Reg Environ Change (2014) 14:1229–1242
DOI 10.1007/s10113-013-0569-5

ORIGINAL ARTICLE

Building resilience to water scarcity in southern Spain: a case study of rice farming in Doñana protected wetlands

Silvestre García de Jalón · Ana Iglesias · Ruth Cunningham · Juan I. Pérez Díaz

Received: 19 April 2013 / Accepted: 30 November 2013 / Published online: 15 December 2013

Abstract Agricultural water management needs to evolve in view of increased water scarcity, especially when farming and natural protected areas are closely linked. In the study site of Doñana (southern Spain), water is shared by rice producers and a world heritage biodiversity ecosystem. Our aim is to contribute to defining adaptation strategies that may build resilience to increasing water scarcity and minimize water conflicts among agricultural and natural systems. The analytical framework links a participatory process with quantitative methods to prioritize the adaptation options. Bottom-up proposed adaptation measures are evaluated by a multi-criteria analysis (MCA) that includes both socioeconomic criteria and criteria of the ecosystem services affected by the adaptation options. Criteria weights are estimated by three different methods—analytic hierarchy process, Likert scale and equal weights—that are then compared. Finally, scores from an MCA are input into an optimization model used to determine the optimal land-use distribution in order to maximize utility and land-use diversification according to different scenarios of funds and water availability. While our results show a spectrum of perceptions of priorities among stakeholders, there is one overriding theme that is to define a way to restore part of the rice fields to natural wetlands. These results hold true under the current climate scenario and even more so under an *increased water scarcity scenario*.

S. García de Jalón · A. Iglesias (✉) · R. Cunningham
Department of Agricultural Economics and Social Sciences, Technical University of Madrid, Madrid, Spain
e-mail: ana.iglesias@upm.es

J. I. Pérez Díaz
Department of Civil Engineering, Hydraulics and Energy, Technical University of Madrid, Madrid, Spain

Keywords Adaptation · Multi-criteria analysis · Ecosystem services · Stakeholders · Land-use optimization

Introduction

Water scarcity in the Mediterranean region is a critical issue and will become more extreme as the frequency of occurrence and severity of climate change impacts are projected to increase (Giorgi and Lionello 2008; Hoerling et al. 2012). Since climate change brings new uncertainties and threats to already existing water scarcity risks, building resilience is crucial as to whether agriculture is to adapt to climate change (FAO/OECD 2012). As water scarcity becomes more noticeable and costlier, some current water management strategies will no longer be useful and the changed situation will call for adaptation strategies that directly tackle the water scarcity issue (Iglesias et al. 2011). Nevertheless, adaptation toward water scarcity generally entails the design of new water policies which may give rise to potential conflicts among stakeholders given the discord among their perceptions and interests.

Agriculture in southern Spain suffers the most adverse effects from water scarcity as it is by far the largest water-consuming sector (Rodríguez Díaz et al. 2007; Nieto and Rodríguez-Puebla 2006). As climate change impacts are expected to notably worsen conditions, the adaptation of agriculture has recently received increased attention in the scientific and policy debate (UNFCCC 2011; Iglesias et al. 2011). However, the situation becomes more complicated when water needs for agricultural and natural systems exceed the total water availability, and the attempt to satisfy the total agricultural water need is mainly caused by natural protected areas having poor ecological conservation status (Falkenmark et al. 2007). When this occurs, the optimal provision of ecosystem services for both agricultural and natural systems cannot be reached separately, and therefore, it should be pursued for both systems as a whole rather than independently (Falkenmark et al. 2007).

The evaluation of climate change adaptation options is a complex process due to the stakeholders' differing needs and views, and further still the difficulties involved in quantifying the effects of the options. For this reason, adaptation assessments typically entail multiple stakeholders from different sectors as well as multiple objectives related to the use of resources and perceived benefits. Various methodologies have been used to assess adaptation options such as cost–benefit analysis, cost-effectiveness analysis and multi-criteria analysis (MCA) among others (UNFCCC 2011). Yet, while all these methodologies are useful tools to assess adaptation options given their inclusivity of economic, social and environmental preferences, one of the main strengths of MCA is that it can accommodate quantitative as well as qualitative information. Due to its flexibility, the use of MCA in decision-making processes for the purpose of adaptation has considerably increased in the last decade as it provides an alternative when only partial data are available and criteria are difficult to quantify. Nonetheless, there are some difficulties associated with MCA when assigning weights to criteria and standardizing scores, principally when there are a large number of criteria and they are very different in character (UNFCCC 2011). As there is not always agreement between criteria and their relative importance, stakeholder participation plays a key role on the assessment of the options.

Building resilience for adaptation to water scarcity contributes to the sustainability of agriculture and calls for the maintenance of the good ecological status of natural areas (FAO/OECD 2012). Hence, the adaptation assessments need to jointly address changes in both agricultural and natural systems and in the benefits they provide. Thus, in order to measure the variations in the quality levels of the benefits provided by agricultural and natural systems, many authors recommend the use of the ecosystem services concept (Costanza et al. 1997; Dale and Polasky 2007), defined as the benefits to humankind from a multitude of resources and processes that are supplied by ecosystems (MEA 2005). However, the use of the ecosystem services concept in MCA is still largely missing, despite the fact that its consideration as criteria in the analysis represents a helpful tool to assess adaptation options effects (Daily and Matson 2008). On the other hand, in using only ecosystem services as criteria in the MCA, some relevant socioeconomic aspects, which may be affected by the adaptation options and are not easily identified within the ecosystem services, could be missed (Koschke et al. 2012). Thus, the combination of ecosystem services with other socioeconomic criteria is strongly recommended to assess the potential effects of adaptation options (Dale and Polasky 2007).

Assessments of climate change adaptation strategies were until recently predominantly conducted at large spatial scales and consequently with high aggregation levels (de Bruin et al. 2009; Stern 2007; EEA 2007; Bindi and Olesen 2011). Some studies have pointed out the need for adaptation assessments on smaller scales and regionalizing the effects of adaptation strategies that are often due to the very coarse grid of climate scenarios (Porthin et al. 2013; Kuik et al. 2011). This study has used climate scenarios on both large (Giorgi and Lionello 2008) and small spatial scales (Spanish Agency of Meteorology 2013; Rodríguez Díaz et al. 2007), which generally agree on their predictions of an increase in temperature and a decrease in precipitation in the Guadalquivir river basin (Spain). In the last years, a multitude of studies have focused on adaptation analysis at regional or local scales (e.g., Huntjens et al. 2010; Porthin et al. 2013; Miller and Belton 2011) from which bottom-up approaches can be used to support policy- and decision-making processes. In doing so, MCA is a helpful tool for decision making in natural and agricultural systems, and its use is quite well accepted in analyzing adaptation options at local or regional scale (e.g., Miller and Belton 2011; Porthin et al. 2013; Mustajoki et al. 2004; UNFCCC 2011).

