Long-Term Ecological Monitoring at the Landscape Scale for Nature Conservation: The Example of Doñana Protected Area

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Abstract This chapter describes, as an example, the integration of a landscape scale approach based on remote sensing applications into the Long-Term Ecological Monitoring program of the Doñana protected area. I report the contribution of the landscape-scale monitoring by using remote sensing tools *sensu lato*, provided by its retrospective vision and multi-scale analysis capacity. The implemented protocols are set up as a multi-scale approach and are validated with a network of ground-truth field plots. The landscape scale monitoring program is being applied not only to habitats but also to species and to track natural and human-driven processes, mainly management actions. The approach is applied to monitor wetlands, terrestrial plant communities and geophysical processes. The chapter focuses on trends and shifts evidenced by the landscape scale approach that have been published or reported for decision making and conservation management planning. Some pros and cons are finally discussed in relation to data source availability, mission continuity and technical requirements.

Keywords Landscape scale • Remote sensing • Global change • Conservation management

Introduction

From its beginnings back in 1969, conservation in Doñana (Southwest of Spain) involved a team of researchers and managers who were aware of the importance of acquiring knowledge for the effective preservation of this protected area. In this process, the birds, Iberian (*Lynx pardinus*) and Cork Oak (*Quercus suber*) populations were critical in raising awareness of the need for systematic long-term data acquisition as a baseline for management.

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Many of these monitoring procedures have allowed retrospective analysis to show trends, changes and even relationships that reflect human impact. This reflects the broad consensus that long term monitoring programs are essential in addressing global change effects and in implementing decision-making (Inouye 2017; Lindenmayer et al. 2015; Magurran et al. 2010; Navarrete et al. 2010; Willig and Walker 2016).

In 2002, the Doñana Biological Station (EBD), a research centre of the Spanish Research Council (CSIC), together with the Doñana National Park Officers, proposed an integrated Long-Term Ecological Monitoring (LTEM) program. Almost a hundred monitoring protocols were defined, some to assess the status of threatened or flagship species and habitats of interest and others to track natural processes and the effects of conservation management actions (Díaz-Delgado 2010). After 15 years of implementation, the program has contributed data to provide evidence of spatial patterns and temporal trends of the target species and habitats: these have been reported in many publications. Consequently, quite a few research projects have been proposed and initiated to seek the scientific causes of the observed trends and their relationships with a range of environmental factors. Furthermore, the different management agencies have had uninterrupted access to the monitoring data and used these for decision-making in several conservation success stories at Doñana (Díaz-Delgado et al. 2016b).

The integration of the program into the Long-Term Ecological Research (LTER) network in 2008 allowed us to enhance the results and their outreach. Since then, the monitoring program and the research associated with it have benefited from the advances provided by the collaboration with the LTER networks, through participation in different research projects.

On the other hand, the program has largely benefited the available remote sensing applications by providing a full set of protocols and assisting in the interpretation of other monitoring results. All across the planet we find different conservation agencies and research projects using remote sensing tools to monitor ecosystems state and trends. Recent advances are also achieving good successes in biodiversity monitoring (Nagendra et al. 2013; Paganini et al. 2016; Pettorelli et al. 2016; Vihervaara et al. 2017; Wulder 2011).

I present an overview of some of the results obtained from the treatment, analysis and interpretation of the information collected through the monitoring program at a landscape scale. Most of these have contributed to conservation management in the Doñana protected area.

Long-Term Ecological Monitoring at Landscape Scale in the Doñana Protected Area

The landscape-scale approach integrated into the LTEM program is implemented in the Doñana Natural Space (END), south-west Spain. The approach has greatly contributed to improving our knowledge of different, ecologically relevant, natural processes (Díaz-Delgado 2010). The protocols associated with this approach are mainly applied using a combination of remote sensing images, *sensu lato*, and ground truth data from permanent field plots (Barrett 2013; Richards 2013). One advantage of this approach is the possibility to look back in time and use the first available aerial photos as a temporal reference. The current availability of long time series of images for many places in the world enables us to identify trends and shifts in different ecological processes and features (Gardiner and Díaz-Delgado 2007).

