Managing agricultural systems for biodiversity conservation

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EXTERSIAL PROJECT 2010-2012: Spanish R&D National Plan

• Objective: To elaborate a methodological proposal on the analysis and the assessment of the territorial externalities created by the economic and institutional activities of the Local Agro-food Systems

➢ In particular: Protected designations of origin (PDO) of olive oil in Spain

➢ The approach incorporates concepts & methodologies influenced by the normative theories of multifunctionality & by the theories of Local Agro-food Systems → it is focused to the implementation of public policies

➢ Institutions participating in EXTERSIAL: CCHS/CSIC, CITA/Aragón, U. Complutense (Madrid), U. Sevilla, U. Zaragoza, INRA Montpellier & UNAM (México)
EXTERSIAL: analysis and valuation of territorial externalities in olive oil PDOs

1. Supply of agri-environmental externalities: agri-env. models on natural heritage and agricultural landscapes

2. Supply of social, economic and cultural externalities: local olive oil chain governance and territorial governance (Social Network Analysis and data anal.)

3. Demand for territorial externalities: analysis of social preferences for valuating non-market goods, based on the opinion of local experts (Analytic Network Process techniques) → weighting factors for the values of the supply of externalities

4. General model for the valuation of the territorial externalities
EXTERSIAL: Supply of environmental externalities (i)

- Environmental externalities, natural heritage and agricultural landscapes: a multivariable methodology through GIS, RS information and statistical techniques for the characterisation of olive landscapes and for the generation of agri-environmental models (including those related to the food industry)

- Hypothesis: whether olive-growing areas which are more marginalised in physical terms (olive groves on slopes) are also more marginalised economically, and whether they also produce more externalities, particularly erosion.
EXTERNAL: Supply of environmental externalities (ii)

- Analysis related to the supply of environmental externalities:
  - Erosion potentiality (GIS)
  - Potential for vegetation colonisation (GIS)
  - Structural and spatial configuration of the landscape (GIS)
  - Land management indicators, agricultural and agro-industrial practices indexes (surveys to farmers and mills)

- Territorial results: zoning of areas in terms of negative environmental externalities values generated by olive oil Local Agro-food Systems
EXTERSIAL: important facts concerning Andalusian olive oil PDOs and envir. externalities

✓ The Andalusian olive oil PDOs are a fine example for the analysis of the multifunctional behaviour → as a result of the collective action, they can produce public goods

✓ It is necessary to reward the stakeholders paying for their function of supplying public goods:

  • One of the most important environmental externalities is soil erosion, mainly in mountains and hillsides (74% of the surface has a slope ≥ 8%) → Introduction of vegetal cover serves for reducing erosion
  • The conservation and enhancement of native vegetation patches improves biodiversity → it produces externalities that improves integrated pest management, essential in integrated and organic olive production.
EXTERSIAL: important facts concerning Andalusian olive oil PDOs and envir. externalities

Managing agricultural systems for biodiversity conservation
Introduction

• Agricultural systems impact on the conservation of biodiversity, but, also, farming landscapes host a rich biodiversity
• It is necessary to raise awareness of the role of biodiversity components in agricultural systems
Introduction (cont.)

• The linkages between agriculture and biodiversity should be noted because:
  - co-evolved wild species dependent on agro-ecosystems
  - wild species and natural habitats that are directly or indirectly linked to agro-ecosystems
  - wild species’ genomes that may contribute to the continued productivity of crop species and biodiversity that contributes to resource productivity and quality
Introduction (cont.)

Agricultural systems and biodiversity value

<table>
<thead>
<tr>
<th>Natural habitats</th>
<th>Extensive use</th>
<th>Shifting cultivation</th>
<th>Permanent croplands</th>
<th>Intensive croplands</th>
<th>Degraded lands</th>
</tr>
</thead>
</table>

Intensification gradient

Biodiversity value

“Yield”, or direct use value

From: Phalan et al. 2011
Empirical cases

**Figure 2.** Ant species diversity as a function of the intensification gradient in coffee plantations in Costa Rica and Mexico (from Vandermeer & Perfecto 2000). From: Perfecto & Vandermeer 2008

**Box 1.4.** Bird species decline due to agricultural intensification. Marked declines in bird species populations across Britain are due to agricultural intensification (Donald et al. 2001). Many upland grassland bird species are especially impacted (Henderson et al. 2004). Figure is from DEFRA (2004). The index is the percentage change in bird species in various categories relevant to a 100% baseline value for 1970. Above are two farmland-dependent bird species that have suffered recent population declines in Britain as a result of farm management practices. From: Jackson et al. 2005
Introduction (cont.)