This paper outlines an approach to assess the adaptation options to water scarcity in an agricultural area strongly affected by the influence of the protection of a national park where water conflicts are expected to be exacerbated with climate change. Table 1 indicates the research questions of this study and the methodological approach undertaken to address each question. Firstly, since stakeholders have different interests, they do not perceive the same adaptation needs and criteria to assess adaptation options. For this reason, an approach that relied on stakeholders' participation and included all different points of view such as MCA was used to assess adaptation options. However, the adaptation assessment is not only influenced by local stakeholders since external policies may have a crucial role in supporting adaptation. In the EU, the current Common Agricultural Policy (CAP) contributes to adaptation of agriculture in several ways (White paper 2009). Firstly, the current CAP provides a basic level of income security to farmers. Secondly, the decoupled support enables adaptation to market and agronomic conditions. Thirdly, the cross-compliance provides a framework for sustainable management of the natural environment. Finally, the rural development policy enables a large array

Table 1 Research questions in the case study, implications for building resilience to water scarcity and methodological approach in the study

Research question in the case study	Main implications for building resilience to water scarcity	Methodological approach in the study
How do stakeholders perceive the need to adapt to an increased water scarcity?	Agreement on perceptions of water scarcity risks and choices for water allocation	Consultation to experts and interest groups and multi-criteria analysis
How do stakeholders perceive the relative importance of the criteria when assessing adaptation strategies?	Agreement on choices of criteria weights for the assessment of adaptation	Analytic hierarchy process and Likert scales
What are the best adaptation options to ensure resilience to water scarcity?	Maximizing ecosystem services provision and other relevant socioeconomic criteria	Multi-criteria analysis
How may the 2014 reform of the Common Agricultural Policy contribute to adaptation?	Implementation of policy may lead to adaptation or maladaptation	Multi-criteria analysis
Can projected water availability maintain current rice area? What is the optimal mix of land use under different scenarios?	Choices of water and budget availability scenarios for optimal land-use distribution	Land-use optimization model

of adaptation options involving adaptive capacity and implementing actions to be supported. However, the CAP reform could change the current contribution to adaptation in which a possible outcome of some determined policies might even lead to maladaptation. For instance, the new design in direct payments, especially the flattening, might lead to a decrease in financial support and consequently diminish the adaptive capacity of the sector. On the other hand, other proposals of Pillar I as the new 'green' payment or the enhanced cross-compliance for climate change may lead to the sustainable management of the natural resources which might help to build resilience to climate change. Pillar II also proposes some measures in order to build resilience to climate change such as improving farm advisory systems and support from research, innovation and knowledge transfer.

Case study: water for rice production near the Doñana National Park

Water for rice production near the Doñana National Park

The study area, hereafter Doñana rice fields, is located in the Guadalquivir River Delta (province of Seville, Spain), bordering Doñana National Park. Doñana rice fields extend over 36,000 ha and exemplify many other areas in the Mediterranean where water for agricultural production needs to be carefully reallocated in view of current and projected limitations, especially considering the conflicts between water for agriculture and water for natural ecosystems.

Building resilience to water scarcity is crucial to ensure the sustainability of Doñana rice fields as it is one of the main threats (del Moral Ituarte 1993; CAP 2007). The average irrigation allocation for rice production is 14,000 m^3 ha^{-1} $year^{-1}$, making it the crop with the highest water consumption within the Guadalquivir basin. The large quantities of water consumed by rice frequently lead to conflicts between rice producers and other water users (Rodríguez Díaz et al. 2007). Rice farming is further threatened by the decrease in financial support from the CAP over time since it has been strongly supported by the CAP in the last decades (CAP 2007). Finally, since the nearby wetlands of Doñana National Park are protected by UNESCO and many other international treaties, one final challenge is the need to solve competition between producers and natural ecosystems, which is expected to be more disputed as societal environmental concern increases.

Climate scenarios and future water availability in Doñana rice fields

Water availability for agriculture is currently challenging rice farming sustainability in the Guadalquivir basin (Spain). Proof of this can be seen in the period 1983–2013 when the average cultivated area of Doñana rice fields as a percentage of the total area decreased by more than 20 % due to recurrent droughts (CAPMA 2013). In addition to this, climate change imposes new challenges due to the predicted decrease in water availability for irrigation and higher water demands in the Guadalquivir basin over the course of the twenty-first century (Giorgi and Lionello 2008; Rodríguez Díaz et al. 2007). There is observational evidence of century-long negative trends in regionally averaged precipitation and discharge from numerous Mediterranean rivers (Hoerling et al. 2012), which has clearly been observed in the Guadalquivir basin and has accelerated toward the turn of the century (Nieto and Rodríguez-Puebla 2006). Using multi-model simulations, Mariotti et al. (2008) state that by the end of the twenty-first century, the average of the models predicts a 20 % decrease in land surface water availability due to precipitation reduction and warming enhanced evaporation, with a remarkably high consensus among analyzed models. This study is based on the climate scenarios of the studies mentioned above to build resilience in Doñana rice fields.

Methods

Identification and categorization of the adaptation options

The adaptation options were indentified on the basis of a previous assessment of risks, impacts and vulnerability of the area in addition to a participatory process of stakeholders (more information available in De Stefano et al. (2013) and Iglesias et al. (2012)). The participatory process was based on three 1-day stakeholder workshops carried out in Seville between February and October 2012. Direct beneficiaries of the Doñana rice fields were identified as rice farmers, environmentalists and policy makers among others, and subsequently through a snowball sampling technique, indirect beneficiaries were identified and invited to participate in the workshops. These beneficiaries included stakeholders representing other sectors such as other agricultural activities, aquaculture and tourism. In the first workshop, stakeholders were asked to propose adaptation strategies to climate change through a brainstorming process. Subsequently, among a large number of the suggested adaptation options, stakeholders were asked to select the three options that they considered most beneficial. In the second workshop, the criteria to assess adaptation options were discussed and a final vote was conducted to reduce the number of options. In the third and final workshop, stakeholders were asked to answer a questionnaire about the weights of the criteria to evaluate the adaptation options as well as the score of the options against each criterion. Some questionnaires were sent via e-mail to those stakeholders who did not attend the third workshop. In total, twenty-three questionnaires from stakeholders were analyzed and used to conduct the MCA. The respondents were classified into three different stakeholder groups, rice farmers ($n = 8$), environmentalists ($n = 6$), and experts and policy makers ($n = 9$).

Additive value function of MCA

Multi-criteria analysis is an approach within multi-attribute value theory, in which the overall values of the alternatives are composed of the scores of the alternatives with respect to each criterion, and of the weights of the criteria (Keeney and Raifa 1976). Each alternative is assigned a score $v_i(x_i)$ for each criteria at the last level x_i (in our case 3rd criteria level). The overall value V (i.e., standardized score) of an alternative (i.e., adaptation option) is then calculated using an additive value function:

$$V(x_1, x_2, \ldots, x_n) = \sum_{k=1}^{q} \sum_{j=1}^{p} \sum_{i=1}^{n} w_k \cdot w_j \cdot w_i \cdot v_i(x_i), \quad w_k, w_j, w_i \in [0,1] \quad v_i(x_i) \in [0,1] \tag{1}$$

where w_k, k ε (1, 2,…, q), w_j, j ε (1, 2,…, p) and w_i, i ε (1, 2,…, n) are the weights of the first, second and third criteria, respectively. The values of the criteria weights w_k, w_j, w_i and scores of the adaptation options $v_i(x_i)$ used in Eq. (1) were the median of the values estimated by stakeholders. The median value has the strength over the average value that is not affected by extreme values. In this case study, the criteria were assumed as mutually preferentially independent.

