

HYDROPERIOD OF DOÑANA MARSHES: NATURAL OR ANTHOPIC ORIGIN OF INUNDATION REGIME?

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ABSTRACT

There is a major concern on current restoration and management programmes being applied over Doñana Ramsar Site. Historical inundation regime has been largely changed according to human transformations. On site measurements along short and recent periods have provided scant local information on inundation variability. Historical inundation patterns on a spatial basis are necessary to understand short and long time effects of human transformations on natural regimes.

By compiling a long time series of Landsat MSS, TM and ETM images (1975-2006) we have mapped inundation levels for every available scene over Doñana wetlands. After coregistration, radiometric correction and time series normalization, we applied the best semiautomatic method for discriminating inundation levels according to ground-truth data. Then, we reconstructed for each hydrological cycle the hydroperiod value for every pixel. The value is calculated as the minimum number of days detected as flooded for the available dates during every cycle. Results reveal a significant increase on the average number of days inundated for the whole marsh and local hydroperiod changes related to human transformations and rainfall variability. Hydroperiod maps are therefore helping to understand hydrological implications of future management decisions.

1. INTRODUCTION

Doñana National and Natural Parks are the largest protected wetlands in Europe (500 km²). They have undergone strong human-induced changes along the 20th century, as a consequence of desiccation for agricultural land practices, water channel redraw, biodiversity conservation and environmental protection against the recent mineral spill waste in 1998.

Overall, changes in the original marsh (estimated around 1500 km², see Fig. 1) at the beginning of 20th century have led to the current 270 km² of shallow water (lost of 82%).

In addition to wetland area reduction, tidal influence, one of the main inundation drivers, was also limited by the construction of a wall along the Guadalquivir River (Fig. 2). Among such dramatic changes, the toxic spill,

occurred in April 1998, led to develop an ambitious restoration project of Doñana marshes, named 'Doñana 2005'. Its main goals are to recover the quantity and quality of tributary waters to the freshwater marsh. In this context, more than ever, it is necessary to know the historical inundation patterns, either spatial or temporal, and their relationships with natural and anthropic conditions.

Details on inundation process, such as interannual and seasonal variation, as well as influence of human transformations have been long time demanded by decision-makers in order to apply a scientific-based management to Doñana marshes. So far, hydrological management has been conducted on an "event-reaction" basis, leading to temporal solutions that became lately part of new problems.

Remote sensing has become a very useful tool to easily derive inundation maps and recently to reconstruct historical hydroperiod [1]

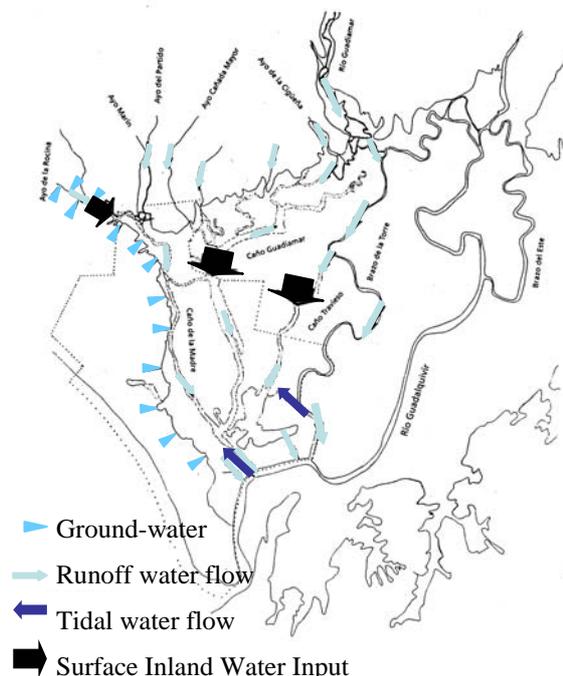


Figure 1. Doñana water inflows at the early XX century.

