004	Queensland Australia			
Schmid *et al.* 2004	La Mancha, Spain	5	1 DAIS 1 Landsat TM & ETM	2000 2000 and1987
Moghaddam and Saghafi 2006	Kahak playa, Iran	17	1 Landsat TM, 1 ETM	1988 and 2002
Bills *et al.* 2007	Salar Uyuni, Bolivia	10^4	MIRS	2001 and 2003
Ma et al. 2007	Ebinur Lake	1000	252 SPOT-VEGETATION 16 Landsat ETM 3 CBERS-1 1 CBERS-2	1998-2005
Lichvar *et al.* 2008	Buckhorn playa, California	4.4	LIDAR 30 Landsat TM	1982-2001
Goerner *et al.* 2009	Lake Beseka, Main Ethiopian Rift	40	4 Landsat 2 ASTER	1973-2002 2000-2001
Scuderi *et al.* 2010	Mexico/New Mexico	70000 and 6600	878 y 371 Landsat TM MODIS	1984-2007

MSS, Multispectral Scanner; NOAA, National Oceanic and Atmospheric Administration; AVIRIS, Airborne Visible/Infrared Imaging Spectrometer; TM, Thematic Mapper; ERS, European Remote Sensing; ASTER, Advanced Spaceborne Thermal Emission and Reflection Radiometer; DAIS, Digital Airborne; Imaging System; ETM, Enhanced Thematic Mapper; CBERS, China–Brazil Earth Resources Satellite; LIDAR, Light Detection And Ranging; MODIS, Moderate Resolution Imaging Spectroradiometer; TOMS, Total Ozone Mapping Spectrometer.

Table II. Number of saladas detected at each date, and saladas persistent between maps from different dates.

Detected saladas		**Number of persistent saladas**		
Map	**Number**	**M1957A**	**M1984A**	**M2006A**
M1927A	136	111	93	89
M1957A	115		88	84
M1984A	101			93
M2006A	96			96

Table III. Number of saladas that recovered (light grey) and disappeared (dark grey) between pairs of maps from the four dates.