Criteria to assess adaptation options for the MCA

The next step was to define the criteria on which the implementation of the options might have some effect. The structuring of the criteria to evaluate the adaptation options was carried out by the research group itself. The selection of the criteria was based on the literature review (e.g., Miller and Belton 2011; Mustajoki et al. 2004; Koschke et al. 2012) and the information collected from the workshops about stakeholders' needs and interests.

The criteria were grouped by themes and aggregated in three different levels. The selected criteria included the ecosystem services that could be modified by the implementation of the proposed adaptation options with other socioeconomic criteria that turned out to be relevant based on the opinion of the stakeholders. The ecosystem services included in the analysis for Doñana area are described in Martín-López et al. (2011) and Palomo et al. (2012).

Figure 1 shows the criteria tree and the adaptation options included in the assessment. It describes the aggregation of the criteria groups within the three criteria levels. The adaptation options were scored over the third criteria level. The third criteria level includes the ecosystem services that act as criteria (gray boxes) and other socioeconomic criteria (transparent boxes). The ecosystem services of the assessment include provisioning services (criteria 6, 7 and 9); cultural services (criteria 10, 15, 16 and 17); and regulating services (criteria 19, 20, 21 and 22).

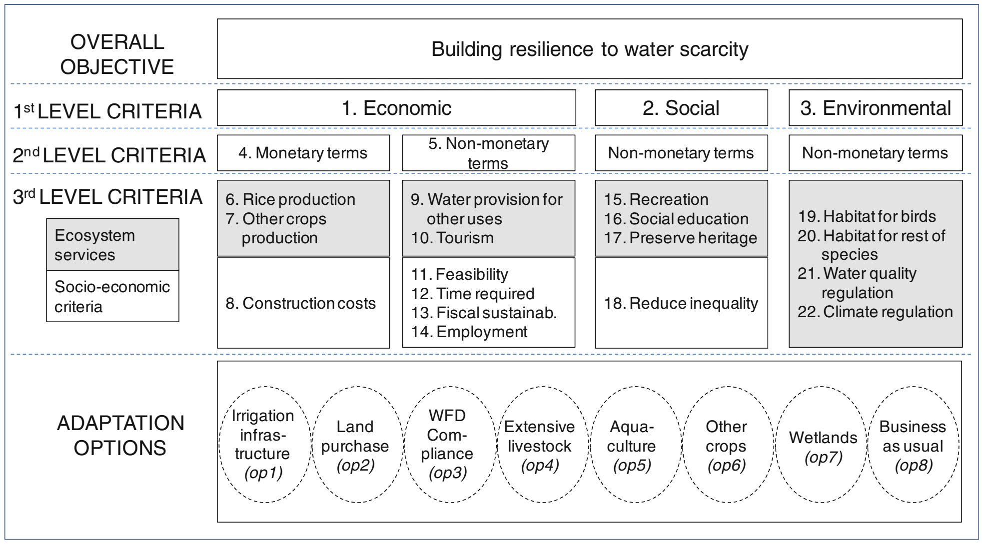

Fig. 1 Criteria tree for evaluating the adaptation options in Doñana rice fields

Weighting methods for the MCA

The weights of the criteria indicate their relative importance in the adaptation options assessment. Therefore, it is important to establish a clear mechanism for weighting selection. In doing so, we estimated the criteria weights according to the stakeholders' perceptions by three different approaches: (1) analytic hierarchy process (AHP), (2) Likert scale and (3) equal weights. The use of three different methods for estimating the criteria weights allows obtaining a final estimation more accurately and also a comparison of the different methodologies (Koschke et al. 2012).

In this study, the weights of the criteria were separately assessed within each criteria group. The criteria groups are formed by the criteria of an upper level. For instance, in the first level there is only one criteria group with three criteria (i.e., *1. Economic*, *2. Social* and *3. Environmental*). In the second level within the economic criteria, there is one criteria group with two criteria (i.e., *4. Monetary terms* and *5. Non-monetary terms*). In the third level, within the criteria of monetary terms, there is one criteria group with three different criteria (i.e., *6. Rice production, 7. Other productions* and *8. Construction costs*). It could be argued that the fact that the number of third-level criteria differs per first- and second-level criteria may lead to imbalance. However, since the weights of the first, second and third criteria were independently estimated by criteria groups, the values of the weights of first-level criteria were not influenced by the other criteria levels and vice versa. Therefore, a different number of third-level criteria did not affect the estimation of the criteria weights for the MCA.

1. Stakeholder weighting using AHP. For each of the criteria groups, stakeholders were asked to compare each criterion with every other criterion within the same group on an AHP scale from 1 to 9, indicating the relative dominance of one criterion over the other in order to obtain criteria weights (see Saaty 1977).
2. Stakeholder weighting using the Likert scale. In this approach, stakeholders were asked to state their preferences toward every criteria referring to a Likert scale from 1 (not at all important) to 10 (very important). As a result, we calculated the relative weights of each criterion.
3. Equal weights. Here, weights are simply calculated by dividing 1 by N, where N is the number of the criteria. The incorporation of this approach in the analysis allows the comparison of the weights with the previous approaches.

The main difference between AHP and Likert scale is that while Likert scale is the direct valuation of each criterion in a given scale, AHP establishes priorities among the criteria by making pairwise comparisons of criteria. For instance, in the criteria group of the first level (i.e., *1. Economic, 2. Social and 3. Environmental*) in the approach of Likert scale, stakeholders were asked to state the importance of each criterion in a Likert scale. However, in the AHP approach, stakeholders were asked to do three different pairwise comparisons (i.e., *Economic vs. Social; Economic vs. Environmental;* and *Social vs. Environmental*). In each pairwise comparison, the stakeholder should indicate the relative dominance of one criterion over the other in a scale from 1 to 9.

Scoring and ranking of adaptation options in the MCA

The adaptation options were independently scored on two different water scarcity scenarios. In the *Current water* *scarcity scenario*, the water availability is the current one [there is only water to irrigate 80 % of the total area since it is the actual average cultivated surface in the period 1983–2012 due to recurrent droughts (CAPMA 2013)]. In the *Increased water scarcity scenario*, water availability is 10 % lower than in the *Current water scarcity scenario* due to future predictions. The latter scenario was based on the climate scenarios described in Sect. "Climate scenarios and future water availability in Doñana rice fields". All these climate scenarios agree on a generalized decrease in water availability but differ in the quantity of reduction. Thus, the selection of a reduction of 10 % in water availability might be considered relatively conservative; however, it is in line with the climate scenarios described for the Guadalquivir river basin.

Some criteria were measured in monetary terms (criteria 6, 7 and 8, see Fig. 1). Table 3 shows the economic valuation of the options measured in 2012. Since MCA allows us to include data in different measurement units, the score of the options in these criteria was included directly in monetary terms. The rest of the criteria were scored by the stakeholders according to how well they would address adaptation needs under current and *increased water scarcity scenario*. A score of −100 corresponded to the greatest negative effect of the individual option, +100 to the most positive and 0 if the adaptation option did not affect that criterion or the effect could be considered as insignificant. The value to be taken into account in the analysis was the median of the values estimated by the stakeholders in order to avoid extreme values. Finally, the ranking of the adaptation options was completed using MCA and was based on the weighted sum of the scores on the different criteria. The aggregate results and sensitivity analyses of the MCA were conducted by Web-HIPRE software (Helsinki University of Technology 2013).

