Delineation and functional status monitoring in small saline wetlands of NE Spain

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Abstract

The small playa-lakes and other saline wetlands of Monegros, scattered over a dry area with winter cereal monoculture, are threatened by the settlement of new irrigation districts and other kinds of human pressure. Enforcing the protection rules of European Union in these valuable habitats requires, first, their delimitation and monitoring. This article shows how these tasks can be undertaken using remote sensing in conjunction with field observations. A series of Landsat images covering different seasons provided a comprehensive view of these wetlands encompassing their changing facies, hydrologic regime, state of conservation, and functional status. Remotely-sensed data were the primary, and in most cases the only available, source of consistent information. Our approach can help planning and surveying for the implementation of saline wetland protection measures in harmony with the conterminous agricultural areas.

Keywords: conservation status; inland wetlands; halophytes; Landsat; playa-lake; Monegros

1. Introduction

Wetlands are priority sites in environmental policies. National and international agencies consider wetland degradation or loss a matter of great environmental concern in terms of biodiversity and hydrological function. Many of the world's most spectacular wetlands are in arid zones of Australia, India, South America, South Africa and Arabia. Arid zone wetlands exhibit a high variability. They range from perennial to temporary, from freshwater to hypersaline, and in size from small pans of less than 0.1 km², like some Spanish playa-lakes, to large intermittent lakes of more than 9000 km², like Lake Eyre. At present, our understanding of arid zone wetlands is relatively poor, in spite of their conservation importance (Ramsar Convention Secretariat, 2004). Characterized by highly variable interannual and seasonal rainfall, arid zone wetlands host plants and animals adapted to live in very extreme conditions.

Inland saline wetlands around the world. i. e., closed lakes, dry lakes, salt pans, inland sabkhas and playa-lakes, have been studied using the classical approaches of sedimentology, limnology, or geochemistry (Castañeda and Herrero, 2005). Detailed description of these environments requires specific diagnostic tools and indicators. As barren lands, often located in desert and remote areas, their mapping has been overlooked, and their study has been marginal and often conducted for scientific purposes only. Environmental concern, especially with regard to increasing urban or agricultural development, is changing the way society looks at saline wetlands.

Castañeda et al. (2005a) reviewed the application of remote sensing to inland wetlands, finding that study had been restricted to playa-lakes or inland sabkhas covering thousands of hectares (Epema, 1992; Harris, 1994; Bryant, 1999). The

techniques used in these studies are not well suited to small saline wetlands due to problems with the spatial resolution of sensors or the image treatment procedures used. The saline wetlands of the Monegros desert require approaches adapted to their average size with a median of 7 ha, to their irregular and rapid change in appearance, and to the lack of *in situ* data. For this purpose, we defined (Castañeda et al., 2005a) the term facies encompassing the soil surface cover, vegetation or other, and soil intrinsic features like cracking patterns, efflorescences, salt pans, ponding, etc.

The aim of this work is to understand the Monegros saline wetland behaviour and to establish a baseline chiefly focused on inventory and characterization, hydrological regime, and conservation status.

2. Study site

The Monegros Desert (Figure 1) includes an arheic area of 36,000 ha with scattered saline wetlands that currently occupy 2% of the whole area (Figures 1 to 3). It is one of Europe's most arid zones (Herrero and Snyder, 1997), with an annual mean rainfall of 388 mm and a mean annual ET_0 of 1255 mm. Soils are shallow and stony, calcareous or gypseous, with low organic matter contents, in agreement with the water deficit of the area and the parent materials. In addition, the soils are saline towards the borders of the wetlands, surpassing thresholds for crop production in agricultural fields surrounding the playas. Barley, the most suitable crop, produces 1050 kg/ha on average, though some years production is zero (McAneney and Arrúe, 1993). Subsidies provide crucial support for farmers' income. This agricultural environment differs from the

profitable farming areas surrounding other playa-lakes in developed countries, such as the High Plains in U.S. (Haukos and Smith, 1994).

The natural vegetation in the area, 825 ha, is limited to the borders and escarpments of playa-lakes and to the bottoms of the closed depressions. Of the vegetation surface area, 45% corresponds to habitats protected by the 97/62/CEE Directive. The perennial halophytes *Suaeda vera* and *Arthrocnemum macrostachyum* account for 99% of the flora.