In this work we propose 2 methods to estimate hydroperiod from inundation masks generated by means

of Landsat imagery for the last 30 years. Hydroperiod is a critical parameter dependent on topography, wetlands connectivity and proximity to inflows [2]. It is then a suitable variable to assess the ecological effects of any transformation since it conditions vegetation type and feedbacks sedimentation processes.

According to the available time series we analyse changes on the hydroperiod and evaluate the main origin of such changes.

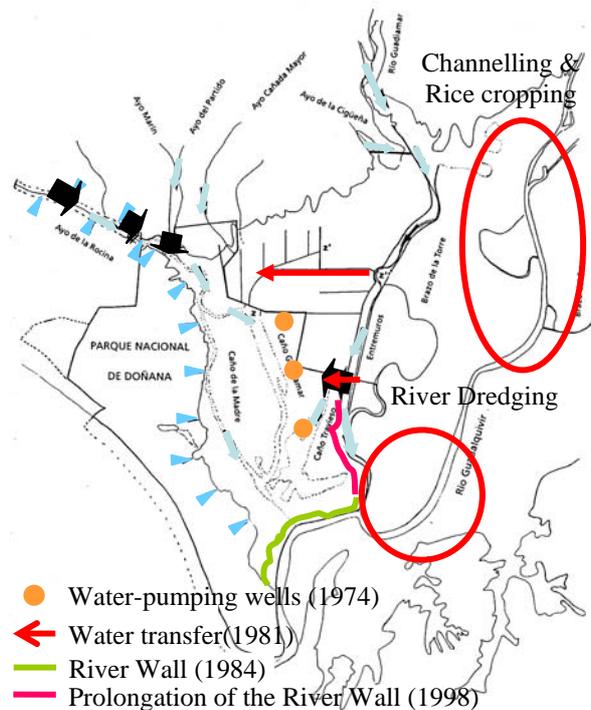


Figure 2. Doñana marshes after the toxic spill (1998).
For the legend see Figure 1.

2. MATERIAL AND METHODS

2.1. Time series of images

We acquired all the available cloud free Landsat MSS, TM and ETM+ scenes for Doñana. In total more than 300 images covering the 1975-2004 period compose the time series. In order to make them comparable we apply a consistent pre-treatment.

A recent Landsat 7 ETM+ reference image from summer with clear sky conditions was georeferenced using 100 ground control points over aerial orthophotos of the Junta de Andalucía [3]. The remaining TM and ETM images were co-registered to this reference image. Resampling method was cubic convolution. RMS error calculated with an independent test point sample on co-registered images was 19.7 m. Images were then radiometrically corrected and transformed into reflectance values applying the Pons & Solé-Sugrañes [4] model. Finally reflectance images were normalized to the reference image using a set of pseudo-invariant

areas covering all the range of reflectance values present in the scene. For MSS images we follow the same approach using as reference one Landsat 4 TM summer scene acquired in 1985 by both sensors MSS and TM aboard of the same platform. RMS error in this case was independently estimated in 23.01 m.

2.2. Flood discrimination

According to results from Bustamante et al [5] we tested the ability of several methods and indices to discriminate land covered by water. The best one consisted on simple slicing of TM band 5 and MSS band 4 enabling to detect different inundation levels. Final inundation masks were produced for every available date on this basis by merging on one hand low inundated and dry soil categories and on the other hand wet and fully flooded pixels.

2.3. Hydroperiod calculations

Two ways to estimate hydroperiod were applied over the time series. The first one estimated the number of days a pixel remained inundated along a complete hydrological cycle by assuming maintenance of inundation among two consecutive scenes. This first approach was reached by assigning Julian day to every inundation mask and calculating the difference in days with the first available scene for every cycle. Thus, final images give information on the number of days a pixel remained inundated per cycle, i.e. annual hydroperiod.

