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Forensic water governance? Analyzing land and water use changes in North-Western Doñana (Spain)

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The region of North-Western Doñana is a key recharge area for the Doñana marshlands, one of the most important wetlands in Europe. In this region, the balance between a traditional economy compatible with environmental conservation has been altered significantly as a result of a disruptive change: the development of intensive agriculture of red berries –locally known as the 'red gold'-. The paper shows how a methodology based on remote sensing and GIS can provide a practical tool to identify and quantify intensive crops and especially, to determine their legal status. The paper describes this as an example of "geographic forensic science" for water governance, understood as a systematic method to gather and examine information on the territorial changes and events in the past with aim to use this information in law enforcement. The analysis shows how geospatial techniques can become an accessible and powerful tool for monitoring water abstractions and land use changes (public accountability), and to raise public participation and transparency, three key principles to advance towards a 'lighter side' of governance.

Keywords: Forensic science, remote sensing, GIS, legal use of water, intensive agriculture.

1. Introduction

The "forensic" aspect of water governance presented in this paper is defined as "a systematic method of gathering and examining information which is relevant to law enforcement and to prevent corruption". It therefore helps characterize the gap between the theory of 'governance' which as identified in this Special Issue presupposes good

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collaboration between public, private and civil-society actors working in concert to get optimum outcomes, and reality which often has suboptimal outcomes.

This paper seeks to increase our knowledge to monitor resource capture, and to mitigate the hidden –darker- side of governance, when the principles of ‘good governance’ of accountability, transparency and participation are difficult to implement due to lack or inaccurate information. The paper shows the potential for geospatial techniques as a means to provide key spatial and temporal information to characterize the dynamics of land and water use –as part of a forensic approach to water governance- in an area pivotal to a key wetland in Mediterranean Europe: Doñana National Park. It is an area mired in conflict due the current prioritization of intensive agriculture over traditional land (and water) uses more attuned with long term wetland conservation. A regulatory framework has been introduced aimed at making economic development compatible with environmental protection. Yet the actual implementation of this regulatory framework has been mixed, as reflected in the “illegal” or non-authorized use of both land and water.

The contribution of this paper centres on the doctrine of public trust by public authorities in the execution of their duties in a context of increased competition for water (and land) resources, when both monitoring and sanctioning aspects take centre stage. Informal water use, which should not be seen as synonymous to ‘dark water governance, is a reality in many parts of the world, including developed countries and must be considered as part of the governance system. The paper will thus focus on tools that can make the process of formalization or exclusion of informal water use more robust and transparent, and potentially more open for all stakeholders involved, in this case through the use of Geographical Information Systems (GIS) for monitoring the enforcement of regulation.

Current debates on governance and open data look at how open data can improve the verification of government performance, against pre-set objectives or rules. In particular, the paper touches on how GIS and forensic governance can enable citizen and user oversight of governments to re-balance information asymmetries. This could eventually lead to a model of co-production of information and more collaborative governance. GIS technology can therefore help first, to make implementation of regulation easier by identifying lack of compliance and regulatory incoherence and second, to help develop ownership at local level on protection of natural resources *and* agro-ecosystems to reward those that play by the rules, and penalize cheaters and free riders that can cause e.g. drops in strawberry prices due to overproduction.

The paper is structured in the following way: first, we analyze the disruptive socio-economic and environmental changes brought about by berry cultivation in what was a traditional low intensity agro-ecosystem and policies undertaken to manage land use changes; second as part of what we call “forensic water governance”, do an audit on land and water use changes to support a key aspect of water governance: water monitoring and control; finally we analyse the potential use of this methodology to improve accountability, participation and transparency in a roadmap to move away from issues inherent to a darker side of governance.

Figure 1. Delimitation of the study area (depicted in brownish red colour) combined with:
[left] Administrative boundaries of Doñana National Park (dark green) and Doñana Natural Park (light green)
[middle] Administrative limit of the Almonte-Marismas aquifer (blue line), main streams coming from NW Doñana (light blue line) and Doñana's marshlands (dark blue area).
[Right] winter satellite image of Doñana.

2. Disruptive change? Berry cultivation near the Doñana marshlands

2.1. The high ecological value of Doñana

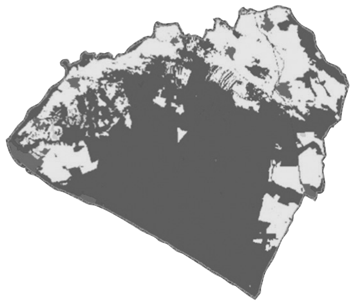
Doñana national park is located in southwest Spain and comprises the former delta and estuary of the river Guadalquivir. It preserves one of the largest and most important remaining wetlands in Europe and one of the largest European breeding areas for migrating birds, with a vast and well preserved continental marsh (25,000 ha) together with a diversity of biotopes compounded by a range of Mediterranean shrubbery and woodlands upon dune ridges and fixed and wandering dunes (García Novo & Marín-Cabrera, 2006).