• An important goal of ecological compensation measures in agricultural areas (mainly CAP regulations) is the conservation and enhancement of regional biodiversity.

• However, some current European agri-environment schemes to conserve biodiversity maintaining productivity seem to be rather ineffective.
• There are two competing solutions for this inefficiency:
  - In intensely cultivated landscapes (homogeneous) a likely explanation of this inefficiency is the lack of source populations and vegetation. In these cases, environmentally (or wildlife or biodiversity)-friendly farming would be applied (land sharing)
  - In heterogeneous agricultural landscapes some native vegetation patches would be maintained (land sparing)
Objectives

- We have determined landscape structure (land uses and land cover) for different years (1956; 1999; 2003) in two olive systems in Protected Designation of Origin (PDO) of Estepa and PDO of Sierra de Segura (Andalusia, Spain).
- We have studied landscape changes during this range of years (1956-2003).
- We have proposed viable agricultural management for biodiversity (landscape) conservation according to landscape structure and landscape change of both PDO.
Study area

Geographic area: Spain, Autonomous Community of Andalusia
Study area: Protected Designations of Origin Estepa and Sierra de Segura
Technical specifications
Reference System: ETRS89 UTM Zone 30 N
Scale: 1:10,000 to 1:100,000
Methodology

• To know environmental and biological characteristics of landscape of both PDO studied we design and build a geodatabase (data of climate, geology, geomorphology, edaphology, hydrology, slope, altimetry -DMT-) using a GIS (ArcGIS 10.0 software)
• To determine landscape composition and configuration we have mapped land uses and land cover, using GIS too, at different years (1956; 1999; 2003 and 2007)
• To detect the type of change of the landscape we have applied transition (confusion or cross-tabulation) matrices (Pontius et al. 2004) and we have established areas and land uses changed (land loss, land gains and net change of each land use in the range of 47 years studied)
• To quantify landscape change (spatial patterns), to infer ecological process (as species dispersion) and to assess the function of landscape we have used landscape metrics (from Fragstats 3.3 software and Rescia et al. 1994; 2010)
The Extersial project: diagram of phases of environmental section
The Exterisial project geodatabase
Transition matrix

<table>
<thead>
<tr>
<th>Category 1</th>
<th>Category 2</th>
<th>Category 3</th>
<th>Category 4</th>
<th>Total time 1</th>
<th>Loss</th>
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<td>P_{12}</td>
<td>P_{13}</td>
<td>P_{14}</td>
<td>P_{1+}</td>
<td>P_{1+}</td>
</tr>
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<td>P_{21}</td>
<td>P_{22}</td>
<td>P_{23}</td>
<td>P_{24}</td>
<td>P_{2+}</td>
<td>P_{2+}</td>
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<td>P_{33}</td>
<td>P_{34}</td>
<td>P_{3+}</td>
<td>P_{3+}</td>
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<tr>
<td>P_{41}</td>
<td>P_{42}</td>
<td>P_{43}</td>
<td>P_{44}</td>
<td>P_{4+}</td>
<td>P_{4+}</td>
</tr>
<tr>
<td>Total time 2</td>
<td>P_{+1}</td>
<td>P_{+2}</td>
<td>P_{+3}</td>
<td>P_{+4}</td>
<td>1</td>
</tr>
<tr>
<td>Gain</td>
<td>P_{+1} - P_{11}</td>
<td>P_{+2} - P_{22}</td>
<td>P_{+3} - P_{33}</td>
<td>P_{+4} - P_{44}</td>
<td></td>
</tr>
</tbody>
</table>

Pontius et al. 2004

PDO of Estepa 1956-1999
Cross-scaling spatial analysis to detect structure and function of landscape