The landscape scale monitoring focuses on three different subject areas: the Doñana wetland ecosystems, including marshes and ponds, geophysical processes, and terrestrial plant communities.

Ground-Truthing

The landscape-scale approach uses plots, transects and *in situ* sampling points as ground-truth for validation purposes, which includes percentage cover for most plant communities present in Doñana.

The multi-scale approach uses involves sampling from the individual plots (microscale) through to the landscape level including mesoscale plots. When dealing with woodlands, the spatial location and associated information on individual trees (size and species) is recorded to allow scaling up using airborne (including drone) and spaceborne data.

Since 1999, we have reported trends and changes in the surface cover of dominant plant communities in Doñana. For example, there has been a general increase in the density and area occupied by Stone Pine (*Pinus pinea*) woodlands and a decrease of *Erica scoparia* healthlands replaced by more xeric species, including woodlands dominated by Juniper (*Juniperus phoenicea spp. turbinata*). These plots also provide information on habitat structure, species density, population dynamics, species abundance and diversity.

Monitoring of Doñana Wetlands

Monitoring the annual flooding and drying out processes of the Doñana natural marshes has allowed to test the ‘largely assumed’ hypothesis of an increase in the hydroperiod in recent decades (Díaz-Delgado et al. 2016a; Díaz-Delgado et al. 2010; Díaz-Delgado et al. 2006). Figure 1 shows the median trend estimated from the 1974–2014 time series of flooding masks retrieved from Landsat MSS, TM and ETM+ images. This approach allows us to spatially locate the temporal trends (increases or reductions) in the duration of the flooding: this is a critical variable for the biological communities of Doñana marshes. The temporal analysis reveals two significant trends: on the one hand, the hydroperiod has increased in the

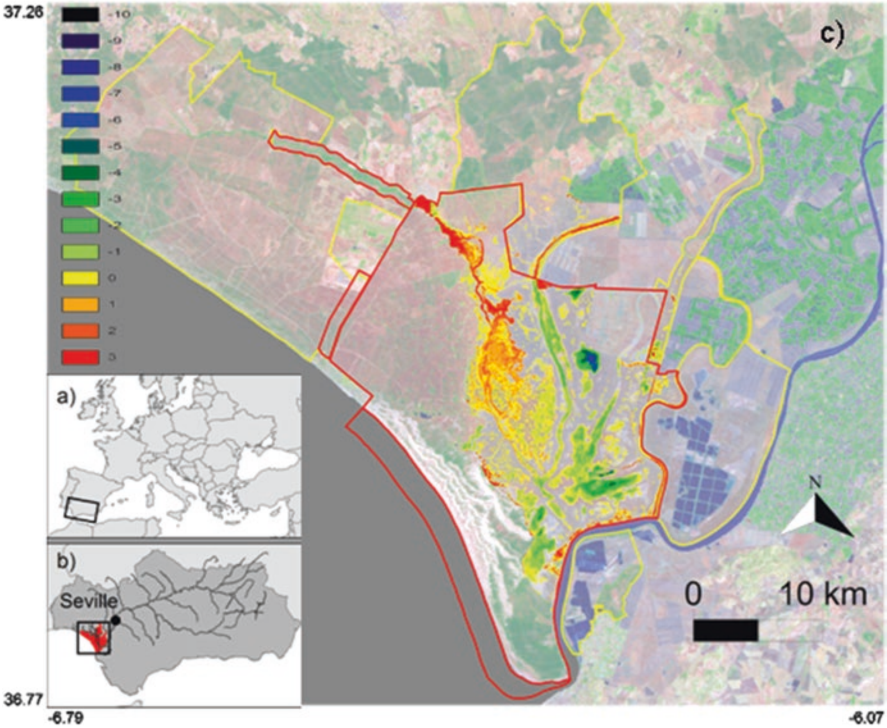

Fig. 1 The location of Doñana protected area (**a**) in Europe and (**b**) in Andalusia and (**c**) the pixel values of the hydroperiod trends (in days per year) for Doñana National (*red lines*) and Natural (*yellow line*) Parks for the 1974–2014 period. *Red and yellow colors* indicate an increase and *green/ blue colors* a decrease. Background: Landsat 5 TM false color composition with bands 5-4-3

northwestern quadrant (*red and yellow colored* pixels) but has reduced in the southeast quadrant (*blue and green colors*) (Díaz-Delgado et al. 2016a).