	M1927A	M1957A	M1984A	M2006A
M1927A		4	8	7
M1957A	**-21**		13	12
M1984A	**-35**	**-14**		3
M2006A	**-40**	**-19**	**-5**	

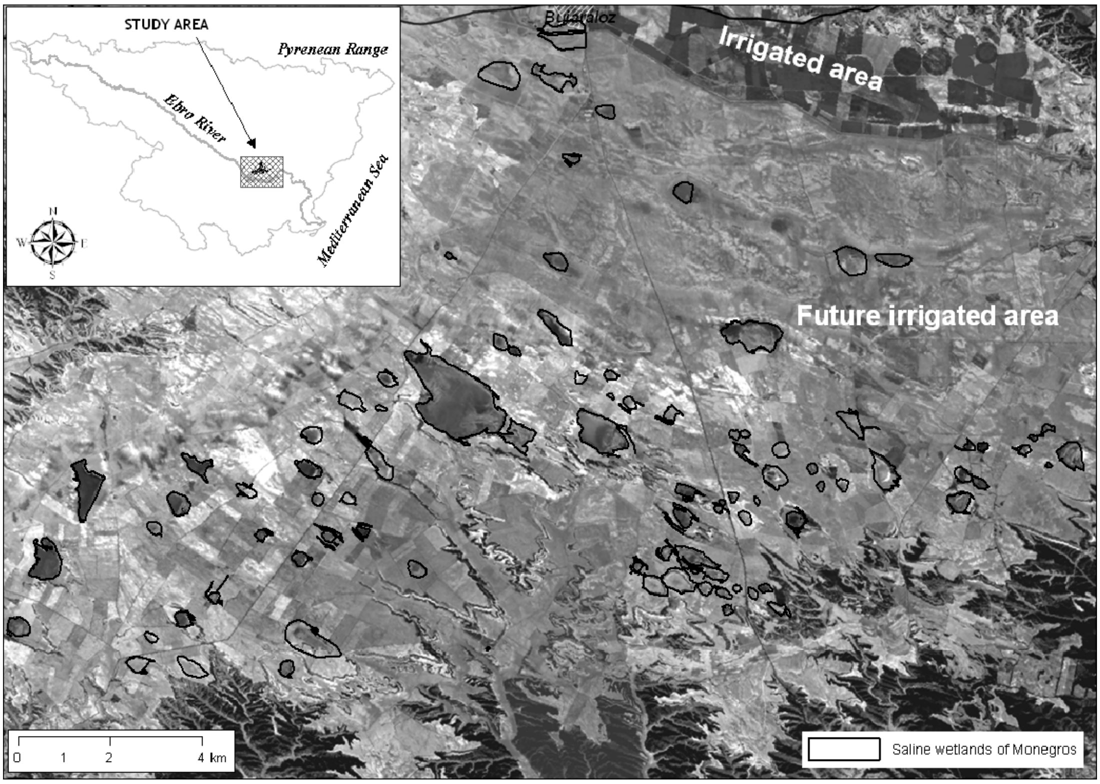

Figure 1. The inventory of saladas is drawn over a RGB 432 composition of an ASTER image of Monegros from 5 July 2005. Irrigated land is highlighted in red and future irrigation in blue. *This figure is available in color online at wileyonlinelibrary.com/journal/ldr.*

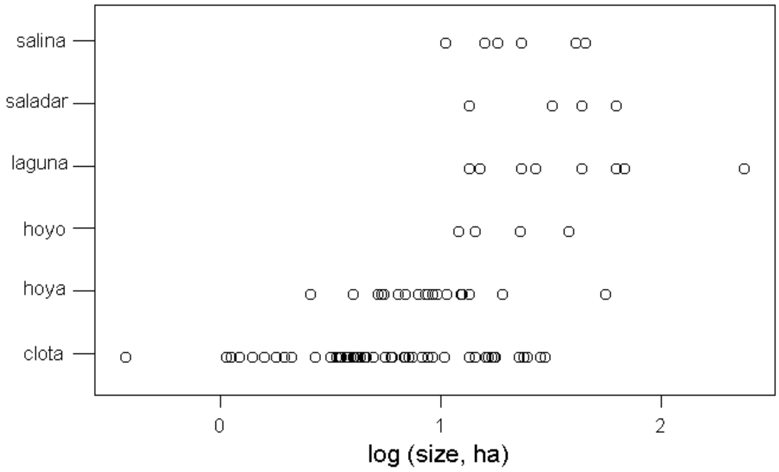

Figure 2. The qualifier of saladas against the decimal logarithm of their surface extent in ha.