Figure 1

The Monegros saline wetlands, locally named “saladas”, range from < 2 ha to > 200 ha in size. Some of them are playa-lakes and others are closed saline depressions of high scientific and environmental value as natural habitats of endemic microbes (Casamayor et al., 2005), plants (Domínguez et al., 2006) and animals (Melic and Blasco, 1999). These saladas differ from other inland playa-lakes in that they are saline groundwater discharge areas (Samper and García-Vera, 1998). The shallow brine, spread over the bottom by the prevailing NW wind, hardly reaches more than 50 cm in depth. The presence of the brine in a few weeks per the year depends on the groundwater dynamics (Castañeda and García-Vera, 2008) and the accumulated previous rainfall (Castañeda and Herrero, 2005). The occurrence and the extent of the transitory water body determine the distribution of the vegetation and the wet surface (Figure 2). The saladas usually appear in stark contrast to the rest of the landscape as a flat surface covered with water and/or salt efflorescence, dark soil, and halophytes.

Figure 2

This landscape is undergoing agricultural intensification. Land consolidation and intensive plowing have destroyed most of the native vegetation and have changed the shape of the fields, which before were more adapted to the landforms. The installation of irrigation was blocked by European Union for 10 years and led to the total exclusion of some areas. Irrigation advance, clearly visible in the satellite images of Figure 3, is the main threat to playa-lakes. Irrigation will modify the saline groundwater hydrologic balance, and new fresh and polluted water flows will discharge into the depressions, increasing the flooding period of these wetlands. The combined effects of these alterations probably will result in irreversible alteration of habitats, with extinction of extremophiles and other valuable organisms. This outcome can be observed in other Spanish saline wetlands which experience permanent flooding and inflows of fresher water, a false positive effect.

Figure 3

3. Methods

We applied remote sensing with ancillary data and field visits to inventory these wetlands (Castañeda and Herrero, 2008). The saladas boundaries were delineated over a Landsat image from April 2, 1997, the wettest year during the last decades. Delineation was performed by visual interpretation of the most suitable Landsat bands (Castañeda et al., 2005a), with the assistance of topographic maps at scales of 1:25000 and 1:50000, georeferenced enumerations of saladas, some of them unpublished, and non-georeferenced sketches. The information was standardized, and the toponymy used by each author was contrasted.

We used a series of Landsat images to extract thematic information for each date. Images were orthorectified and resampled to 25 m. The non supervised classification used in Castañeda et al. (2005a) to identify water surface and their associated facies were employed to produce a series of 52 Landsat TM and ETM+ images spanning 20 years from 1984 to 2004. This series improved the seasonal distribution of the series used in Castañeda et al. (2005b), with 10 images belonging to the winter-early spring; 14 to the spring; and 33 to the summer. Field knowledge was crucial to assign thematic meaning to the spectral classes obtained by imagery classification.

Standard definitions of the playa-lake land-covers applicable to this study were not available. The catalogue of facies associated with the flooding and drying events defined in Castañeda et al. (2005b) was applied to the above-mentioned, extended time period. These facies were identified in the field and in the images, and their distribution is often in concentric fringes with diffuse borders. Together with the spectral behaviour of each facies, additional criteria contributed to their accurate definition: their entity, i.e., persistence in the images and occurrence in most saladas, their ecological meaningfulness, and their separability, i.e., the ease of field and remote recognition.

Following the methods established in Castañeda and Herrero (2005) we studied in the whole series of 52 images (i) the distribution of the satellite water extent in different seasons and (ii) the relationship between water satellite data and the previous accumulated rainfall and evapotranspiration (ET_0). These are the main meteorological factors controlling the hydrological status in the playa-lakes. For these analyses, we have included five different periods for calculating the rainfall accumulated as well as the ET_0 and the difference ($P - ET_0$) previous to the water record date: 15, 30, 90, 180 and 365 days.

Finally, we define systematic descriptors of the saladas to depict their current conservation status and the changes occurring in the saladas in the last decades (Castañeda and Herrero, 2008). Their current conservation status was studied using indexes for quantifying the field observations and for systematizing their study. All this was included in a Geographic Information System (GIS), enabling linkage and comparison of scattered observations, from different sources, some of them of great historical value.