The results from the landscape scale monitoring were used to evidence the effects of different restoration actions under the framework of the Doñana 2005 project (Chans and Díaz-Delgado 2006; Frisch et al. 2009; Santamaría et al. 2006).

Different studies have revealed the importance of the hydroperiod variable in explaining the presence, abundance and breeding success of different waterfowl (Kloskowski et al. 2009; Márquez-Ferrando et al. 2014; Ramo et al. 2013; Rendón et al. 2008; Toral et al. 2011). By using remote sensing, we were able to map the expansion of the invasive aquatic fern *Azolla filiculoides* using Landsat images and target detection techniques (Díaz-Delgado et al. 2008, 2011) enhanced by the use of hyperspectral images (Bustamante et al. 2009a). The hydroperiod was also linked to the spread of *Azolla* in the Doñana marshes (Espinar et al. 2015).

The landscape scale monitoring has benefited from the use of hyperspectral images from airborne sensors, as these have allowed more detailed mapping of the

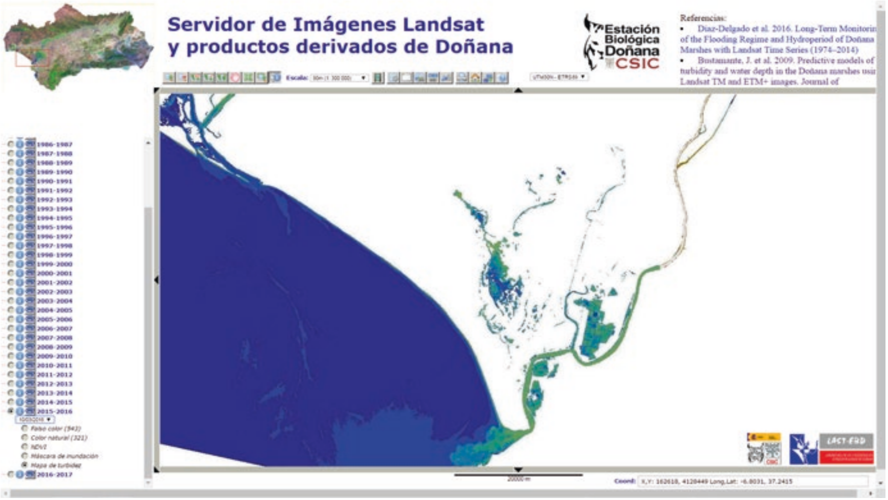

Fig. 2 The website offering the results of the Doñana wetlands monitoring program at landscape scale. The example shows the turbidity mapped for the 10th March 2016. RGB composites, flooding masks and NDVI images are also available for visualization and download

location of most of the temporal water pools in the Aeolian sands of the Doñana protected area (Gómez-Rodríguez et al. 2011). Gómez-Rodríguez et al. (2008) used this detailed cartography to produce an enhanced predictive model for the breeding habitats of the different amphibian species of Doñana. The decrease of the hydroperiod in the recent decades has been also evidenced in the Doñana water bodies (Bustamante et al. 2016) and was shown to be one of the most relevant causes of the decline in amphibian reproduction (Gómez-Rodríguez et al. 2010).

The multispectral information provided by the Landsat satellite images is systematically used to map water turbidity in both the Doñana marshes (Bustamante et al. 2009b) and the Guadalquivir estuary (Díaz-Delgado et al. 2010). The analysis of the turbidity time series has helped to quantify the spatiotemporal variability and reconstruct the turbidity regime by differentiating extreme turbid events from long-term turbid trends (Díaz-Delgado et al. 2015). Periodic flooding masks and turbidity maps from the landscape scale monitoring are accessible online through OGC Web Map Services at http://venus.ebd.csic.es/imgs/ (Fig. 2).

Monitoring of Geophysical Processes

Geophysical processes are usually quite conspicuous in remote sensing images. In the case of Doñana, the dynamics of the large sand-dune system and of the shoreline are being reconstructed and periodically mapped by applying a very simple procedure based on image segmentation (Berberoglu and Akin 2009; Pardo-Pascual et al.