On the other hand, we generated decadal hydroperiod composites by adding every available date per month and subsequently averaging the results per decade. The latter method was designed to allow inter-decadal comparison after important transformations in the marshland and the former aiming to detect quantitative regional changes in hydroperiod trends when subjected to natural variability and anthropic transformations.

3. RESULTS

Inundation masks were produced for more than 300 Landsat images. Annual hydroperiod was calculated for every hydrological cycle of the 1975-2004 period, starting the 1st September and ending 31st August. We discarded cycles with less than 224 days (7 months) between first and last available image. Annual composites were then visually compared in order to assess for local changes during the last 30 years. Average hydroperiod trend for the natural marsh did not show any significant increase or decrease for the study period ($r^2 = 0.02$, $p > 0.05$, Fig. 3). However, visual interpretation did show a soft increase in recent years of hydroperiod for hydrological cycles with similar values of rainfall.

Decadal hydroperiod aided to asses about local changes along the 3 analyzed decades. For this purpose, final decadal composites were subtracted one to each other to evaluate the areas that have undergone dramatic changes in hydroperiod and reclassified to show the percent of change (Fig. 4). These areas were spatially identified and the processes involved were addressed according to the historical and current transformations. Several processes were detected to be the main cause of the trends observed for inter-decadal comparison:

- Hydroperiod decrease:** Northern areas have been isolated from the original water inflows (number 1 in Figure 4) and accelerated siltation processes are altering topography and consequently reducing hydroperiod (number 3 in Figure 4),
- Hydroperiod increase:** Siltation processes are promoting upstream areas to remain for longer time inundated, so that they are acting as casual dams (number 2 in Figure 4); on the other hand, appearance of new inundable areas such as fish cultures and salt works have increased hydroperiod in places where inundation used to be shorter (number 4 in Figure 4).

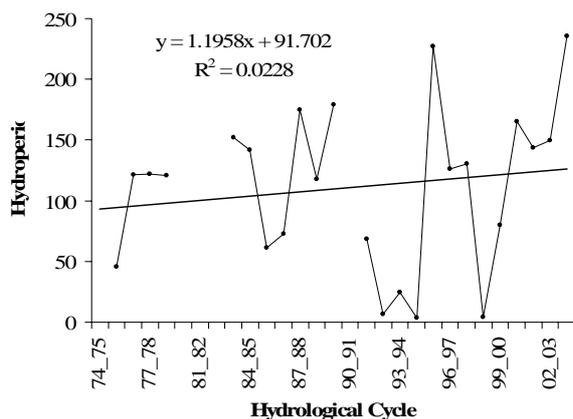


Figure 3. Average trend of Doñana natural marshes hydroperiod along the last 30 years.

In order to address the question on the main driving force for hydroperiod changes we analysed the relationship between average annual hydroperiod and accumulated rainfall per cycle. Results show a significant and positive relation explaining up to 70% of variance in hydroperiod during the last 30 years (Fig. 5). The unexplained 30% of variance might account for other driving forces related to human transformations.

Non-linear models were not attempted to be fitted although a loglinear curve would be apparently better fitted to data, revealing inflexion points between the amount of rainfall and the corresponding inundation time.