4. Results and discussion

4.1. Inventory and facies distribution

The first comprehensive map of the saladas was created from remote sensing. All the collected information, revised and superimposed on our wetlands delineations, was compiled and managed in a geographic information system to create the geospatial saladas database. The visual analysis of orthophotographs at 1:10000 scale and the field data recorded in 17 visits allowed a detailed drawing of the saladas borders and enlarged the remotely-sensed inventory. The resulting map, labeled *Inventory 2003*, shows a total wetland area of 860 ha, distributed in 53 saladas (Figure 1).

Five soil surface covers, defined as facies, were extracted in each date to describe and monitor the valuable habitats hosted by the playa-lakes (Figure 4). In order of decreasing humidity, they were as follows *Water*, *Watery Ground*, *Wet Ground*, *Vegetated Ground*, and *Dry Bare Ground*. The adopted criteria make these facies easy to distinguish, both in the field and using the Landsat images.

Figure 4

Satellite imagery enabled us to quantify the extent of the facies and study their evolution from 1984 to the present (Figure 5). This knowledge is crucial for detecting environmental alterations or other changes in the saladas. In practice, the extent of each facies can only be estimated from remote sensing. These extents will be the key to appraise the conservation status of these unique habitats and to study their evolution. In the entire saladas area, the mean extent of the flooding surface, i.e., Water plus Watery Ground, is only 12.5%, with a maximum of 53.2% in January 1987 and a minimum extent of 0% only in May 1991. The mean extent of Dry Bare Ground is 11.4%. Vegetated Ground has a mean extent of 25.7%. Wet Ground, the facies with the highest average extent, has a mean of 50.4%, reaching a maximum of 71.3% in August 1985 and a minimum of 5.8% in March 2000. Temporal variations are noticeable, but they were small for the 20 year span of this study. Increasing the number of images does not modify the temporal trend observed in Castañeda et al. (2005b), confirming that the Vegetated Ground shows an increase over the period studied, probably due to agricultural intensification.

Figure 5

4.2. Hydrological regime

The playa-lakes inundation regime reveals both the hydrological and climatic conditions. Remote sensing has yielded excellent synoptic information and quantitative data on water occurrence and on the hydrologic behavior of the Monegros playa-lakes (Castañeda and Herrero, 2005). The water presence-absence cycles in the major Monegros playa-lakes have been identified using ground observations and satellite data

from 1984 to 2004 (Figure 6). Both data sources agree, allowing us to group the playalakes according to their inundation patterns.

Figure 6

There is a close relationship between each of these groups and their location on hydrogeological units established by other authors. Previous studies showed the relationship of water occurrence (Water plus Watery Ground) to both previous rainfall and ET_0 and established the role of aquifers in the hydrological cycle of these arid wetlands. We have corroborated the consistency of these relationships using a larger number of dates. The playalakes show a significant relationship ($P < 0.05$) for the 180 day accumulated rainfall period. The playalakes also show a significant relationship between ET_0 and flooded surface area: the shorter the accumulation period the stronger the relationship. The water occurrence, computed also as *Water plus Watery Ground*, also shows a significant relationship ($P < 0.05$) for the 15 days of accumulated difference ($P - ET_0$); and this relation decreases as the accumulation period increases (Figure 7). Only Salineta is an exception to the first case, probably due to its connection to two aquifers (Samper and García-Vera, 1998) or to the possible influence of nearby irrigated lands (Figure 3).

Figure 7

The groundwater connection with some playalakes and their water budget has been modeled in Castañeda and García-Vera (2008). These models produced coherent results and updated knowledge about the saladas' hydrologic balance, thus improving our understanding of their hydrological behavior.

4.3. *Status of conservation and degradation*

The saladas, usually considered an agricultural wasteland, have undergone a siege of agricultural intensification, limited only by spots of flooding and extreme salinity. More than 75% of studied saladas are easily accessible across a smoothed escarpment. Of these, 28% are now unrecognizable as functional wetlands and are incorporated into the surrounding farmland or are impacted by roads and debris. Fully 90% of the saladas are used for stone dumping and 80% of the saladas are invaded by crops to some degree. The extent of the saladas has shrunk due to the elimination of native vegetation.