2012). Shoreline regression and progradation (beach creation) are mapped along the 25 km of coastline (Díaz-Delgado 2008).

We also monitor the sedimentation processes in Doñana marshes: these data enabled us to assess the effects of the restoration actions of the Doñana 2005 project. For instance, we mapped the progressive reduction of the dejection cone caused by the *Arroyo del Partido*, one of the main tributaries to the marshes. We also located the emergence of new streams from the artificial lagoons created to retain the sediments.

Monitoring of Terrestrial Plant Communities

The application of a landscape scale monitoring approach to the Juniper woodlands has revealed the dramatic effects of the mortality events in the autumn of 2005. Mortality and damage in these plant communities affected juvenilies (canopy height lower than 1 m) more than adults (higher than 1 m). Greater damage and mortality was observed in areas with high plant density (Díaz-Delgado et al. 2014). The effects of these types of events persist during the following years despite the vigorous sprouting observed from damaged individuals (Fig. 3). In addition, a retrospective spatial analysis starting from 1956 revealed both an expansion of Juniper woodlands and a increase in plant density (García et al. 2014).

This monitoring program also benefited from using airborne hyperspectral images to map the abundances of the dominant woody species in the shrublands, by using spectral unmixing techniques (Jiménez 2011; Jiménez et al. 2005, 2011) based on spectroradiometric ground measurements (Jiménez and Díaz-Delgado 2015). The periodic detailed mapping provides evidence of the dramatic effects of drought on the *monte negro* hygrophytic plant communities and the defoliation processes in *monte blanco* xeric shrublands.

The setting-up of permanent ground-truth monitoring plots has provided a better understanding of the resilience of Doñana shrubland communities. By quantifying the functional diversity of the different plant species combined with the ground survey information on the percentage cover, structure and density of plants, we have established the great stability of shrubland communities in Doñana after extreme events (Lloret et al. 2016; Pérez-Ramos et al. 2017; de la Riva et al. 2017).

In the case of the permanent plots in the floodplain forest of Arroyo de la Rocina (tributary to Doñana marshes), we have evidenced the need for an integrated monitoring approach using field plots and remote sensing (Rodríguez-González et al. 2017). We found a consistent and decreasing trend of the area occupied by Willows (*Salix atrocinerea*) and an increase in the stem density of Narrow-leaved Ash trees (*Fraxinus angustifolia*) (Fig. 4). We found a higher percent of fallen Willow trunks in the plots. The results highlight the recent hydrological changes in one of the most important tributary rivers entering the Doñana marshes.