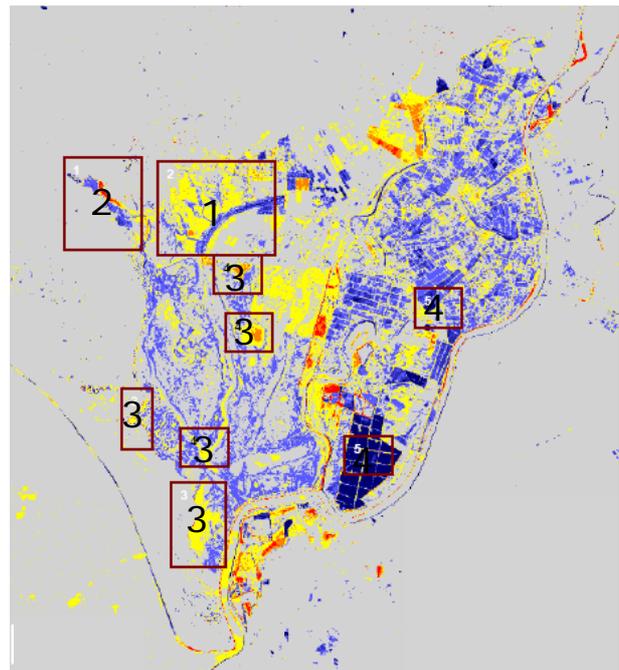


Figure 4. Areas with relevant local changes in inter-decadal comparison of hydroperiod (1985-95 versus 1995-2004). Red and yellow zones indicate hydroperiod reduction and blue pixels account for a consistent increase (see text for details).

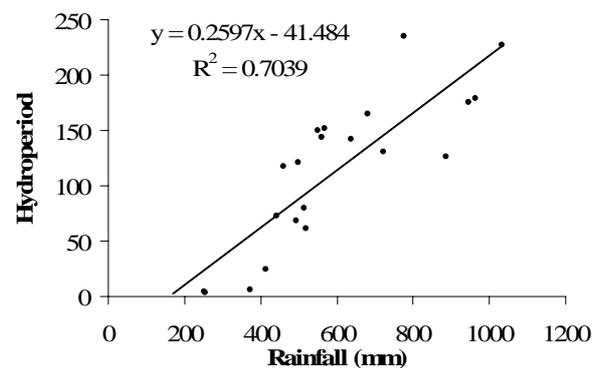


Figure 5. Relationship between hydroperiod and rainfall.

4. DISCUSSION

Doñana wetlands are being monitored through a semi-automatic approach leading to reveal historical patterns of inundation in the marsh. The approach is time-consuming since pre-treatment of the time series of images has to be applied over more than 300 Landsat images.

Inundation mapping is easily achieved by applying a simple threshold to TM band 5 and MSS band 4 revealing the spatial patterns of water cover for 3 decades. Agreement with ground-truth data validates the methodology for accurately discriminate inundated

areas, either turbid or clean, plant-covered or bare water.

Historical reconstruction has been summarized through the calculation of hydroperiod following 2 proposed methods. Assumed trends of hydroperiod changes by the local managers could be re-assessed with the help of such valuable information. Annual hydroperiod show not significant trend for the whole marsh although local changes are fairly visible on a inter-annual comparison basis. For instance, hydrological cycles with similar rainfall amount yielded quite different spatial patterns of annual hydroperiods. Further work is on going to evaluate the effects of short-term transformations.

Complementarily, decadal hydroperiod composites allowed to locally compare changes on the time of water persisted after large wetland transformation. Channeling of Travieso stream, one of the main tributary inflows has initiated an accelerated siltation process at the North of the marsh. Such dynamics are responsible for the increase of hydroperiod upstream and the decrease in the new deposited sands. Alternatively, loss of Northern inflows connection has been slowly performed by wetland drainage for agricultural practices. Other human transformation and exploitations such as fish cultures located at the South-eastern part of the marsh and rehabilitation of salt-works in the last decade have caused an artificial increase on local hydroperiod.

Besides, during the last decade an important phenomenon of overinundation has taken place as a consequence of the construction and prolongation of the River wall. Apart of such regional effect, new inflows derived from management decisions have increased local siltation processes reducing hydroperiod.

Finally, results from the analysis of annual rainfall show that rainfall accounts for 70% of the hydroperiod variability. This fact leads to interpret that the main driving force in the process of filling in and maintenance of inundation is rainfall. However, there is still a remaining 30% of variance which could be explained by local and consistent changing trends.

As a concluding remark, current decisions on Doñana 2005 restoration programme are taking into account results from this historical reconstruction and helpfully aiding to validate expected results from its implementation.

5. ACKNOWLEDGEMENTS

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