Doñana was designated as a National Park due to its high ecological value, the maximum level of conservation under Spanish legislation for protected areas. Since 1982 it has also been designated as a Ramsar List of Wetlands of International Importance[1]. Yet, in 1990 Doñana was placed in the Montreux Record[2] due to the potential effects human activities had in altering the good ecological status of Doñana's marshlands.

Our study area -North-Western Doñana (NW Doñana from now on)- behaves as a central area for recharging Doñana's marshlands, through a series of rivers, seasonal streams and the shared aquifer system of Almonte-Marismas (figure 1). Alterations in water usage and land transformations in NW Doñana can have severe impacts on the protected area as a result of drops in aquifer levels and/or the alteration of water dynamics and quality.

[1] In 1969, an area of 53.365 hectares was declared National Park and was doubled in size after the creation of the Doñana Natural Park, as a buffer protection area. Beyond the National level protection, the Doñana region has also been designated as part of several conservation networks and programs: The Man and Biosphere Programme of the UNESCO (1981), Ramsar List of Wetlands of International Importance Convention (1982), European Management Certificate (1985), World Cultural Heritage of the UNESCO (1994), and EU Natura 2000 Network.

[2] The *Montreux Record* is a register of wetland Ramsar sites where adverse change in ecological character has occurred as a result of human activities.



Land use	Surface (ha)
Agriculture/ Cattle breeding	31,066
Forest/Natural vegetation	71,357
Quarry/Bare soil	1,004
Urban/Infrastructures	3,232

Figure 2. Main land uses in NW Doñana

The soil in NW Doñana is largely composed of sand, part of an aeolian sheet stabilized by vegetation which constrained the development of the region that remained largely uninhabited (see figure 2), facilitating its conservation. Traditional economic activities were based on stockbreeding, lumber, pine nut harvesting, firewood, and hunting.

2.2. A disruptive change in the agricultural landscape of NW Doñana

The traditional agricultural model however changed dramatically from the 1970s when experimental plantations, led by private entrepreneurs, succeeded in introducing berries agriculture in the area. The success of a series of trials on sandy soils, low in organic matter, meant the opportunity to grow a highly profitable crop, which required low initial investment in infrastructure and technology. The use of greenhouses and plastic covers allowed the production of early harvests which could generate significant revenues.

Public and private initiatives have turned NW Doñana into the main Spanish (nearly 67%) and European production area for strawberry (Junta de Andalucía, 2012). This phenomenon is locally known as the ‘red gold’ fever. Throughout the past 30 years, with a slight decrease and stabilization in the past 10-15 years, the introduction of strawberries provided a boost to the local economy and has become one of the major sources of income, leading to high local demographic growth. For instance, the population in the municipality of Palos de

Figure 3. Examples of greenhouse red berry cultivation on sandy soils

la Frontera, grew 189% between 1980 and 1990, trebling during the harvest season. In some of the municipalities of the region, almost 50% of the employment is directly related to the crop. Nowadays, the prices per hectare of red berries agricultural land is 3–4 times higher than land occupied by rain-fed vineyards or olive tree plantations (Junta de Andalucía, 2010), with average gross income estimated at around €6,000 per hectare and a revenue of up to €1.6 per m^3 for applied water (Aldaya, García-Novo, & Llamas, 2010).

Therefore, the drivers for non-authorized use are still deeply imbricated with the current economic development model in the area, which as a result of the "red gold fever", has been transformed from a marginal and relatively poor region, to a wealthy area based on high value export agriculture, which however due to its intensive use of natural resources clashes with nature conservation.

Two main governance issues have been: first, the lack of coordination between public institutions, and second, the politicians' reluctance to take unpopular decisions. While land use planning and agriculture are regional competencies, water competencies are under legal dispute between the regional and national governments; complicated by the fact that provincial and municipal authorities also intervene in some policies. Under a situation of natural resource scarcity, water has a real added value in terms of socio-economic development, and thus also a political value, a key political issue where social and economic criteria often trumps regulatory and technical criteria. The local importance of irrigated agriculture, a major source of employment and economic income for some municipalities in the region creates considerable political pressure which can affect the full implementation of regulation. Thus national and regional priorities come head to head with the preservation of biodiversity and ecosystem services required from public bodies with a wider accountability at national and international scales. The opportunity from transitioning in the system comes from the fact that the same northern Europe consumers that generate the main social pressure for Doñana conservation are also the main driving force increasingly demanding retailers to sell red berries cultivated respecting the legal framework.

The European market is the largest destination for the crops, with more than 50% of berries going to Europe. European markets are becoming increasingly more demanding in terms of environmental regulations, with the export of strawberries to the EU falling under environmental regulation standard N 543/2011[3], consisting on a series of detailed obligations concerning production methods. Therefore, the intensive agricultural model is now becoming one of the main challenges not just for the environmental conservation in Doñana but also due to changes in consumer demand on the overall sustainable use of resources in the economic production model.

