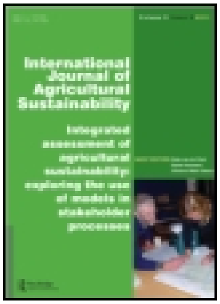

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Limits to agri-environmental schemes uptake to mitigate human-wildlife conflict: lessons learned from Flamingos in the Camargue, southern France

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Limits to agri-environmental schemes uptake to mitigate human–wildlife conflict: lessons learned from Flamingos in the Camargue, southern France

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Agri-environment schemes (AES) favouring the maintenance of hedges were implemented in the Camargue (southern France) as it has previously been proven to reduce the risk of damage caused by Greater Flamingo incursions into rice fields. Given the persistent incursions, we estimated the economic cost of damage from 2007 to 2009, the uptake rate of hedge-related AES and explored the limits of these schemes as a mitigation effort. Semi-structured and key informant interviews, site mapping and field visits were made to verify claims and estimate damage. Number of plants/m^2 and fertile stems/plant were estimated on 1,498 and 312 grids, respectively, spread over 26 rice fields. Damaged areas of rice fields forayed by flamingos presented from 1.35 to 3.06 t/ha lower yield than undamaged areas. We estimated 228€/ha average loss in forayed fields for a total of 400,000€ in yield loss in 2008. Administrative constraints limited AES and free seedlings distribution, preventing the problem from being addressed at an appropriate scale. The trivial financial support for hedge management relative to more lucrative AES with lower constraints resulted in low uptake rate. We propose that modifications of AES take into account landscape factors over administrative boundaries and that the financial support for AES be scaled up relative to other subsidies in order to address the efforts necessary to achieve landscape changes to reduce human–wildlife conflict.

Keywords: agri-environment schemes; crop damage; human–wildlife conflict; flamingos; rice fields

Introduction

Human–wildlife conflict (HWC) arises when wildlife's requirements overlap with those of human populations, creating costs to residents and wild animals (IUCN 2003). HWC is a global problem, which is not limited to specific geographical regions, climatic conditions or economic development (Distefano 2005); however, the incurred damage is often locally endured. On the other hand, wildlife also offers numerous benefits to local communities and agricultural production (Triplett *et al*. 2012). Sustainable agriculture aims to reduce the damage caused to production, while at the same time promoting ecosystem services and the biodiversity that enables these services (Tscharntke *et al*. 2012); thus, wildlife mitigation is an important step towards sustainable agricultural practices.

Dickman (2010) has suggested that wildlife mitigation could be reinforced by measuring not only the perceived (reported) data on damage induced by wildlife, but also estimating the actual cost of the damage caused. This relationship between perceived and actual costs could help mitigate the conflict. Damage compensation schemes and agri-environmental schemes (AES) are the

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principal measures implemented to reduce HWC. Compensation schemes have been criticized because they may decrease efforts to prevent damage and increase wildlife conflict (Bulte and Rondeau 2005). They may also be viewed as subsidies for agriculture and contribute to maintain practices detrimental to wildlife (Nyhus *et al*. 2003, Bulte and Rondeau 2005). AES, on the other hand, can be used as incentives aimed at preventing damage and promoting sustainable agriculture; as such, they have been incorporated into the general European Common Agricultural Policy (EC Directorate General for Agriculture and Rural Development 2005) across Europe. AES are payments to farmers or other landowners to address environmental problems or to promote the provision of environmental benefits. The environmental efficiency of AES has been discussed extensively (Parris 2001, Hanley *et al*. 2003, Knop *et al*. 2006, Kleijn *et al*. 2006, Whittingham 2011), as well as farmers' perception and acceptance of AES (review in Siebert *et al*. 2006). This is a critical point because AES may be highly efficient where they have been contracted but given their voluntary nature, farmer's participation is necessary to reach policy objectives (Wilson 1996). Participation can be measured using both 'farmer factors' and 'scheme factors' (Brotherton 1989, 1991). Farmer factors analyse the individual characteristics of a farmer or farm, whereas scheme factors analyse the features that influence the economic attractiveness of a particular scheme.

Greater Flamingos (*Phoenicopterus roseus*) have bred intermittently in the brackish lagoons of the Camargue for centuries (Johnson and Cézilly 2007). They inhabit freshwater, brackish and salt marshes where they forage on invertebrates and aquatic seeds filtered from water or mud. In 1978, the first flamingos were observed feeding in the rice fields of the Camargue. In 1980, damage affected up to 12% of the rice field surface area. Since then, there have been yearly claims that damage continues to cover between 3 and 5% of the rice field surface area yearly (Regional Park of the Camargue/Tour du Valat, unpublished data).