Land-use optimization for building resilience to water scarcity

In this study, adaptation options were not assumed to be mutually exclusive, and the combination of the options was analyzed by a land-use optimization model. The MCA outcome expresses the standardized scores of each adaptation option. This score determines the utility provided by each option in terms of economic, social and environmental criteria. The utility of the land use was determined based on the standardized scores for those criteria on which an alternative land use was proposed (e.g., return to natural wetlands, extensive livestock, etc.). In doing so, it was then possible to define the optimal land-use distribution in terms of maximizing the utility of the study area.

The model presents a multi-objective problem, where two different objectives are pursued, maximizing the utility from MCA results and maximizing the land-use diversification. Land-use diversification is one of the objectives as diversification per se is an adaptation strategy (Zoroma et al. 2013) and it turned out to be relevant during the participatory process. In order to solve this multi-objective problem, a mixed integer linear programming (MILP) model was utilized, where the objective function is:

$$\text{Max}.U = Z + R \tag{2}$$

where U is the expected utility; Z is the utility provided by each land use (Eq. 3); and R is the utility provided by the land-use diversification (Eq. 4).

$$Z = \sum_{i=1}^{N} \text{MCA}_i \cdot X_i \quad i \in \{1, \ldots, N\} \tag{3}$$

where MCA_i is the average utility provided by the land use i obtained from MCA results and X_i is the area of land use i.

$$R = \sum_{i=1}^{N} I_i \cdot \text{Ku} \quad i \in \{1, \ldots, N\} \tag{4}$$

R is the utility provided by the land-use diversification. I_i is a parameter that can only take the value 0 or 1, and I_i is 0 when X_i is lower than the considered minimum area to be beneficial for land-use diversification and 1 if X_i is greater than or equal to the considered minimum area. Ku is the land-use diversification coefficient to duly calibrate and validate the model.

It was assumed that the minimum area to provide benefits to society from a land-use diversification was 3 % of the total rice field area, which equalled approximately 1,000 ha. As far as the authors know, there is no source of the minimum area required for benefits. However, in the scientific literature, there are numerous studies that underpin the benefits that diversification can provide for the resilience of socioecological systems (e.g., Zoroma et al. 2013; Bindi and Olesen 2011). The choice of the minimum beneficial area from land-use diversification is open to interpretation, however, by not setting a minimum area we could be left with an unfeasible solution such as dividing <1 ha of land into various different practices.

The model is subject to three different constraints, regarding the availability of land, water and budget. Firstly, the availability of land has to be lower than or equal to the rice field area (Eq. 5). Secondly, the availability of water differs in the two water scarcity scenarios (Eq. 6) which are described in Sect. "Scoring and ranking of adaptation options in the MCA". Thirdly the availability of budget to invest in adaptation options was evaluated by several scenarios using a sensitivity analysis (Eq. 7). The MILP model is solved with the program General Algebraic Modelling System (GAMS).

$$\sum_{i=1}^{N} X_i \leq \mathrm{LA} \quad i \in \{1, \ldots, N\} \tag{5}$$

$$\sum_{i=1}^{N} X_i \cdot \mathrm{WN}_i \leq \mathrm{WA} \quad i \in \{1, \ldots, N\} \tag{6}$$

$$\sum_{i=1}^{N} X_i \cdot \mathrm{CN}_i \leq \mathrm{BA} \quad i \in \{1, \ldots, N\} \tag{7}$$

where LA is the total land availability; WN is the water needs of 1 ha of land use i; WA is the total water availability; CN is the necessary costs to implement 1 ha of land use i; and BA is the total budget available for investment.

Results

Adaptation options: building resilience to water scarcity in Doñana rice fields

Among the large number of adaptation options (Op) suggested by stakeholders, eight were selected according to their ability to build resilience to water scarcity, feasibility of implementation and by attempting to include the interests of all stakeholders. This section responds to the first research question about how stakeholders perceive the need for adaptation. It summarizes how stakeholders perceived the options during the participatory process and shows MCA results analyzed separately for each stakeholder group (see Table 2). Table 3 shows the economic valuation of the adaptation options for the criteria measured in monetary terms.

The option of *Irrigation infrastructure* (Op_1) was strongly supported by rice farmers since the measure aimed to ensure a greater quantity of water for rice production than currently, and consequently, it would enhance rice farmers' welfare. However, its construction would be relatively expensive and would provoke environmental damages in the riparian zones of the Guadalquivir river (Iglesias et al. 2012). Due to the effects provoked by this measure, Op_1 would be perceived differently by rice farmers and environmentalists, and hence, there was significant disagreement on the level of acceptance. *Land purchase* (Op_2) would have the highest implementation cost because of the relatively elevated price of the rice land (the most frequent price of 1 ha of rice field in Seville was 27,471 €) (CAP 2011), and it was strongly supported by environmentalists. *WFD compliance* (Op_3) would provide the highest water saving and consequently very high economic losses for rice farmers given a great reduction of the

Table 2 Adaptation options for Doñana rice fields and multi-criteria analysis results of stakeholders in the *Current water scarcity scenario*

Adaptation options	Description	Rice farmers ($n = 8$)	Environmentalists ($n = 6$)	Experts and policy makers ($n = 9$)
Irrigation infrastructure (Op1)	Water transfer from the upper basin to ensure quantity and quality	0.500 (0.502)	0.362 (0.322)	0.310 (0.273)
Land purchase (Op2)	Public state purchase of the 20 % of the rice fields to match the mean non-cultivated surface because of water shortages during the period 1983–2012	0.452 (0.481)	0.563 (0.583)	0.557 (0.594)
WFD compliance (Op3)	Compliance of the water framework directive (WFD) to maintain the good ecological status of the water within the Guadalquivir basin	0.472 (0.472)	0.631 (0.653)	0.586 (0.620)
Extensive livestock (Op4)	Change 20 % of the current rice area to extensive livestock farming and maintain current rice subsidies associated with the new activity	0.506 (0.542)	0.556 (0.574)	0.544 (0.569)
Aquaculture (Op5)	Change 20 % of the current rice area to aquaculture production and maintain current rice subsidies associated with the new activity	0.519 (0.544)	0.554 (0.578)	0.485 (0.474)
Other crops (Op6)	Change 20 % of the current rice area to other crop types such as sunflower, beet or cotton, which require much less water than rice and maintain current rice subsidies associated with the new activity	0.496 (0.526)	0.482 (0.505)	0.531 (0.546)
Wetlands (Op7)	Set-aside of 20 % of the current rice area and restore it to natural wetlands while maintaining current rice subsidies associated with the new activity	0.506 (0.535)	0.621 (0.640)	0.605 (0.642)
Business as usual (Op8)	This option proposes a status-quo situation, i.e., keeping the current situation of the rice fields and not implementing any adaptation option	0.545 (0.538)	0.520 (0.510)	0.529 (0.517)

Figures in brackets show multi-criteria analysis results in the *Increased water scarcity scenario*

Table 3 Economic valuation of the adaptation options in the criteria measured in monetary terms

	Rice production (*cr. 6*) (million €)	Other productions (*cr. 7*) (million €)	Construction costs (*cr. 8*) (million €)	Total costs in criteria of monetary terms (million €)
Op1. Irrigation infrastructure	46.4	0.0	151.8	−105.4
Op2. Purchase of land	−65.0	0.0	203.0	−268.1
Op3. Cross-compliance of WFD	−129.0	0.0	0.0	−129.0
Op4. Extensive livestock	−90.8	14.1	11.5	−88.2
Op5. Aquaculture	−116.6	171.8	129.0	−73.8
Op6. Other crop type	−116.6	43.4	5.0	−78.2
Op7. Wetlands	−65.0	0.0	5.0	−70.0
Op8. Business as usual	0.0	0.0	0.0	0.0

Iglesias et al. (2012)

cultivated area due to a lack of water availability. For this reason, there was also a significant disagreement on the support for this option. *Extensive livestock* (*Op_4*), *Aquaculture* (*Op_5*), *Other crops* (*Op_6*) and *Wetlands* (*Op_7*) were proposed to change 20 % of the current land use while maintaining the same current public rice farming subsidy independently of the land use.