The disorderly land transformation into irrigated farmland for the purpose of expanding berry cultivation has dramatically changed the landscape in the region and increasingly occupied important areas within NW Doñana. Intensive agricultural activities have increased the fragmentation, deforestation and diversion of streams, affecting to connectivity of natural areas. This fragmentation threatens the biodiversity of the region and makes the long-term survival of Doñana's species increasingly difficult.

[3] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:157:0001:0163:EN:PDF

In terms of land and water, over the past decades, irrigated crops have exerted increasing pressure on available groundwater resources from the Almonte-Marismas aquifer to the wetlands of the National Park. Furthermore, rivers and soil pollution of represents an important hazard to the ecological health of the region. The accumulation of waste (mainly plastic), the high fires rate and desertification are collateral issues that also threaten the natural area.

2.3. Land use management plans and policies to tackle the negative effects of intensive crop expansion

As a response to the significant transformation taking place in the region, a normative land use plan (*Plan de Ordenación del Territorio en el Ámbito de Doñana*, known as POTAD – referred to from now on as '*General Plan*') was approved for Northwest Doñana in 2004. The aim was to establish legal boundaries (zoning) for land deemed to have stricter environmental protection.

The 2004 General Plan divides the region into areas under progressive levels of protection, where different land uses are permitted. It focuses on guaranteeing socio-economic progress whilst preserving the environment against land transformations in designated protected areas. This includes the definition of areas where cultivation of berries would be allowed[4]. However, it does not have an allocated budget and it does not include a specific program of measures.

In 2007, the Regional Government commissioned the preparation of a more specific Plan, subordinated to the General Plan and aimed at providing regulation to plan land and water use by agriculture. This specific plan (Special Plan for the Regulation of Irrigation in the Northern Part of Doñana', commonly known as the Special Plan for strawberry), was published at the end of 2010 for public information, but was still not approved in April 2014. It includes more specific tools and programs for the management and reorganization of water uses in agriculture, with a budget of 4.5 M€ for a 12-year period. The 2007 Special Plan includes the designation of ecological corridors, the reduction of subsidies for irrigated crops and training for irrigator communities.

Despite the approval of the 2004 General Plan, new land transformations for irrigated crops have been detected even inside protected areas, infringing current environmental policy and regulations stated under the General Plan and highlighting the usefulness of a forensic water governance approach to monitor land and water use changes.

3. An audit on land use policies using satellite imagery

Our analysis is designed following a 'forensic geographical science' approach, which we understand as a method based on scientific criteria for collecting information on geographical dynamic changes and events in the past, with aim of using this information

[4] Information included in this baseline cartography on intensive crops is based on; first, the analysis of aerial photographs taken in the years 2001–2002, second, direct interviews to farmers and third, field work conducted by technicians in 2001.

as legal evidence. In our case study, the 'crime' under analysis is illegal land and water use, with direct implication on the ecological status of a high-value ecosystem; the 'motivation' is considered to be a symptom of a deeper problem: the conflict between natural and human ecosystems; with a 'forensic analytic tool' based on integration of remote sensing and GIS.

Remote sensing has become one of the most powerful tools in the description and monitoring of land use changes, especially for regional scale studies, and has been utilised to map berry crops in NW Doñana in the years between 2002 and 2012. The applied methodology has already been tested in the area with reliable results (WWF-Spain, 2009). The availability of high-quality information depicting the spatial distribution and year of occurrence of land transformations has allowed an auditing process (figure 4) focused: first, on monitoring land use changes related to berry crops cultivation and second, on the comparison between information included in the management plans, and observed reality through GIS, which can in turn support policy and planning.

The outcomes answer three pivotal questions:

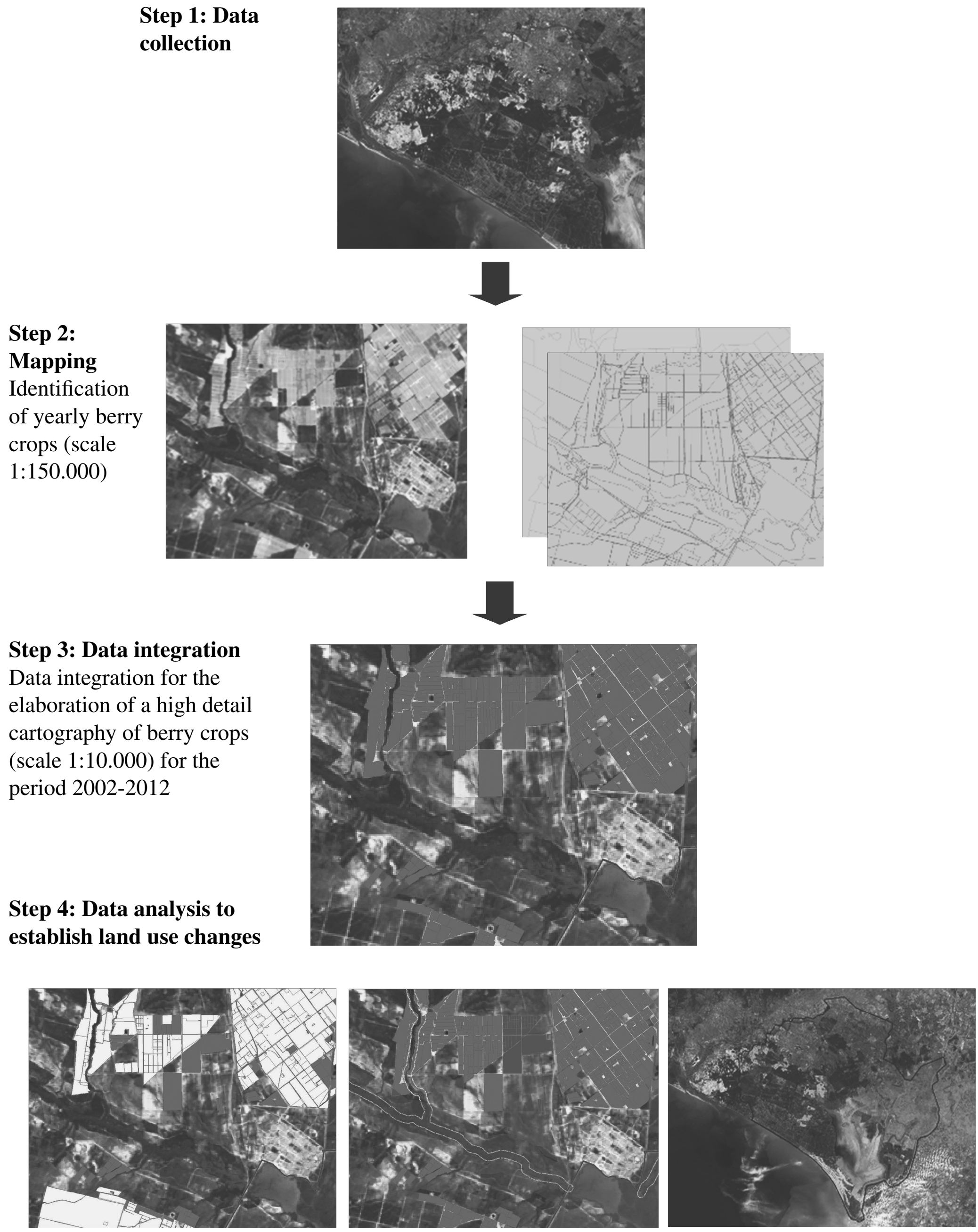
- **First**, whether *land and water use changes* are contemplated in the existing regulatory framework;
- **Second**, the *direct effect on land occupation* from lack of management plan enforcement
- **Third**, the *indirect effect on water inflow reduction* into Doñana marshlands from lack of management plan enforcement.

3.1. Analysis of farmlands awarded with legal rights for the cultivation of berry crops

In terms of *legal agricultural land use*, the cornerstone of any control procedure is the definition of legal users and rights. The method to identify potentially unauthorized farms is straightforward to implement *if geospatial data on the legal characterization is accurate and reliable*. The key enabling factor is the availability of high quality cartography that marks the spatial distribution of authorized farms within the territory. In this case, all agricultural uses outside the boundaries of the reference cartography can be easily identified. Meanwhile, a lack of definition in the distribution of legal plots provokes a situation of uncertainty on authorized use.

In this section, we analyse the geographic regulatory framework for allowed cultivation of berry crops in NW Doñana both for the 2004 General Plan and the 2007 Special Plan (still pending approval). It analyses how uncertainties and lack of enforcement have favoured an anarchic use of land and water resources.

According to the cartography in the *2004 General Plan*, the area in which berries can be cultivated covers 10,312 hectares. This includes both cultivated areas (8,568 hectares according to our analysis) and some non-agricultural areas, such as roads, service pathways, irrigation reservoirs, built-up infrastructures and bare soil. If a strict criterion is applied, farms located within this cartography are the only ones that should be considered legal. There are however, two cases where farms not included inside the General Plan cartography could be considered legal.



1. Identification of farmlands potentially not-legal

2. Quantification of not-authorized land use transformations: protected areas, green corridors, public forests.

3. Estimation of water abstraction for agriculture affecting Doñana marshlands.

Figure 4. Graphic presentation of the data audit: methodology of spatial analysis

The first case refers to farms that are not referenced within the cartography of the 2004 General Plan, due to inaccuracies. According to that Plan's directives, only farms which were cultivating berries in the 2002 season or before are entitled to a legal permit. The analysis of satellite images for 2002 demonstrates 524 ha occupied by greenhouses for berry cultivation that were not included within the official cartography.