- Landscape matrix
  - Unit of analysis: Land use patches
- Mediterranean forest network (potential natural restoration of the landscape)
  - Unit of analysis: woody and shrubland patches
- Olive crops (food productivity)
  - Unit of analysis: olive crops patches
Landscape metrics from Fragstats 3.3

(C122) Connectance Index

\[
\text{CONNECT} = \frac{\sum_{j<k} c_{jk}}{n(n-1)}
\]

- \(c_{jk}\) = joining between patch j and k (0 = unjoined, 1 = joined) of the corresponding patch type (i), based on a user-specified threshold distance.
- \(n\) = number of patches in the landscape of the corresponding patch type (class).

Description:
- CONNECT equals the number of functional junctions between all patches of the corresponding patch type (sum of \(c_{jk}\), where \(c_{jk} = 0\) if patch j and k are not within the specified distance of each other and \(c_{jk} = 1\) if patch j and k are within the specified distance), divided by the total number of possible junctions between all patches of the corresponding patch type, multiplied by 100 to convert to a percentage.

Units: Percent

Range: 0 \(\leq\) CONNECT \(\leq\) 100

CONNECT = 0 when either the focal class consists of a single patch or none of the patches of the focal class are "connected" (i.e., within the user-specified threshold distance of another patch of the same type). CONNECT = 100 when every patch of the focal class is "connected".

Comments:
- Connectance is defined as the number of functional junctions between patches of the corresponding patch type, where each pair of patches is either connected or not based on a user-specified distance criterion. Connectance is reported as a percentage of the maximum possible connectance given the number of patches.
- Connectance can be calculated on either Euclidean distance or functional distance, as described elsewhere (see Euclidean/Functional Distances), although this is not implemented yet. Also, note that Euclidean distances are calculated from cell center to cell center. Thus, two patches that have 10 10-m cells between them have a computed distance of 110 m, not 100 m.
## Landscape metrics from Rescia et al. 1994; 2010

<table>
<thead>
<tr>
<th>Landscape Indices</th>
<th>Definition</th>
<th>Spatial Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N )</td>
<td>Total number of boundaries between land uses ((N \geq 1))</td>
<td>Indicates the grain size of land uses and suggests the degree of fragmentation of the landscape</td>
</tr>
<tr>
<td>( n )</td>
<td>Richness. Total number of types of boundaries between land uses ((1 \leq n \leq N))</td>
<td>Indicates the variety (different boundaries) of land uses of the landscape</td>
</tr>
<tr>
<td>( E_b )</td>
<td>Evenness. Relative abundance of the different boundaries between land uses ((0 \leq E_b \leq 1))</td>
<td>Indicates the spatial configuration of landscape. The maximum (E_b) indicates a landscape with an even distribution of boundaries between uses (inversely to dominance)</td>
</tr>
<tr>
<td>( D_b )</td>
<td>Diversity of boundaries. It takes into account ( n ) and ( E_b ). Strictly speaking, measures the degree of uncertainty of finding at random determined boundary between land-uses ((0 \leq D_b \leq \log_2 N))</td>
<td>Indicates the variety and distribution of the boundaries between land uses. It is a measure of information (organization and history) contained in the landscape</td>
</tr>
<tr>
<td>( H_b )</td>
<td>Landscape heterogeneity. It takes into account, ( N ), and ( H_b ). When ( n = N, H_b = 1 ) ((0 \leq H_b \leq 1))</td>
<td>Indicates the spatial variability or structural heterogeneity of the landscape but does not express landscape functionality (Two equal ( H_b ) landscapes do not imply two equal spatial complexity landscapes)</td>
</tr>
<tr>
<td>( C_{(e)} )</td>
<td>Spatial complexity. Measurement of the combination of spatial neighbours found in a space with a given ( N, H_b ), and ( H_b )</td>
<td>Indicates landscape functionality (possibility of flows of matter, energy and species). It enables the number of interactions between land uses and the degree of landscape connectivity to be inferred (the highest ( H_b ) implies the greatest ( C_{(e)} ))</td>
</tr>
</tbody>
</table>
Results

PDO of Estepa and PDO of Sierra de Segura have different landscape structure.