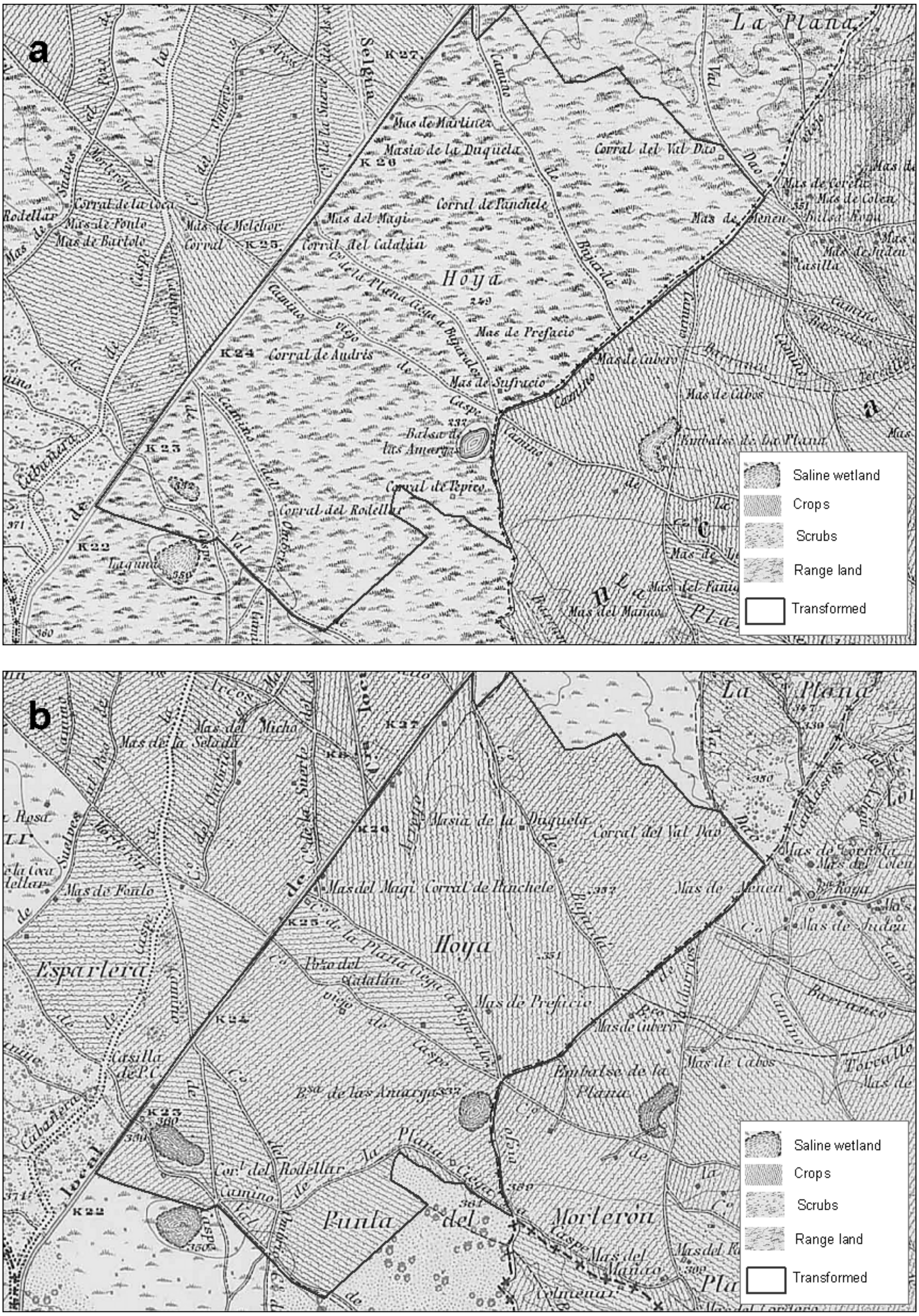

Figure 3. Parts of sheet number 414 of the National Topographic Map, editions from 1929 (a) and 1952 (b). We enclose in a red line the area changed from brush and idle land to rainfed cereal. *This figure is available in color online at wileyonlinelibrary.com/journal/ldr.*