The second case are farms affected from the delay between the acquisition of data for the elaboration of the 2004 General Plan's official cartography (2001-2002) and the date that the Plan was brought into force (February 2004). In between the process to approve the General Plan and after the initial map of existing berry areas had been produced and opened for public information, 596 hectares were transformed into areas of berry cultivation.

The *2007 Special Plan* was devised to refine and further develop the 2004 General Plan to establish a detailed legal geographic framework for irrigated areas to control water abstractions and protected land from intensive agriculture. The areas where irrigation would be permitted have been defined as the legal *land* identified in the 2004 General Plan, and second, *water* use for farms legally entitled by the Water Authority to irrigate, independently of the type of crop. There is an additional condition for berry farms: only those farms that have kept irrigated agriculture after the approval of the 2004 General Plan will be included in the final cartography. However, the maps of the 2007 Special Plan are significantly different from those of the 2004 General Plan, and create uncertainty regarding the future legal status of several farms.

First, the reference area encompasses a smaller area than that of the 2004 General Plan, accounting for 60.5% of NW Doñana region. Second, the map considers a wider scope of irrigation categories: intensive horticultural crops, citrus trees, other fruit trees, and other irrigation categories. Finally, the map of the Special Plan comes out from overlaying different maps, which exposes a number of incoherencies since the graphical representation of many plots do not correspond to their real shape (figure 5).

Figure 5. Graphical comparison between official maps of 'irrigable areas' (left image with yellow outline) and maps produced from this study (right image with blue border).

Table 1
Extension of potentially illegal berry crops (ha).

Area occupied by potentially not legal berry crops (ha)			
Scenario A:	Scenario B:	Scenario C:	Scenario D:
2004 General Plan	2004 General Plan + additional berry cultivated area before approval	2007 Special Plan	2004 General Plan + Additional berry cultivated area in 2004 + 2007 Special Plan
2,859	1,739	1,635	1,042
More restrictive scenario	→	→	Less restrictive scenario

As regards to the comparison between the 2004 General Plan and 2007 Special Plan, our analysis shows that an area of 606 ha included within the original 2004 General Plan maps have not been listed as irrigable area in the 2007 Special Plan; despite maps for berry crops, 2011–2012, showing that irrigation activity took place in these plots. Also, another 79 hectares of berry crops cultivated before 2004 not considered by the 2004 General Plan have not been incorporated into the 2007 Special Plan cartography. Meanwhile, 237 hectares labelled as 'horticultural crops' in the Plan were in areas where there were no greenhouses according to GIS data as well as some berry crops included within the map of irrigable areas also misclassified into other categories.

3.2. Consequences on land occupation of the lack of enforcement of land-use plans

The comparison between maps describing the formal regulatory framework (in terms of water and land use rights) and maps depicting real uses allows the identification of areas where land has been transformed without permission and /or water is potentially illegally abstracted.

3.2.1. Potentially illegal farms[5] The quantification of potentially illegal areas has been looked at under four possible different scenarios, depending on which plots are considered legal (see Table 1). The first scenario A (most restrictive) applies a strict criterion allowing only those areas identified within the 2004 General Plan as having rights to cultivate red berries. The second scenario B assumes that plots cultivated before the 2004 General Plan became enforceable would also be considered legal. The third scenario C includes as legal all areas identified as irrigable in the 2007 Special Plan. Finally, the last scenario D includes all farms that could have legal claims. Scenarios B and C coincide numerically but are in fact quite different in spatial terms: with only 697 ha coinciding as considered legal according to both set of conditions.

[5] Under Spanish Laws an action cannot be considered as illegal until a Court certifies that it is not in compliance with the Law. Under this premise, in this article we use the term 'potentially not legal' instead of the word illegal unless it refers to cases where a firm court sentence has been issued.

The total area cultivated with berries for the full period is estimated at 11,427 hectares. Thus, the percentage of potentially illegal berry land transformation ranges from 9% to 25% depending on the scenario considered. That is, under the strictest criteria in Scenario A, approximately a quarter of the area is potentially illegal, whereas in the most accommodating Scenario D, it would be closer to one tenth.

3.2.2. Non-authorized land use transformations Beyond the legal status of the farm plots, the effects from the expansion from red berries cultivation have resulted in an intense process of land use change: namely public land occupation, impact on green corridors, and transformation of natural spaces within protected areas.

a) *Public Forests*: One of the largest impacts has been deforestation into agricultural land. A large part of the forest area in the NW Doñana region is managed as public property under a specific figure known as 'Public Forest'. These lands are leased to private individuals or to companies licensed by the regional authorities for the temporary exploitation of land, as long as land use is compatible with forest conservation. However, a total surface of 2,554 hectares of 'Public Forest' has been transformed into berry crops. Furthermore, almost one fifth (417 hectares) were cultivated after the approval of the 2004 General Plan, even though the Plan established as a priority, that berry cultivation was not a suitable land use change (see Table 2).