Flamingo forays begin in April when paddy fields are flooded and last until a solid vegetative cover is established in June. Flamingos enter into rice fields at sundown and feed throughout the night until sunrise. The damage is multi-faceted: feeding on rice seeds and other aquatic plants, but more importantly trampling young seedlings and creating muddy turbidity that suffocates growing plants. Tourenq *et al*. (2001a, 2001b) showed that large rice fields lacking hedgerows had the highest probability of being forayed. Fields with no hedges were 1.7 times more likely to be affected than those with one hedge, four times more than fields with two hedges and up to eight times more frequently than fields with three or four hedges (Tourenq *et al*. 2001a, 2001b). The protected status of the Greater Flamingo led to the proposition of soft management options of hedge restoration to limit flamingo incursions in rice fields and to mitigate the HWC (Tourenq *et al*. 1999). The Natural Regional Park of the Camargue initiated campaigns giving free hedgerow plant seedlings to support the practice. In addition, a set of measures were developed under an AES from the European Common Agricultural Policy to give financial support to promote environmentally friendly practices for rice farmers in the Camargue. The AES had a three-fold objective: to maintain wetland agriculture, to encourage environmentally friendly practices in rice farming and to mitigate HWC between rice farmers and flamingos through a measure aiming at encouraging hedge maintenance. The AES in the Camargue are restricted to: (i) agricultural land located in a Natura 2000 perimeter, (ii) individual farmers (not companies), (iii) recipients younger than 60 years old, (iv) total amount $<$ 10,000€ per farmer and (v) farmers willing to sign a 5-year agreement. After 15 years of awareness campaigns and $>$103,000€ of investments by the Natural Regional Park, few new hedges have been planted.

Given the persistence of the damage claimed by farmers each year and the continued suppression of hedges in the Camargue, we first aimed at estimating the actual damage caused by flamingos. We thus estimated the extent of the economic loss caused by flamingos by estimating natural agricultural compensation processes (e.g. rice tillering) and replanting effectiveness to estimate yield and yield loss in damaged and non-damaged areas. Second, we aimed at identifying the root causes for limited uptake of hedge-related measure of the AES, using a scheme factor approach. This was done by conducting interviews with local rice farmers affected by flamingo forays to determine their perception of different prevention practices. We also compared the types of AES available, the number and type of contracts signed and the localization of damage in relation to AES eligibility boundaries. Building upon these results, we propose possible options to improve the existing scheme and improve HWC mitigation.

Methods

Study area and species

The entire Rhone delta is a Biosphere Reserve (UNESCO) and one of the largest wetlands in the Mediterranean basin and as such, it is of international importance for staging, wintering and breeding of water birds (Ramsar 1986). The Natural Regional Park of the Camargue encompasses over 80,000 ha within the central delta, with around 15,000 ha of natural reserve. The Camargue is characterized by large property owners hosting various economic activities including salt production, rice farming, extensive grazing (bovine and equine), hunting and tourism (Mathevet 2004) and private and public nature reserves.

Rice production was first developed in the Camargue during the 1800s in order to reduce soil salinity and increase agricultural surface area. The surface area dedicated to rice has increased from 250 ha in 1942 to 21,000 ha in 2009. The mechanization of rice farming practices has led to a multiplication of the average surface area of rice fields by four, causing the destruction of hedge networks (Durieux 1998).

Expansion of the salt industry created ideal breeding conditions for Greater Flamingos by providing predictable foraging opportunities annually (Béchet and Johnson 2008, Béchet *et al*. 2009, 2012). Despite these ideal conditions, breeding halted in the early 1960s because of lack of safe breeding islands. An artificial island, built in the salt pans in 1969, was quickly adopted by flamingos and they have since bred annually. The Camargue is the only breeding site for Greater Flamingos in France with an average of 13,000 pairs, making the Camargue one of the most important breeding sites for the species in the Mediterranean area (Johnson and Cézilly 2007). In Spring, rice fields (16 000–21,000 ha) may represent up to 35% of the Camargue flooded wetlands (~60,000 ha, including freshwater, brackish and saltpans) available for flamingo foraging (Tour du Valat, unpublished data). However, flamingos do not depend on rice fields but rather take advantage of this pulse of highly profitable food (Deville *et al*. 2013) heterogeneously distributed in time and space for the 1-month period of rice sowing.