Significant changes in the saladas in recent decades due to agricultural intensification and new irrigation projects were recorded by comparing the current descriptions with those of previous authors. From 1988 to 2003, the escarpment was degraded for 23% of the saladas due to earth moving and machinery access; 30% of saladas were invaded by crops and 63% by stone (Figure 8) and debris; 38% of the saladas decreased in size when the halophytic cover was reduced by the advancing tillage. Many saladas inventoried in 1988 were not longer recognizable in 2003; some of them disappeared. The current degradation, though more visible in the smallest saladas, is affecting all saladas regardless of their size or the presence of water (Figure 9).

Figure 8

Faced with the lack of standard indicators at the appropriate scale, we have selected several viable indicator components. Abiotic and biotic features were combined into meaningful indexes of conservation and vulnerability, thus creating a systematic assessment of the saladas in a scenario of advancing irrigation works.

For the first time, the conservation status and threats to the Monegros saline wetlands have been assessed with a standardized widely-applicable methodology previously established for this purpose (Castañeda, 2004). Our indicators include visual field observations, satellite data, and GIS analysis; the integrated result enabled us to gauge the condition of these valuable habitats, yielding a coherent ranking of the saladas according to their conservation status (Figure 9) and vulnerability.

Figure 9

Only 20% of the saladas studied present a *pristine* or *slightly disturbed* landscape appearance. Fully 60% of the saladas have *high* current vulnerability; they are the smallest saladas and have the lowest water occurrence. The prognosis on the effect of the irrigation plan on these wetlands is that 73% will have a *high* or *very high* future vulnerability. Within the irrigated area, saladas Agustín, Benamud and Gramenosa have the lowest water occurrence; they are the most representative of those saladas and host some of the priority habitats listed by the Habitats Directive (97/62CEE) of the European Union.

5. Conclusions

Remote sensing has provided an inventory of these wetlands that will be a baseline for future research and monitoring. In the study area, 53 saladas have been registered and described systematically to determine their conservation status, limits and functions. The Landsat TM and ETM+ images have been a useful source for historical data about the water presence and associated facies in these wetlands and help fill in the gaps left by the scarce field records.

252 This study will be crucial for studying the evolution of these habitats, especially
253 with the integration of new environmental factors such as increased water input from
254 newly irrigated conterminous lands.

255 Both abiotic and biotic features are found to be highly useful as indicators of
256 ecological integrity for these wetlands. This methodology offers a rapid, consistent and
257 comprehensive assessment of the condition of the wetlands, in terms of conservation
258 and vulnerability.

259 The saladas assessment enables the establishment of priorities for surveillance,
260 conservation, and future restoration purposes. Remote sensing, especially when coupled
261 with ground data, ought to be used for saladas monitoring and for decision-making on
262 conservation measures and policies.

263 The Monegros region can serve as a good test site for the study of many small
264 saline wetlands in desert areas around the world. The systematic acquisition of Landsat
265 imagery since the 1970's covering the whole globe, enables the integrated procedure
266 described in this work to be applied in other wetlands with similar arid environments
267 and cloud-free weather.

268
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List of Figures

- 314
- 315
- 316 Figure 1. Location of the Monegros wetlands.
- 317 Figure 2. Changing appearance of two saladas La Playa (a and b) and Salineta (c and d).
- 318 Figure 3. Landsat 5 TM RGB 741 August images spanning 19 years show the advance
- 319 of irrigation, land consolidation and changes in fallow.
- 320 Figure 4. Facies distribution in La Playa. Pueyo and Pito saladas in January 1987 (a)
- 321 and August 1999 (b).
- 322 Figure 5. Facies extent in every date
- 323 Figure 6. The water extent of the Monegros wetlands as extracted from the images
- 324 studied, from 1984 to 2004.
- 325 Figure 7. Determination coefficients (R^2) between the total flooded surface (Water plus
- 326 Watery Ground) in the largest playa-lakes, extracted from a series of Landsat
- 327 images and the accumulated difference ($P - ET_0$) for the 15, 30, 90, 180, and 365
- 328 days previous to the image date.
- 329 Figure 8. Current status of the saladas: stone dumping.
- 330 Figure 9. Conservation status of the remotely-sensed inventoried saladas and changes in
- 331 the saladas vulnerability due to the installation of new irrigation.