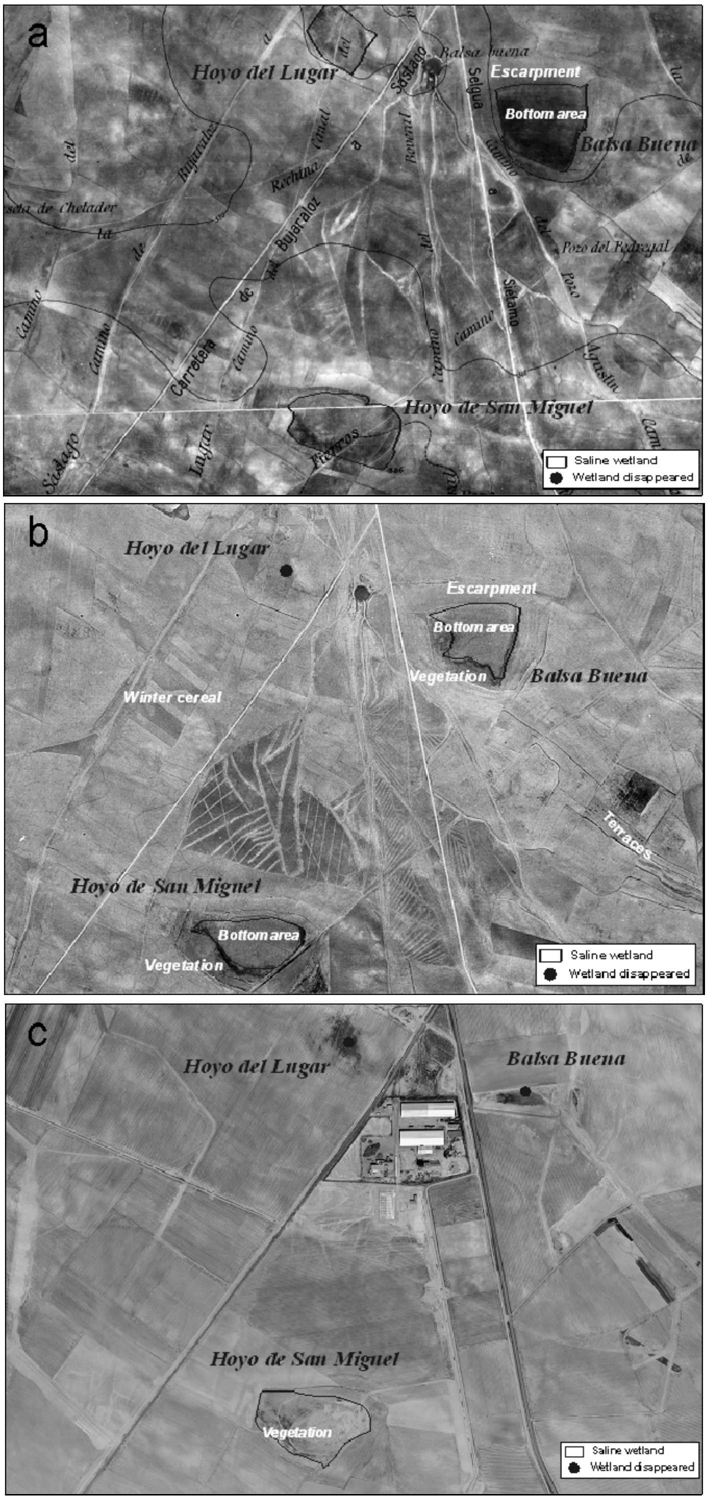

Figure 4. Example of landscape changes in the north, from 1927 to 2006. Photomap from 1927 (a), aerial photograph from 1957 (b), and PNOA orthophotograph from 2006 (c). *This figure is available in color online at wileyonlinelibrary.com/journal/ldr*.

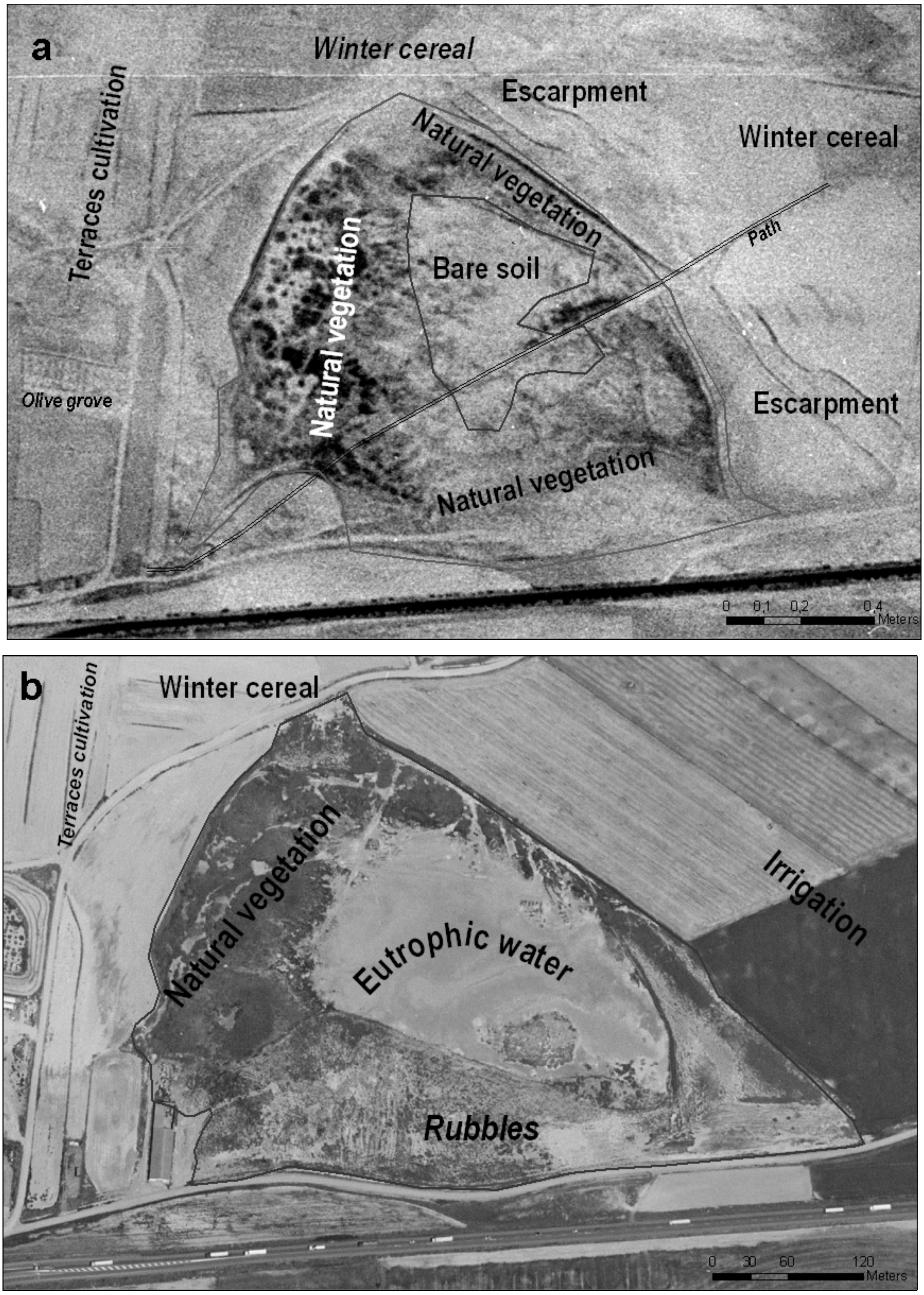

Figure 5. Changes in Salobral from the 1956 aerial photograph (a) to the 2006 orthophotograph (b). *This figure is available in color online at wileyonlinelibrary.com/journal/ldr.*

Figure 6. Aerial photograph from 1981 (a) and orthophotograph from 2006 (b) showing the destruction of Hoyo Garra after the construction of a drainage ditch. Green area in (b) is under irrigation. *This figure is available in color online at wileyonlinelibrary.com/journal/ldr*.