Extent of flamingo forays to rice fields and farmer surveys

From 2007 to 2009, damage to rice fields was estimated using both systematic telephone interviews and voluntary declarations. Telephone interviews were conducted with 34 rice farmers spread over 8 different zones in the Camargue. The same sample (33–34 farmers) was contacted every year over the 3-year period, representing >4,000 ha of rice field surveyed, that is, >20% of the rice fields of the Camargue. Voluntary declarations were also encouraged by the Rice Farmer's Union which sent letters to the ensemble of rice farmers (200) requesting that they call the Union when/if their fields suffered from flamingo forays. Follow-up interviews were conducted using semi-structured questionnaires in each of the affected farms. The types of scaring devices and tactics used, the time spent on dissuasive tactics and the farmer's perception of the incurred damage (extent of the turbid area created by flamingo forays in each field) were recorded.

Qualitative information was gathered about the perceived effectiveness of different scaring devices and tactics, the probable impact of the incursions and the principal limits preventing farmers from replanting hedges. The location of flamingo forays was recorded using a geographical positioning system (GPS). The combination of both quantitative and qualitative data allowed accounting for not only the physical data on damage and scaring techniques, but also for the perception of the farmers related to their implementation.

In order that the results from the survey be considered independent from the rice farmers, Tour du Valat and the Natural Regional Park were responsible for field visits and interviews; the Rice Farmer's Union only provided initial contacts, facilitating communication between technicians and farmers. Within 48 hours of the declarations, two technicians visited the declared sites, confirmed the incursion and visually estimated the extent of damage based on the turbid area caused by the flamingo forays.

Crop damage estimates

In 2009, 26 rice fields (totalling 81.7 ha) were randomly selected from six farmers who declared damage and allowed an economic evaluation of the damage caused by flamingo forays. This sample provided a minimum of four fields for the three most important rice varieties found in the Camargue (4 fields of *Brio*, 9 fields of *Selenio* and 13 fields of *Augusto*). Each field was classified as non-forayed ($n = 9$), forayed (visited by flamingos during April–May and not replanted, $n = 9$) or replanted (damaged by flamingos in April–May and replanted, $n = 8$).

As yield may vary among fields for agronomical reasons, we estimated the yield in the area of the field damaged by flamingos and in the non-damaged part of the same field. In the forayed fields, the damaged area was mapped with a GPS using a visual ranking of plant establishment. For a given area z, the yield was calculated as (Mouret 1988):

$$y_z = p_z s_z g_z w_z$$

where y_z, the yield (g/m^2); p_z, number of plants per m^2; s_z, number of fertile stems per plant; g_z, number of grains per stem; and w_z, average dry weight per grain (g).

The yield of a given field was then estimated by

$$Y = A_d y_d + A_n y_n$$

where A_d is the extent of the damaged area and A_n the extent of the undamaged part of the field.

Fields were visited by technicians three times during the growing season (June, August and September). Given that there were no consistent spatial patterns for foraying, the number of plant/m^2 (p_z) was estimated in June (2–20 June), after plant establishment, by counting the number of plants in 50 cm × 50 cm square grids distributed every 5 m along transects designed to cover most of the field heterogeneity in plant establishment. Hence, the number of transects per field varied from one in uniform undamaged fields to six in very heterogeneous damaged fields (Figure 1). All forayed fields had grids in the two types of areas (damaged and non-damaged). The number of plants/m^2 (p_z) was estimated on a total of 1,498 grids along 89 transects spread over 26 rice fields of 6 farmers selected for estimation of yield loss. Transects and grid locations were recorded using a GPS.

The number of fertile stems/m^2 was estimated in August by returning to the same fields and counting the number of fertile stems in 312 50 cm × 50 cm square grids along 19 transects spread over 2 unforayed, 8 forayed and 2 replanted fields of the same 6 farmers. The number of fertile stems/plant (s_z) was then estimated as the ratio of the p_z estimated in