These measures would increase the diversity of land uses and would be in line with the European Commission's proposal which highlights the need to move toward fully decoupled crops and to establish a flat fee that puts an end to the historical prioritization of water-intensive crops (European Commission 2011). All these options were slightly opposed by rice farmers because of a common denial to change their current agricultural practices and positively supported by environmentalists because they would save water and diversify the land use that was generally seen as beneficial in order to lower the climate change vulnerability of the area. So as to compare the current situation with the performance of the rest of the adaptation options, a status-quo situation [i.e., *Business as usual* (*Op_8*)] was incorporated in the analysis. Therefore, while all the listed options represented water saving, *Business as usual* (*Op_8*) proposed to continue with the same water consumption.

In order to respond to the research question of how the CAP reform may contribute to adaptation, several proposals of the CAP reform were included among the adaptation options. The option of *Compliance of WFD* (*Op3*) and the new 'green' payment are some of the CAP reform proposals that can contribute to building resilience to climate change through the sustainable management of the natural resources. The proposal of the new 'green' payment was not included in the assessment due to the fact that rice cultivation would not be affected by this measure. Finally, the proposal of moving toward fully decoupled crops and to establish a flat fee is addressed in the options *Op4, Op5, Op6* and *Op7*, which proposed changing 20 % of the current land use while maintaining the same public subsidy.

Criteria weights

In order to respond to the research question of how stakeholders perceived the relative importance of the criteria when assessing adaptation strategies, three different approaches were used to estimate the criteria weights. Table 4 shows the criteria weights calculated from pairwise comparisons AHP, Likert scale and equal weights. As shown, the trends of the weights distribution were similar for the three weighting methods except in the first criteria level, where stakeholder preference toward *Economic* (*1*), *Social* (*2*) and *Environmental* (*3*) criteria notably varies. The strong stakeholder preference toward the environment is noticeable, which could be explained by the close proximity of the Doñana National Park potentially leading to an elevated societal environmental concern (García de Jalón et al. 2013). It is noteworthy to highlight that despite the proximity of the Doñana National Park, an economic criterion such as *Constructions costs (8)* was the criterion with the highest weight among the third-level criteria. The highest-weighted criteria within the groups of social and environmental criteria were *Reduce inequality (18)* and *Habitat for rest of species* (*20*), respectively.

The criteria of *Habitat for birds* (*19*) and *Habitat for rest of species* (*20*) belong to the same ecosystem service, which is called *Habitat for species* (MEA 2005; Palomo et al. 2012; Martín-López et al. 2011). However, it was assumed that Doñana rice fields could provide different or even contrary effects on these two criteria given the quantity, diversity and fame of the local bird population. While due to the use of pesticides and herbicides rice fields can negatively affect the habitat for a multitude of species (del Moral Ituarte 1993; Tortosa et al. 2011), they also can provide notable benefits for birds since they provide food during the summer when habitually natural wetlands dry up. Therefore, rice fields have positive repercussions on some species and negative on others. Thus, in order to score the options more accurately, the research group decided that the criteria of *Habitat for birds* (*19*) and *Habitat for rest of species* (*20*) should be separately assessed.

The mean standard deviations of criteria weights (SD) show the ambiguity of the judgments of the weights and the degree of disagreement among the stakeholders due to their different interests. Unsurprisingly, the higher weights lead to higher deviations, for example, the criterion of *Construction costs* (*8*) has both the highest weight and mean standard deviation. The lowest SD values are within the environmental criteria, whereas the highest ones are within the economic criteria.

Ranking of adaptation options

Figure 2 presents the results of the MCA and aims to respond to the research question of what were the best adaptation options to ensure resilience to water scarcity in Doñana rice fields according to stakeholders' view. It shows the standardized scores of the adaptation options at the first criteria level (environmental, social and economic criteria). As shown, the standardized scores of the options are similar for both water scarcity scenarios. The option of *Wetlands* (Op_7) has the highest score in both scenarios, implying that its implementation would provide the highest utility for the society as a whole. Similarly, *Irrigation infrastructure* (Op_1) has the lowest score due to its elevated environmental impact and hence a low score on the criteria within the environmental group. *Land purchase* (Op_2) together with *Wetlands* (Op_7) has the highest score in the environmental and social criteria but also has the lowest score in the economic criteria due to its elevated cost. *Business as usual* (Op_8) has the highest score in the economic criteria as it would not imply any construction cost. It is noteworthy that Op_8 has a total standardized score higher than other options, which reflects that there are not many feasible alternatives to the current land use in the area, where natural wetlands seem to be the best alternative to rice fields regarding the current lack of water availability. The scores of *Land purchase* (Op_2) and *Wetlands* (Op_7) considerably increase in the *Increased water scarcity scenario*, which confirms the fact that under a climate change context, the conversion of part of the rice fields to natural wetlands is even more favorable. It could be explained by the fact that as water scarcity increases, provisioning ecosystem services such as agricultural

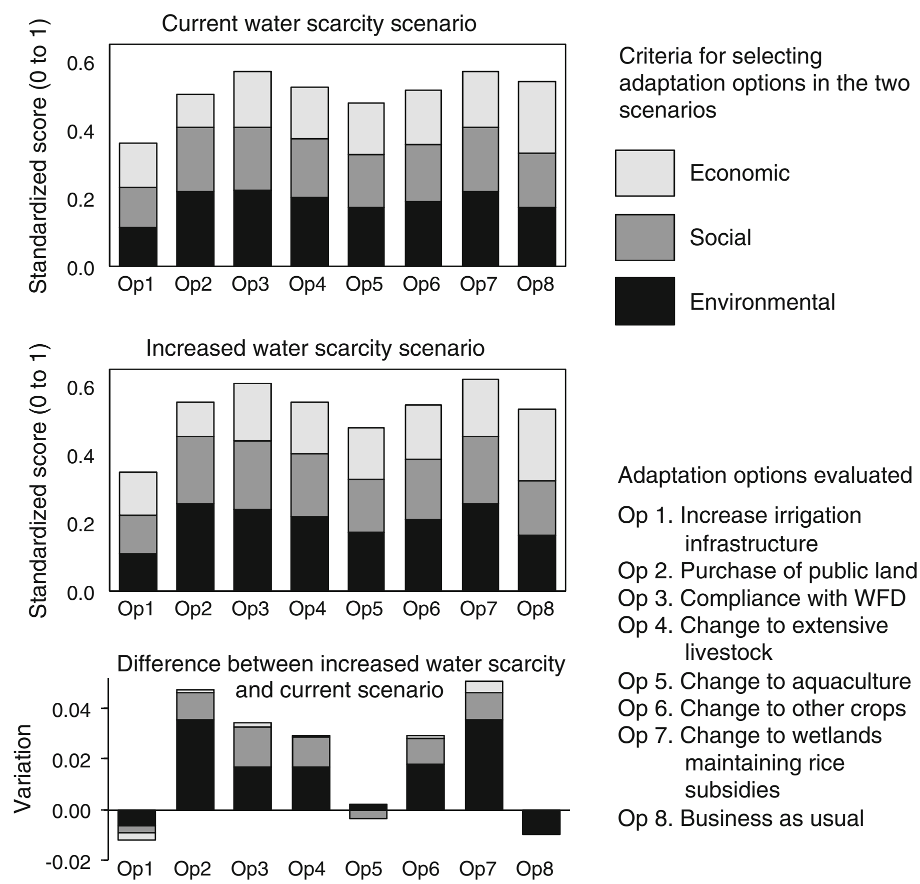

Fig. 2 Standardized scores of the adaptation options from the multi-criteria analysis evaluated in two different water scarcity scenarios (*Current water scarcity* and *Increased water scarcity scenario*)