b) *Protected areas*: The high percentage (42.9%) of Protected Areas inside the NW Doñana region illustrates its ecological importance. Under European legislation, there are six areas included within the *Natura 2000 network* as Sites of Community Importance (SCI), which include three national protected areas. The total amount of land area transformed within protected areas has been estimated at 586 hectares, as shown in Table 3.

c) *Green corridors*: the 2007 Special Plan develops a proposal formulated in the 2004 General Plan for the creation in NW Doñana of a green corridor network. The aim was to ensure the inter-connection and movement of species, especially land vertebrates between natural habitats. The total area transformed for berry cultivation within the boundaries of these proposed ecological corridors totals 243.6 hectares, of with 43.8 hectares might be considered illegal (shown in Table 4).

Table 2
Quantification of berry plastic-covered crops (ha) inside Public Forest areas.

'Legal' situation of the plot	Transformed area (ha)
Included in the 2004 General Plan (original transformations)	1,881.7
Out of the 2004 General Plan – cultivated in 2002 or 2004	254.9
Out of the 2004 General Plan – transformed after 2004	417.3
TOTAL	2,553.9

Table 3
Quantification of berry crops (ha) inside Protected Areas.

Protected area	Area occupied by berry crops (ha) Included in 2004 General Plan	Out of 2004 General Plan – cultivated in 2002 or 2004	Out of 2004 General Plan – transformed after 2004
Doñana Natural Park	-	-	178.4
Laguna de Las Madres	245.8	-	2.4
Estero de Domingo Rubio	2.6	-	0.4
North & West Doñana SCI	31.1	44.8	76.4
Doñana SCI	-	2.6	-
Marismas del Río Tinto SCI	0.9	-	0.8
TOTAL	280.4	47.4	258.4

Table 4
Quantification of berry plastic-covered crops inside proposed Green Corridors.

Surface occupied by berry crops inside green corridors (ha)	
Potentially legal areas	Potentially illegal areas
199.8	43.8

d) *Areas dedicated to environmental protection:* The 2004 General Plan segments the NW Doñana region into three zones according to its environmental value and protection level. The area of highest interest: "Zone A" incorporates protected areas, forests and the confluence of rivers and streams. The baseline for including all areas stipulated under any of the administrative figures discussed earlier is the year 2004 and a detailed cartography is provided in the 2007 Special Plan. Our final map of for berry cultivation transformed areas contains 626 hectares inside zone A of maximum environmental protection, according to the 2007 Special Plan area, and an additional 451 hectares in zone A of the 2004 General Plan yet outside the spatial scope of the 2007 Special Plan. Besides berry crops, other land-use changes into irrigated crops from forest/protected areas have been detected, which corresponds in most cases to new plantations of citrus and deciduous fruit trees, adding up to 250 and 50 hectares respectively.

e) Land use changes for cultivation of berry crops after the approval of the 2004 General Plan (described in Table 5).

The impact of groundwater abstraction on regular water contributions to Doñana National Park marshlands Irrigation practices in NW Doñana are based on pumping groundwater from the Almonte-Marismas aquifer and interconnected water courses, and strongly influence the water balance of Doñana marshlands (Custodio, Manzano, & Montes, 2008). The 2007 Special Plan stresses the importance of controlling water use for agriculture

Table 5
Quantification of land use change into berry crops since 2001.

Primary land use	Transformed area (ha)	Secondary land use	Transformed area (ha)
Agriculture (irrigated)	284.7	Farmlands (Irrigated)	106.8
		Fruit trees (including citrus)	177.9
Agriculture (rainfed)	376.6	Farmlands (rainfed)	253.8
		Olive trees	75.7
		Vineyard	47.1
Forest	563.7	Forest	281.6
		Forest (replanted)	5.9
		Forest/Pasture	2.9
		Forest/Shrubs	18.9
		Pasture	190.8
		Shrubs	63.6
Non-productive	514.4	Bare soils	95.8
		Non productive (agriculture)	366.5
		Non productive (peri-urban)	12.7
		Quarry	39.4
TOTAL	1,739.4		

in order to keep the minimum environmental flow to preserve the high ecological value of Doñana's ecosystems. In the case of the area in NW Doñana located on the Almonte-Marismas aquifer (see figure 1), the Plan determines a maximum groundwater consumption of 23 hm^3/year, with an additional contribution of 4 hm^3 coming from a diversion (to be constructed) from a neighbouring river basin. Our analysis for 2011[6] estimates the number of hectares cultivated with berries within NW Doñana and on the Almonte-Marismas aquifer to be 5,022 ha. No specific remote sensing study has been performed for other crops, so data on fruit tree distribution have been taken from the 2007 Special Plan (1,520 ha), after omitting plots with berry crops.