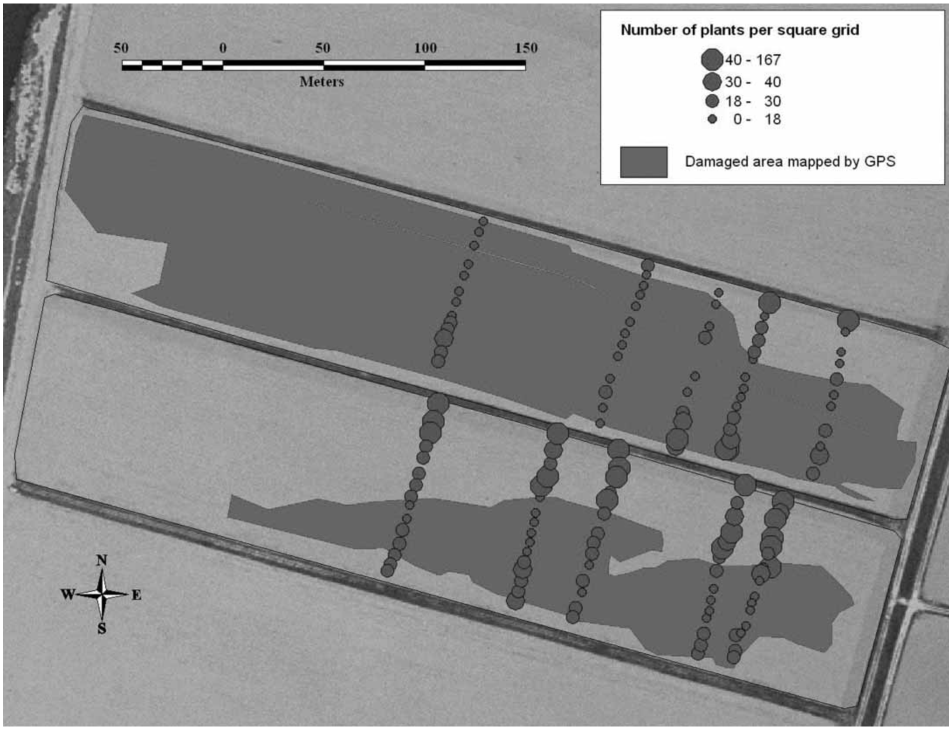

Figure 1. Extent of the damaged area (dark grey) in two sample fields forayed by flamingos and number of plants per m^2 in 50 cm × 50 cm grids along transects distributed to cover most of the field heterogeneity in plant establishment.

June and the number of stems/m^2 estimated in August for each variety and type of area (damaged/non-damaged).

We estimated the dry weight of rice per stem (product $g_z \times w_z$) in September just before harvest by collecting 10 samples of 30 rice panicles (1 panicle per stem) from each variety in damaged and undamaged areas of 9 fields from 5 farmers. Fresh weight of extracted grain was recorded immediately and dry weight was recorded after drying samples at 80°C for 3 days.

AES agreements

Given the site-specific character of AES, we listed the AES available for rice farmers in the Camargue using local reports (Direction départementale de l'agriculture et de la forêt des Bouches-du-Rhône 2008), and key informant interviews with staff from the Natural Regional Park of the Camargue and the Rice Farmer's Union. We then estimated the uptake rate of each AES available to the 200 farmers registered within the Rice Farmer's Union.

Statistical analyses

As rice growth may differ among farmers because of their practices, and among fields because of local conditions, we took into account the non-independence of grids from the same farms and from the same fields in our analysis. We thus used linear-mixed models (Pinheiro and Bates 2000) to estimate plant establishment, stems, grain weight and grain humidity. We evaluated the effects of farmers and/or fields as random factors while testing the fixed effects of the type of area (damaged/undamaged), the rice variety and their interaction. Following Pinheiro and

Bates (2000), the random term structure was checked using Akaike information criterion (AIC) comparisons among full models fit with restricted maximum likelihood (REML). For fixed effects, model selection relied on AIC comparisons of models fit by maximum likelihood (ML). Models were fit using package *lme4* of R (R Development Core Team 2010). Model selection relied on the AIC (Burnham and Anderson 2002). The model with the lowest AIC was accepted as the best approximating model for the data. The normalized Akaike weights, AIC ω, were used as an index of relative plausibility when comparing models (Burnham and Anderson 2002).

We estimated variety and area-specific yield as the product of the number of fertile stems/ha and the weight of grains per stem. Given that yield is estimated as a product of two random variables, we estimated the standard error by the standard deviations of 50,000 mean yields generated randomly by bootstrapping (i.e. resampling with replacement) both the observed number of fertile stems/ha and the weight of grains per stem and calculated their product (Manly 1991). We present means $\pm$ 1SE.