PDO of Estepa have a relatively homogeneous landscape with a predominance of olive crops (62% of total area).

PDO of Sierra de Segura presents a heterogeneous landscape where olives are not predominant (21% of total area). Furthermore, this PDO is part of a Protected Natural Park of Sierra de Segura, Cazorla-Las Villas.
Results

Land use changes between 1956-2003

• In PDO of Estepa main change tendency was the increase of olive crops (close to 4,000 ha) but also some parcels were abandoned (7,000 ha, essentially in the range of years 1956-1999)

• The urbanization process is not important but it was bigger in the last 4 years that in the past 43 years. 7,500 ha of herbaceous crops was lost

• In PDO of Sierra de Segura main change tendency was the decrease of herbaceous crops (more than 13,000 ha) and shrubs (8,000 ha). Olive crops increase 8,300 ha, but not olive crops were abandoned. Forests and plantations have increased (close to 11,000 ha)
Type of change in PDO Estepa

Loss and Gain of each land use between 1956-1999

- Zonas ind.com y...
- Talas y...
- Pastizal arbolado
- Olivares regados
- Mosaico de cultivos
- Matorral
- Cultivos herbaceos...
- Bosque
- Aguas continentales

Loss and Gain of each land use between 1999-2003

- Zonas ind.com y...
- Talas y plantaciones...
- Pastizal arbolado
- Olivares regados
- Mosaico de cultivos
- Matorral
- Cultivos herbaceos...
- Bosque
- Aguas continentales

Olive crops

- Olivar
- Loss
- Gain

Herbaceous crops

- Cultivos herbaceos...
- Loss
- Gain

Area (ha)
Type of change in PDO Sierra de Segura

Loss and Gain of each land use between 1956-1999

- Urbano
- Talas y plantaciones forestales recientes
- Roquedos y suelos desnudos
- Pastizal arboreto
- Pastizal
- Olivares regados
- Olivar abandonado
- Olivar
- Mosaico de cultivos y vegetación natural
- Mosaico de cultivos
- Matorral arboreto
- Matorral
- Cultivos leñosos
- Cultivos herbaceos arboreto
- Cultivos herbaceos
- Bosque
- Balsas alpechin
- Aguas continentales

Hectareas

- Gain
- Loss
Type of change in PDO Sierra de Segura

Loss and Gain of each land use between 1999-2003

- Hectareas

- Zonas ind, com y transportes
- Talas y plantaciones forestales recientes
- Pastizal arbolado
- Olivares regados
- Olivar
- Mosaico de cultivos
- Matorral
- Cultivos herbaceos arbolados
- Bosque
- Aguas continentales

- Pastures
- Olive crops
- Shrubs
- Herbaceous crops

- Loss
- Gain
Results

Landscape spatial structure change

• In PDO of Estepa the spatial structure has changed but essentially in a greater presence of olive crops: Interspersion and Connectivity indices related to this land use have increased.

• At landscape scale the Patches Richness, Diversity, Evenness and Complexity indices have increased but Connectivity is decreasing.

• In PDO of Sierra de Segura changes in the spatial structure have reflected a decrease in the Connectivity and Interspersion of olive crops.

• At landscape scale Patches Richness increased but Diversity, Evenness and Complexity have decreased.
Landscape structure changes in PDO Segura

Olive patches evolution in PDO Segura

Percentage

1956

Landscape evolution in PDO Segura

Percentage

1956

Landscape evolution in PDO Segura

Nat


Years
Synthesis of Results (land use changes)

In general, in both cases olive crops (several parcels with irrigation) have increased mainly replacing herbaceous crops (arable lands)

PDO of Estepa

• There was abandonment of olive crops and an incipient process of urbanization
• Landscape structure remains relatively similar with a high presence of connected olive land use
Synthesis of Results (land use changes)(cont.)