production become less profitable. However, regulating and cultural services such as biodiversity, water quality and climate regulation seem to become more relevant as water availability decreases. It is also worth noting that in the *Increased water scarcity scenario*, the scores become more extreme than in the current scenario, i.e., the highest scores in the current water scarcity become higher in the *Increased water scarcity scenario* and vice versa with the lowest scores.

Optimal land-use combination under different scenarios

Among the aforementioned adaptation options, five different land uses were proposed in the optimal land-use assessment. In order to respond to the research question of what is the optimal mix of land use, Table 5 presents a sensitivity analysis according to different scenarios of water and budget availability. Based on the standardized score from MCA results, the land use with the highest utility is natural wetland. Thus, as the budget availability increases, the percentage of wetlands also increases. As seen, the minimum budget to obtain the maximum utility in both water scarcity scenarios, without regard to the Ku coefficient, is approximately € 25 million.

It is noticeable that without the implementation of any adaptation options, i.e., at zero budget availability, the average annual surface that remains uncultivated and useless for other land uses ranges from 20 to 28 % of the total surface. As shown, the minimum budget to totally cover the study area (i.e., 36,000 ha) with profitable land uses is approximately €5 million and 7 million in the current water scarcity and in the *increased water scarcity scenario*, respectively.

The model was tested for three different values of the land-use diversification coefficient (*K*u) in order to analyze the possible support by policy makers of the land-use diversification. At the maximum utility level, the land-use distribution varies considerably among the three different values of Ku coefficient. At Ku equal to zero, the optimal land-use distribution is only wetland, whereas with Ku equal to 200 the optimal land use is a mix of rice, wetlands, extensive livestock, aquaculture and other crops such as sunflower, cotton and sugar beet.

Table 4 Criteria weights calculated from analytic hierarchy process (AHP), Likert scale and equal weights. Standard deviations (SD) are also given

Criteria	AHP		Likert		Balanced (1/*n*)
	Weights	SD	Weights	SD	Weights
1. Economic	0.363	0.045	0.318	0.102	0.333
2. Social	0.332	0.021	0.280	0.057	0.333
3. Environmental	0.306	0.032	0.402	0.102	0.333
Economic					
4. Monetary	0.522	0.135	0.508	0.021	0.500
5. Non-monetary	0.478	0.135	0.492	0.021	0.500
Monetary terms (Economic)					
6. Loss of rice production	0.260	0.089	0.322	0.074	0.333
7. Profits from other productions	0.256	0.096	0.272	0.073	0.333
8. Construction costs	0.484	0.185	0.407	0.128	0.333
Non-monetary terms (Economic)					
9. Water provision for other uses	0.125	0.023	0.162	0.031	0.167
10. Tourism	0.092	0.031	0.138	0.034	0.167
11. Feasibility	0.280	0.050	0.203	0.053	0.167
12. Time required	0.130	0.008	0.180	0.050	0.167
13. Fiscal sustainability	0.194	0.041	0.168	0.062	0.167
14. Employment	0.179	0.024	0.149	0.044	0.167
Social					
15. Recreation	0.144	0.015	0.204	0.036	0.250
16. Social education	0.231	0.037	0.231	0.048	0.250
17. Preserve heritage	0.266	0.045	0.296	0.034	0.250
18. Reduce inequality	0.360	0.061	0.269	0.064	0.250
Environmental					
19. Habitat for birds	0.280	0.103	0.244	0.021	0.250
20. Habitat for rest of species	0.327	0.070	0.239	0.025	0.250
21. Water quality regulation	0.234	0.042	0.277	0.025	0.250
22. Climate regulation	0.159	0.053	0.239	0.034	0.250

$n = 23$ ($n_{\text{farmers}} = 8$; $n_{\text{environmentalists}} = 6$; $n_{\text{experts}} = 9$)

Discussion

It is worth noting that there are some limitations to our findings. Firstly, the interests and perceptions of stakeholders greatly varied since some options were strongly supported by some stakeholders and at the same time notably rejected by some others. This reflects the complexity and delicacy of the process in which the participation of all stakeholders played a key role. The list of proposed adaptation options for the rice fields did not capture the full range of possible options as it did not include all those proposed during the participatory process. Nevertheless, if all options had been included, this would have led to an extremely complex evaluation, and as such, it was decided to select the eight most important options that encompassed the interests of all stakeholders. For some determined criteria, such as cultural and regulating ecosystem services, the scores of the options may be considered as relatively imprecise. However, it can be justified by a lack of available data and uncertainty, which is widely acknowledged in the measurements of changes in the provision of ecosystem services (Boyd and Banzhaf 2007; Daily and Matson 2008).

The optimization model was particularly simple for a small area and included neither a wide range of land uses nor restrictions. This is due to the study's aim to develop a simple easy-to-understand approach to assess adaptation measures which can be easily transferred to other case studies. Due to a lack of detailed information about soil characteristics of the study area, our optimization model is non-spatially dependent. In this way, the model only suggests an optimal land-use distribution independently of what areas within Doñana rice fields would be more or less favorable for each land use. Thus, further research on soil characteristics and the specific performance of each land use in the different parts of the study area are needed before putting into practice the land-use conversion suggested by the optimization model.

Despite these limitations, this study presents an innovative way to evaluate adaptation strategies with the purpose of building resilience to water scarcity in southern Spain. This work provides a comprehensive stakeholder assessment of the adaptation options by jointly analyzing the variations in the affected ecosystem services and relevant socioeconomic criteria. Likewise, this paper also shows an approach to analyze the combination and synergies of adaptation options and optimal land-use distribution under different scenarios.

Our approach by three different weighting methods also allows the comparison of them. In our analysis, we concluded that Likert scale was much easier to implement than AHP although it had some limitations. In Likert scales, some stakeholders expressed the maximum weight for all the criteria within the same group, which led to equal weights and impeding to differentiate the relative importance of those criteria. On the other hand, the drawback of AHP was that it required a greater number of questions than Likert scale and that some stakeholders had problems in doing pairwise comparisons between some determined criteria. These results suggest that both approaches may provide some errors due to their applicability. Previous studies have also highlighted these findings and recommend combining different approaches of weighting criteria in order to minimize errors and obtain a more precise estimate (e.g., Koschke et al. 2012; Mustajoki and Hämäläinen 2000).