The annual water supply for irrigated crops is the main uncertainty in estimating overall water abstractions. The 2007 Special Plan states that maximum production for strawberries and fruit trees could be achieved with 4,000 m^3/ha if irrigation is applied efficiently and soils are correctly prepared before sowing. Thus, this water amount is the supply that is intended to be established as compulsory per hectare. However, in the same document it is also recognized that common irrigation practices consume considerably more water. Other references indicate that average yearly water use for strawberry cultivation varies between 5,500 and 7,500 m^3/ha, depending on the plant variety and soil

[6] This year was selected due to the availability of both satellite images and digital ortophotography.

structure. Reductions in this quantity seems difficult to achieve, since the share of water in the overall production cost is small and pricing schemes induce farmers to reach their production peak as soon as possible (Rodríguez & De Stefano, 2012). A similar quantity (7,000 m^3/ha) is used by farmers for fruit trees and citrus irrigation in the area. A simple calculation combining these data estimates total water abstraction at 43.3 hm^3, almost twice as much as would be permitted by the 2007 Special Plan.

The identification of legal/illegal water abstraction is again limited by the lack of clear definition, or indeterminacy, on the legal status of farms, thus it also needs to be analysed under different scenarios. The stricter Scenario considers that 1,142 hectares (22.7% of the 2011 berry crops area on NW Doñana and Almonte-Marimas aquifer) could be illegal, whilst the less restrictive identifies 673 illegal hectares (13.4%) in 2011, which means an estimate ranging between 4 and 7 hm^3.

4. Using geospatial data for 'better governance': accountability, participation and transparency

The detailed case study presented shows that, considering that many drivers are outside the water sphere, good accountability on water and land use, in this case as good *water accounting* and monitoring of water use and land use changes, is an essential condition for the implementation of a robust regulatory frame for adequate water governance (Dworak, 2010). Furthermore, in addition to monitoring and control, recent court rulings highlight that technology is seen as a legitimate source of information for sanctioning. Sanctioning is in fact also considered a fundamental aspect for robust institutional frames to prevent free riding and penalise cheaters. An example from the identification of illegal land use changes was the case of an agricultural site known as *El Avispero,* symptomatic of the anarchy in some areas within NW Doñana. A sentence by the Spanish Supreme Court meant that three land owners were found guilty of land transformations. This carried a jail sentence and paying for the costs associated with the restoration of the forest area and the diverted stream (estimated in nearly 600,000 Euros). It also included the sentencing of an environmental officer, who was found guilty of accepting bribes and being in collusion with the land owners.

An expert report presented by WWF-Spain displaying a sequence of satellite images and ortophotography (see figure 6) was admitted by the Court as evidence, stating that "the report depicting satellite images that reflect land use transformations between 2003 and 2009 is especially illustrative. There is no doubt about the authenticity of the images, since it is backed by official public agencies[7]". Therefore in a governance context, this example shows how new technology has given tools to oversee the execution of public functions, which normally were circumscribed to the administration, opening governance to prevent corruption and illegal land conversion and water use.

[7] This phrase is a direct translation from a part of the sentence 54/2012 [emitted in Spanish] by the Supreme Court, Criminal Courtroom.

Figure 6. Sequence of images showing the land use transformation into *Avispero* site.

Beyond monitoring, controlling and sanctioning, the outcomes of a ‘forensic geographical analysis’ are potentially useful in terms of bolstering two other principles (in addition to accountability) presupposed for ‘good governance’: participation and transparency.

In terms of the relationship between geographical monitoring and *participation*, this paper shows how information was used by an NGO as a means to an end: as advocacy to address unregulated land and water use changes in the proximity of a highly sensitive natural protected area. It also provided the information that could be followed up by the NGO in a participative manner. WWF-Spain developed an online tool[8] which depicted potential illegal water boreholes. This initiative was one of the drivers that provoked the National Public Prosecutor’s office to order an [open] investigation about the legal situation of agricultural boreholes in the region. The tool also enabled the local population and other stakeholders to interact by adding other potential illegal boreholes and thus completing the map through collective action. This in fact is relevant when considering that an aspect of the still to be approved 2007 Special Plan includes support to Irrigation Communities in their functions.

As regards *transparency* (in terms of information which is publicly accessible) it can help open the evidence on which the decisions are based. This in turn can facilitate public and stakeholder participation, as required under Art 14 of the EU Water Framework

[8] http://www.wwf.es/que_hacemos/donana/pozos_ilegales/

Directive, through the involvement by e.g. citizens, non-governmental organizations, academics and interested parties. Information transparency can prevent corruption in cases like NW Doñana, where the economic incentives for short term (illegal) land and water use change, combined with a risk of (local) political clientelism and rent seeking are high. Indeed, new technologies like the Internet, or in our case GIS, can enable greater citizen and user participation in policy formation and evaluation (Kim & Lee, 2012), and to create greater information exchange between citizens, users and public authorities.