PDO of Sierra de Segura

• There was a loss of shrubs and an increase of forests (and plantations)
• Landscape structure is more dynamic than Estepa (in area and land uses involved). Apparently there has been a little nature forest restoration but a loss of other native vegetation (as shrubs and pastures)
Synthesis of Results (landscape changes)

In both cases the olive crops area have increased but with different spatial pattern

• In Estepa the increase of olive land use was disperse through total PDO area, consolidating an agricultural landscape with one predominant crop very connected

• In Sierra de Segura the increase of olive land use occurred in a concentrated area (Northern of PDO) and other changes occurred in the Mid and Southern of PDO. Sierra de Segura is an heterogeneous landscape with agricultural areas but with an important presence of native vegetation
Discussion (about land use changes and landscape changes)

• In PDO of Estepa, has been an intensification process (increase of irrigation practices) in the olive crops together with an incipient rural abandonment process as European rural world in general due to socioeconomic changes (very influenced by CAP regulations)

• In the last years the urbanization process developed in Spain has led to an expansion of industrial and habitability constructions in the area

• Landscape is more diverse and complex because of the occurrence of ‘new’ land uses (as abandoned and irrigated olive crops)
Discussion (about land use changes and spatial pattern)

• In PDO of Sierra de Segura, olive crops have expanded in a relatively concentrated area due to landform restrictions but other land uses, as plantations, are being developed in more restricted areas (with higher slope) affecting native vegetation.

• Much of the territory of Sierra de Segura is a protected area then, is very important to maintain an heterogeneous landscape (food production and biodiversity conservation) but land uses changes are leading to a less diverse and complex landscape.
Discussion (about management for biodiversity)
Land sparing vs. Land sharing

From: Phalan et al. 2011
Land sparing vs. Land sharing: underlying scientific foundations

From: Fischer et al. 2008

<table>
<thead>
<tr>
<th>Coarse grain and abrupt change</th>
<th>Fine grain and spatial continuity</th>
</tr>
</thead>
<tbody>
<tr>
<td>(“Land sparing”)</td>
<td>(“Wildlife-friendly farming”)</td>
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</tbody>
</table>

**Underlying scientific traditions**

<table>
<thead>
<tr>
<th>Binary landscape (“island model”)</th>
<th>vs Continuous and heterogeneous landscape</th>
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<tbody>
<tr>
<td>Optimization for equilibrium</td>
<td>vs Maintenance of resilience</td>
</tr>
<tr>
<td>Species treated as additive</td>
<td>vs Species interactions of major interest</td>
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<tr>
<td>Nature and agriculture treated as separate</td>
<td>vs Externalities and ecosystem services considered</td>
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<tr>
<td>Humans considered separate from nature</td>
<td>vs Humans considered part of nature</td>
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</table>
Land sparing vs. land sharing: how best to reconcile food production and biodiversity?
Agricultural canonical landscape for biodiversity conservation

Example of biodiversity management on the farm

- Remnants of natural and seminatural habitats (and vegetation) can contribute to regional biodiversity in various ways:
  - as essential habitats for specialised species
  - as stepping stones
  - as potential for vegetation restoration
Conclusions

• Tendency of landscape changes show an expansion of olive crops accompanied by an intensification process (irrigation) and an extensification process (abandonment)

• Landscape spatial pattern is changing too. Patch and landscape indices allow to appreciate a loss of spatial diversity in Sierra de Segura and an increase of landscape diversity in Estepa
Recommendations

- We propose to conserve remnant patches of natural or seminatural habitats (and vegetation) that provide the most important source populations and potential restoration of native vegetation for agri-environment schemes in order to enhance biodiversity. An agricultural landscape planning should be focused on conserving farm genetic resources, agricultural ecosystem services and biodiverse agricultural landscape.
- In Sierra de Segura this approach would be possible but in the case of Estepa a ‘wildlife friendly’ management would be advisable.
- Complementary paying for ecosystem services to farmers would be a good option to conserve agricultural landscapes.
Possible trade-offs between agricultural production and biodiversity

From: Brussaard et al. 2010
Characteristics of ecosystem services and payment mechanisms

<table>
<thead>
<tr>
<th>Ecosystem service</th>
<th>Public-good type</th>
<th>Verifiability</th>
<th>Space</th>
<th>Time</th>
<th>Jurisdiction</th>
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From: Kinzig et al. 2011