Since the main concern for this region is an increase in water scarcity, all the adaptation options involved a reduction in water consumption and consequently a water saving that would make more water available for other uses. Nevertheless, the feasibility of the listed options was generally seen by stakeholders as low due to the biophysical and socioeconomic limitations of the area. del Moral Ituarte (1993) stated that there are not many land-use alternatives for rice production in the area due to elevated salinity concentrations in the soils and wetland terrain. Thus, keeping the rice fields and not implementing any adaptation option (Op_8) had higher total scores than other options.

MCA results indicate that the conversion of part of the current rice area to natural wetlands (Op_7) is the best adaptation option in both water scarcity scenarios and consequently provides the greatest utility to society. Due to the lack of water availability to satisfy the water needs of the area, the conversion to natural wetlands in the driest areas of the rice fields seems to be the option that could provide the highest benefits at lowest cost. It would provide water for other uses and at the same time would be a buffer zone of the Doñana National Park, increasing the regulating and cultural ecosystem services of the area. Nonetheless, this option has the limitation that it is subject to maintaining the current public rice farming subsidy in which the 2014 CAP reform will play a key role. This option had the highest score in the ranking in spite of the fact that during the participatory process it was not seen by most of rice farmers as a suitable adaptation option to climate change. However, regarding its low economic costs, it provides a considerable improvement in the majority of the ecosystem services. On the other hand, the construction of *Irrigation infrastructure* (Op_1) had the lowest score despite being the option most desired by rice farmers. This reflects the relatively high degree of disagreement among stakeholders which came out during the participatory process. While rice farmers mainly claimed the need to ensure the future water supply for rice production disregarding environmental cost, environmentalists strongly insisted on the purchase of the rice fields by the public state in order to protect the wetlands of Doñana National Park at any economic cost. This level of disagreement is also reflected in the high values of the mean standard deviations of the criteria weights (Table 3).

The assessment of the adaptation options through the MCA results provides information supported by the stakeholders in terms of a prioritization of the options. However, implementing local adaptation policies frequently requires specific information about to what extent the options should be implemented, which cannot be provided by a simple MCA. Thus, the combination of this information with an optimization model allows for the analysis of the degree of adoption for each option under different scenarios. In this study, the MCA results suggest that the conversion into natural wetlands seems to be the

Table 5 Sensitivity analysis of the optimal land-use distribution according to multi-criteria analysis results

Budget availability € (millions)[a]	Ku	Rice (%)	Wetlands (%)	Extensive livestock (%)	Aquaculture (%)	Other crop (%)	Non-productive area (%)	Increase in utility (%)
Current water scarcity scenario								
0	0	80	–	–	–	–	20	0.0
1	0	80	4	–	–	–	16	5.1
	100	80	4	–	–	–	16	5.7
	200	80	4	–	–	–	16	6.3
5.1[b]	0	80	20	–	–	–	–	25.9
5.1[b]	100	80	20	–	–	–	–	26.4
5.2[b]	200	79	18	–	–	3	–	27.7
10	0	60	40	–	–	–	–	26.8
	100	64	30	3	–	3	–	27.6
	200	64	30	3	–	3	–	29.3
25.3[c]	0	–	100	–	–	–	–	29.5
25.5[c]	100	3	92	3	–	3	–	30.4
42.7[c]	200	3	89	3	3	3	–	32.5
Increased water scarcity scenario								
0	0	72	–	–	–	–	28	0.0
	0	72	4	–	–	–	24	6.2
1	100	72	4	–	–	–	24	6.8
	200	72	4	–	–	–	24	7.5
7.1[b]	0	72	28	–	–	–	–	43.9
7.1[b]	100	72	28	–	–	–	–	44.3
7.1[b]	200	72	28	–	–	–	–	44.6
10	0	60	40	–	–	–	–	46.4
	100	60	37	–	–	3	–	47.7
	200	64	30	3	–	3	–	47.7
25.3[c]	0	–	100	–	–	–	–	56.7
25.5[c]	100	3	92	3	–	3	–	56.7
42.7[c]	200	3	89	3	3	3	–	58.6

[a] Estimated values in 2012 €

[b] Min. budget at max. productive area

[c] Min. budget to obtain max. utility

most beneficial option. However, this may change if policies were to seek other objectives such as financial capital saving or promoting economic development among rural populations. This implies that the land-use conversion may be subject to the budget available for investment in spite of the apparent benefits of the wetlands. Thus, the combination of both approaches allows the optimal balance between surface of wetlands and rice fields to be estimated, taking into account imposed constraints or objectives sought by policies (Table 5).

Conclusions

Our study in Doñana rice fields shows that the most widely supported adaptation options to increased water scarcity are either the conversion of the current land use or the improvement of irrigation infrastructure. However, our results show a spectrum of perceptions of priorities among stakeholders. While the MCA scores of rice farmers indicate that the most beneficial option is to keep the rice fields as they are, both experts and environmentalists suggest a conversion of the land to natural wetlands. In this way, the restoration into natural wetlands seems to be the most beneficial option according to the stakeholders included in this assessment. These results hold true under the current climate scenario and even more so under an *increased water scarcity scenario*. The optimization model suggests that the maximum utility is reached at more than € 25 million. However, at approximately € 5 million water scarcity would not represent an impediment to the complete use of the total area, and therefore, the whole area would be providing ecosystem services. To this end, a combination of MCA and an optimization model based on stakeholders' opinion seems to be particularly appropriate to assess adaptation options.

Acknowledgments We acknowledge the financial support of the Spanish Biodiversity Foundation project of Adaptation in Doñana, implemented by the Spanish branch of the WWF Spain and the European Commission Animal Change project (contract no. KBBE-266018) (http://www.animalchange.eu/).

References

Bindi M, Olesen JE (2011) The responses of agriculture in Europe to climate change. Reg Environ Chang 11(1):151–158

Boyd J, Banzhaf S (2007) What are ecosystem services? The need for standardized environmental accounting units. Ecol Econ 63:616–626

Consejería de Agricultura, Pesca (CAP) (2011) Encuesta de precios de la tierra en Andalucía. Servicio de Estudios y Estadísticas. Secretaría General del Medio Rural y la Producción Ecológica. Consejería de Agricultura y Pesca. Junta de Andalucía. http://www.juntadeandalucia.es/agriculturaypesca/portal/export/sites/default/comun/galerias/galeriaDescargas/cap/servicio-estadisticas/estadisticas-agrarias/precios/Encuesta_de_Precios_de_la_Tierra_en_Andalucxa_2011_v1.pdf

Consejería de Agricultura, Pesca y Medio Ambiente (CAPMA) (2013) Boletín semanal de información agraria, 1983-2012. Secretaría General del Medio Rural y la Producción Ecológica. Junta de Andalucía. http://www.juntadeandalucia.es/agriculturaypesca/portal/servicios/estadisticas/boletines/boletin-semanal-de-informacion-agraria-2011.html

Consejería de Agricultura y Pesca (CAP) (2007) El cultivo del arroz en Andalucía. Junta de Andalucía, Sevilla. http://www.juntadeandalucia.es/agriculturaypesca/portal/export/sites/default/comun/galerias/galeriaDescargas/cap/servicio-estadisticas/Estudios-e-informes/agricultura/herbaceos-extensivos/arr07121.pdf

Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Sutton P, van den Belt M (1997) The value of the world's ecosystem services and natural capital. Nature 387:253–260