Information *transparency* is an enabler for participation. As Coglianese, Kilmartin, and Mendelson (2009, p. 2) state, when people have access to the information upon which an agency relies, they can more meaningfully speak on the accuracy and adequacy of the information and conclusions that an agency chooses to draw from that information. Equally, according to Welch (2012) "Transparency provides stakeholders with knowledge about the processes, structures and products of government". Participation refers to the quantity, quality and diversity of input of stakeholders into government decision making and it is often bolstered by transparency of information, although in our case, its technical nature can be a barrier to participation.

Information transparency would be a fundamental element towards strengthening the role of Irrigator Communities for the detection of potentially not legal activities, ideally supported by participatory GIS tools, to help develop a potential collaborative co-produced tool and information between users and regulators to help ensure compliance in terms of land and water access and use rights. Illegal activities cause economic problems from the unfair competition by free-riders which on the one hand, results in lower product prices due to farming surpluses and on the other hand, the loss of reputation due to unsustainable practices, ever more important for export markets. Transparency on existing data –by means of online publication of data in e.g. a map format- could help improve governance through stakeholder involvement, resulting in a better defence of legitimate legal interests, while gradually helping to reduce corruption; a virtuous circle away from resource capture and accumulation, and towards increased local democratic governance and oversight (Sorensen & Torfing, 2007).

The analysis undertaken in the case study shows how advances in the use of GIS and remote sensing under a forensic science approach can facilitate monitoring and control: a classic sign of 'healthy' water management systems, which increases transparency, participation and makes water managers and users mutually accountable (Lopez-Gunn & Llamas, 2008).

5. Conclusions

When data availability and transparency are low, the dark side of governance can take root. Tools that enhance transparency and good quality data provide means to bolster governance (Koundouri, Kougea, & Stithou, 2012), particularly when there are heavy immediate short term political costs from the implementation of environmental regulation.

This paper has tested the concept of forensic water governance and how through technology, the monitoring and sanctioning aspects related to land and water use change can be strengthened. The case of NW Doñana has shown that, even for areas where information tends to be missing and/or is most inaccurate, technologies like remote sensing can help provide valuable data that supports a 'forensic analysis' of the system.

As shown in this paper, in the short term technology can offer a relatively affordable means to address one of the issues in the equation: namely, monitoring and control, meanwhile in the long term, increasing transparency and generating a robust baseline of accessible shared information on uses (and also of cheaters) can also help inform the local population on resource access and use. An increase in environmental awareness at the local level, facilitated through accessible information, could trigger the necessary involvement of civil society in discussions over water resource allocation. As pressures increase over limited resources, increased collaboration between public, private and civil society actors will be increasingly necessary, where 'forensic geographical science' could help determine or co-produce an accepted baseline through e.g. remote sensing and GIS to support monitoring, control and sanctioning under a more transparent, collaborative and participative governance process.

The forensic analysis evidenced as quantitative data presented in this article shows severe impacts on public forests, green corridors and protected areas due to unplanned and intensive land and water use changes. Political costs from regulatory compliance and inaccurate information translate into the slow implementation of the programs of measures. This in turn is provoking a situation of partial anarchy in current water management. The existence of potentially illegal boreholes seems to be socially accepted and indeed, some local and provincial public figures demand a general amnesty for these farmers, thus in one fell swoop gaining popularity while side stepping public accountability. This stresses the need for accurate and agreed information on land and water use in NW Doñana, which would have to consider and decide on the number of choice scenarios -and public policy actions needed- linked to the legal status of farmlands.

Information transparency can prevent corruption, cronyism and inertia, whilst supporting decisions that sometimes are politically difficult yet necessary (Bulkeley & Mol, 2003). In terms of future "lighter governance", GIS is particularly powerful because of its visualization potential, and its ability to communicate complex data in an accessible and verifiable format, supporting a dialogue between different stakeholders, which can be contrasted and ground-truthed with more local and experiential knowledge, to give the whole process greater legitimacy (Elwood, 2006). It can be the key to Pandora's box of dark side governance, since it can open debates and discussions that are normally kept locked, especially when it involves difficult political decisions on the part of rational politicians that seek to maximize their short term political stability, often by delaying fundamental public policy decisions.

Water governance in the case study region needs a clear frame that allows the co-existence of a sustainable agricultural model which also ensures the preservation of a unique space: Doñana. It also has to guarantee the continuity and viability of red berry crops, essential for the region's economy. With this aim, geospatial techniques can become an accessible and powerful tool for monitoring abstractions (public accountability), and to raise public participation and transparency. Forensic water governance supports three aspects to prevent or treat the dark side of governance; first, means and tools like e.g. participatory GIS to monitor and control land (and water) use, second, help oversee the implementation of regulatory frames in a clear and transparent manner, and help enforcement of regulation e.g. through sanctioning of illegal water use. It offers an inroad for some basic governance functions like clear regulatory frames, monitoring and sanctioning supported by governance principles like accountability on water use, transparency through better data, and open the door for user and civic society participation.

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