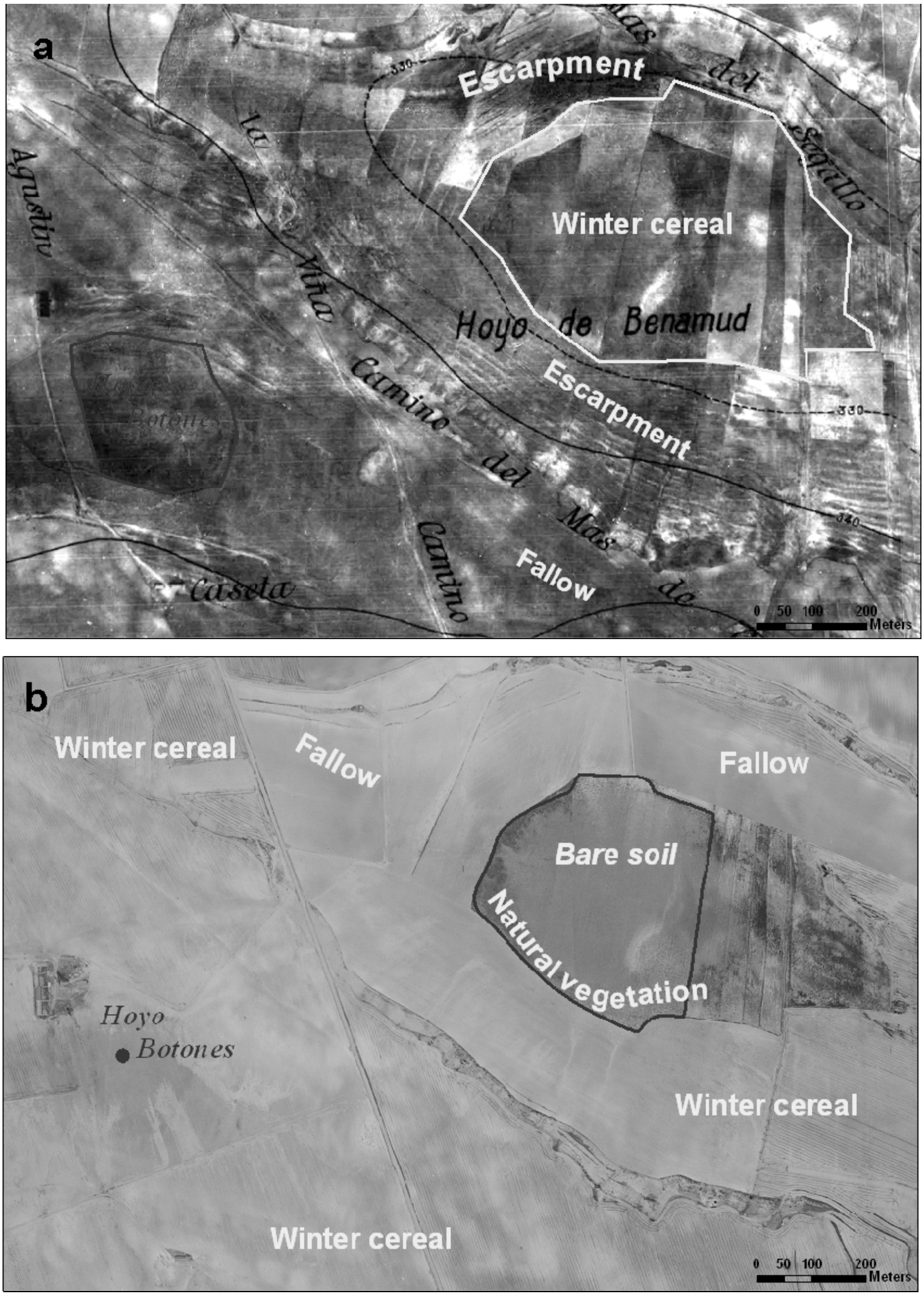

Figure 7. Salada Benamud in 1927 (a), and 2006 (b). Yellow lines encircle cultivated or plowed saladas; red lines mark saladas with natural vegetation at the date the photograph was taken. *This figure is available in color online at wileyonlinelibrary.com/journal/ldr.*