Daily GC, Matson PA (2008) Ecosystem services: from theory to implementation. Proc Natl Acad Sci USA 105(28):9455–9456

Dale VH, Polasky S (2007) Measures of the effects of agricultural practices on ecosystem services. Ecol Econ 64:286–296

de Bruin K, Dellink RB, Ruijs A, Bolwidt L, van Buuren A, Graveland J, de Groot RS, Kuikman PJ, Reinhard S, Roetter RP, Tassone VC, Verhagen A, van Ierland EC (2009) Adapting to climate change in The Netherlands: an inventory of climate adaptation options and ranking of alternatives. Clim Chang 95:23–45

De Stefano L, Hernández-Mora N, Iglesias A, Sánchez B (2013) Water for rice farming and biodiversity exploring choices for adaptation to climate change in Doñana, southern Spain. In: Lopez-Gun E, Stucker D (eds) Adaptation to climate change through water resources management. Earthscan Studies in Water Resources Management, UK

del Moral Ituarte L (1993) El cultivo del arroz en las marismas de Doñana: Situación actual y perspectivas. Agricultura y sociedad. No 67. p 205–233. http://www.magrama.gob.es/ministerio/pags/Biblioteca/Revistas/pdf_ays%2Fa067_07.pdf

EEA Technical Report (2007) Climate change: the cost of inaction and the cost of adaptation. No 13/2007. Copenhagen, Denmark

European Commission (2011) Proposal for a regulation of the European parliament and of the council establishing rules for direct payments to farmers under support schemes within the framework of the common agricultural policy. http://ec.europa.eu/agriculture/cap-post-2013/legal-proposals/com625/625_en.pdf

Falkenmark M et al. (2007) Agriculture, water, and ecosystems: avoiding the costs of going too far. In: Molden D. (Ed). Water for food, water for life: a comprehensive assessment of water management in agriculture. London, Earthscan, UK, IWMI, Colombo, Sri Lanka p 233–277

FAO/OECD (2012) Building resilience for adaptation to climate change in the agriculture sector. In: Proceedings of a Joint FAO/OECD Workshop. http://www.fao.org/agriculture/crops/news-events-bulletins/detail/en/item/134976/

García de Jalón S, Iglesias A, Quiroga S, Bardají I (2013) Exploring public support for climate change adaptation policies in the Mediterranean region: a case study in Southern Spain. Environ Sci Policy 29:1–11

Giorgi F, Lionello P (2008) Climate change projections for the Mediterranean region. Glob Planet Chang 63:90–104

Hoerling M, Eischeid J, Perlwitz J, Quan X, Zhang T, Pegion P (2012) On the increased frequency of Mediterranean drought. J Clim 25:2146–2161

Huntjens P, Pahl-Wostl C, Grin J (2010) Climate change adaptation in European river basins. Reg Environ Change 10:263–284

Iglesias A, Mougou R, Moneo M, Quiroga S (2011) Towards adaptation of agriculture to climate change in the Mediterranean. Reg Environ Change 11(1):159–166

Iglesias A, Sánchez B, García de Jalón S, Cunningham R, Hernandez-Mora N, De Stefano L (2012) Study of climate change vulnerability for rice production in Doñana, Spain (in Spanish), Fundación Biodiversidad-WWF-Universidad Politécnica de Madrid, Madrid, Spain (in Spanish with an Executive Summary in English)

Keeney R, Raifa H (1976) Decisions with multiple objectives: preferences and value tradeoffs. Wiley, New Jersey

Koschke L, Fürst C, Frank S, Makeschin F (2012) A multi-criteria approach for an integrated land-cover-based assessment of ecosystem services provision to support landscape planning. Ecol Ind 21:54–66

Kuik O, Buchner B, Catenacci M, Goria A, Karakaya E, Tol R (2011) Methodological aspects of recent climate change damage cost studies. Integr Assess J 8(1):19–40

Mariotti A, Zeng N, Yoon JH, Artale V, Navarra A, Alpert P, Li ZXL (2008) Mediterranean water cycle changes: transition to drier 21st century conditions in observations and CMIP3 simulations. Environ Res Lett 3:044001

Martín-López B, García-Llorente M, Palomo I, Montes C (2011) The conservation against development paradigm in protected areas: valuation of ecosystem services in the Doñana social–ecological system (southwestern Spain). Ecol Econ 70(8):1481–1491

Millennium Ecosystem Assessment (MEA) (2005) Ecosystems and human well-being: synthesis. Island Press, Washington

Miller K, Belton V (2011) Water resources management and climate change adaptation in the Sana'a Basin, Yemen. Contribution to the MCA4 climate initiative. http://mca4climate.info/_assets/files/Sana_basin_case_study_final.pdf

Mustajoki J, Hämäläinen RP (2000) Web-hipre: global decision support by value tree and AHP analysis. Infor J 38(3):208–220

Mustajoki J, Hämäläinen RP, Marttunen M (2004) Participatory multicriteria decision analysis with Web-HIPRE: a case of lake regulation policy. Environ Modell Softw 19(6):537–547

Nieto S, Rodríguez-Puebla C (2006) Comparison of precipitation from observed data and general circulation models over the Iberian Peninsula. J Clim 19:4254–4275

Palomo I, Martín-López B, Potschin M, Haines-Young R, Montes C (2012) National Parks, buffer zones and surrounding lands: mapping ecosystem service flows. Ecosyst Serv. doi:10.1016/j.ecoser.2012.09.001

Porthin M, Rosqvist T, Perrels A, Molarius R (2013) Multi-criteria decision analysis in adaptation decision-making: a flood case study in Finland. Reg Environ Change. doi:10.1007/s10113-013-0423-9

Rodríguez Díaz JA, Weatherhead EK, Knox JW, Camacho E (2007) Climate change impacts on irrigation water requirements in the Guadalquivir river basin in Spain. Reg Environ Change 7:149–159

Saaty TL (1977) A scaling method for priorities in hierarchical structures. J Math Psychol 15:234–281

Spanish Agency of Meteorology (2013) Updated climate projections. http://www.aemet.es/en/serviciosclimaticos/cambio_climat/result_graficos?w=0&opc1=Espan&opc2=P&opc3=Anual&opc4=1&opc5=a2

Stern N (2007) The economics of climate change—the stern review. Cambridge University Press, Cambridge

Tortosa G, Correa D, Sánchez-Raya AJ, Delgado A, Sánchez-Monedero MA, Bedmar EJ (2011) Effects of nitrate contamination and seasonal variation on the denitrification and greenhouse gas production in La Rocina stream (Doñana National Park, SW Spain). Ecol Eng 37(4):539–548

UNFCCC (2011) Assessing the costs and benefits of adaptation options an overview of approaches. The Nairobi Work Programme on impacts, vulnerability and adaptation to climate change. United Nations Climate Change Secretariat. Bonn, Germany. http://unfccc.int/resource/docs/publications/pub_nwp_costs_benefits_adaptation.pdf

White paper (2009) Adapting to climate change: towards a European framework for action {SEC(2009) 386} {SEC(2009) 387} {SEC(2009) 388} {COM(2009) 147 final}. http://ec.europa.eu/agriculture/climate-change/index_en.htm

Zoroma M, Barbier B, Mertz O, Servat E (2013) Diversification and adaptation strategies to climate variability: a farm typology for the Sahel. Agric Syst 116:7–15