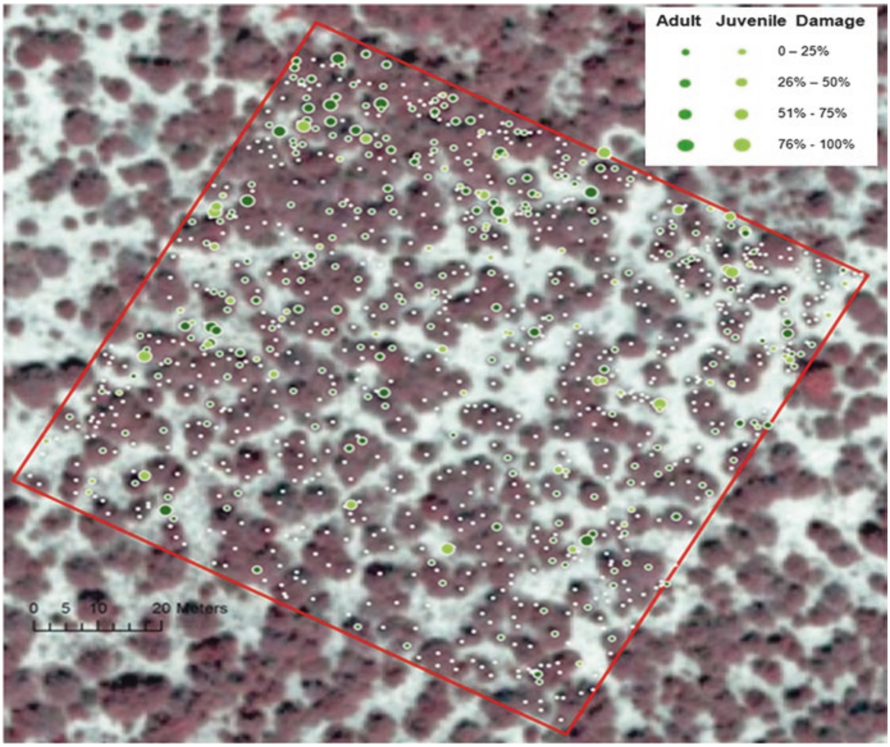

Fig. 3 An example of one of the meso-scale ground-truth plots for the monitoring of Juniper woodlands in Doñana protected area. The distribution of adult and juvenile individuals is depicted together with the percent of canopy damage measured for every individual inside the 1 ha plot

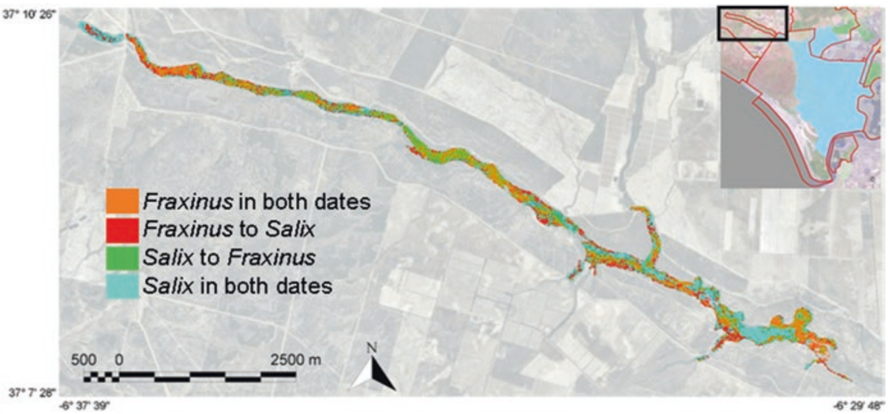

Fig. 4 Map of changes in species dominance in the Arroyo de la Rocina from the comparison of 2004 and 2015 hyperspectral image classifications. The image in the right corner shows the location of the Arroyo de la Rocina in relation to Doñana protected area (*red line*) and Doñana marshes (*blue area*)

The Pros and Cons of Integrating Remote Sensing in Nature Conservation

The use of remote sensing is strongly recommended to complement traditional long-term ecological monitoring programs based on field sampling (Gross et al. 2009; Willis 2015; Rodríguez-González et al. 2017). Monitoring at a landscape scale provides a synoptic view of natural processes and enhances the interpretation of data collected in field plots. In addition, historical time series of remote sensing images are now widely available, and this can inform our selection of reference points for restoration projects (Reif and Theel 2016) or to assess temporal trends, anomalies or shifts of relevant ecological and biodiversity indicators (Pettorelli et al. 2016; Skidmore et al. 2015).

However, the major constraints for conservation managers using remote sensing applications arise from:

- A lack of sufficient knowledge and skilled staff to integrate remote sensing techniques into decision making.
- A lack of clear guidelines on how to apply the procedures or to access the most reliable data available online.
- The lack of specific scientific and technical committees offering assessment and supervision on the optimal products, methods and technologies to be used in the long run to manage and preserve natural areas.

In addition to these specific limitations, the users of remote sensing images and products are aware of the limited lifetime of sensors and satellites: this can be an issue for the agencies responsible for maintaining continuity in their missions. Hopefully, the recent launching of Landsat 8 with the OLI instrument and the constellation of Sentinel satellites by ESA has secured the provision of Earth Observation images to the remote sensing community and will increase the use of its applications.

Conclusions

While traditional long-term ecological monitoring programs are typically underpinned solely on field sampling, a combined approach incorporating remote sensing tools is essential to providing a landscape-scale perspective. The integration should be carried out according to the specific monitoring program targets and implemented with complementary methods of ground-truth.

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