Results

Scaring method inventory and perception of effectiveness

All surveyed farmers ($N = 33-34$) declared the use of dissuasion techniques to prevent flamingo incursions and 96% of the farmers made nightly rounds after having sown the rice for 2–4 weeks to maintain a human presence in the fields and reduce flamingo incursions. According to farmers, the most effective dissuasion materials were alarm guns (19% of the farmers ranked it first), canons (14%) and sheets (14%); however, 43% of the interviewed farmers declared that none of the methods were completely effective. Although 80% of the farmers interviewed acknowledged the importance of hedges, they perceived hedges as constraints to current agricultural practices (i.e. helicopter spraying, levelling and water management).

Extent of Flamingo visits to rice fields

There were 11, 16 and 3 farmers who voluntarily declared flamingo forays to the Rice Farmer's Union in 2007, 2008 and 2009, respectively. The voluntary declarations plus the telephone survey provided a sample of rice fields extending over 34–43% of the cultivated rice surface area in the Camargue (Table 1). The percentage of rice surface area forayed by flamingos varied

Table 1. Extent of the cultivated area, number of farmers surveyed, extent of the sampled area, observed number of fields forayed and area damaged by flamingos.

Year	Cultivated rice area (ha)	Number of farmers surveyed		Sampled area (ha)	In sample surveyed			Overall area damaged (ha)
		Voluntary declarations	Telephone interviews		Number of fields forayed	Area damaged (ha)	Proportion damaged (%)	
2007	17,274	11	34	7567	79	51.5	0.68	117.5
2008	16,640	16	33	5681	205	262.7	4.62	768.8
2009	21,100	3	34	7283	60	71.7	0.98	207.7

Using the proportion of area damaged in the sample provides an estimate of the total rice cultivated area damaged by flamingos assuming that our sample is representative of the whole Camargue.

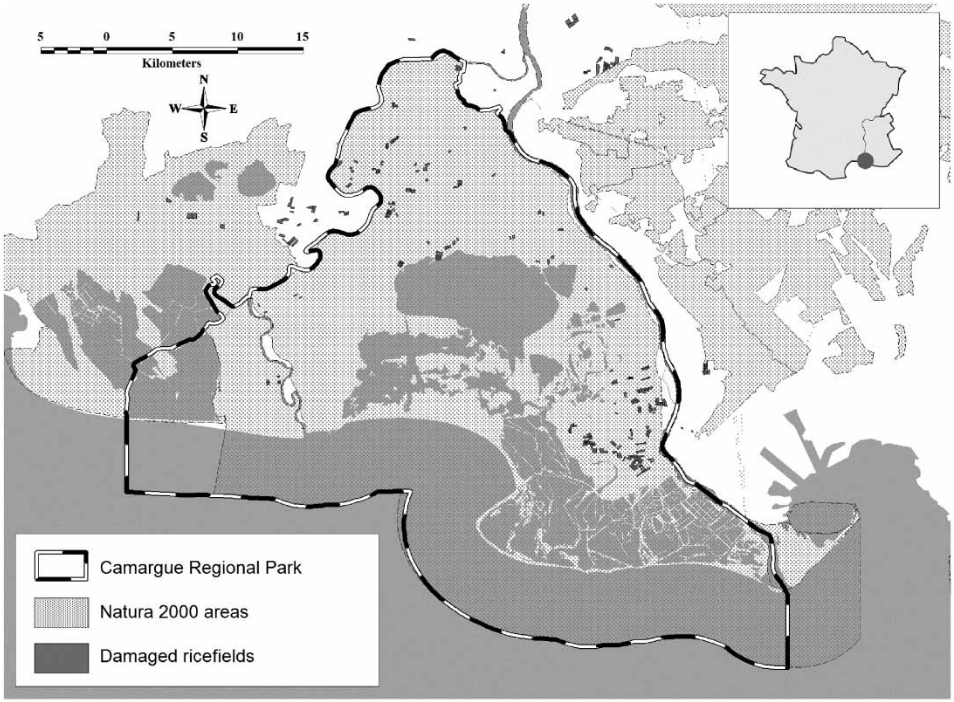

Figure 2. Distribution of the fields forayed by flamingos from 2007 to 2009 in the Camargue, southern France.

during the 3-year period ranging from 0.68 to 4.62% of the rice cultivated area (Table 1; Figure 2). From 27 to 44% of the declared damage was outside the Regional Park and the Natura 2000 perimeter. On average, 25% of the area damaged was outside the Natura 2000 perimeter and 33% outside the Regional Park of the Camargue (Table 2; Figure 2). Seventy-one per cent of the forayed fields located in the Regional Park had no surrounding hedges.

The mapping of rice plant establishment during the June field visits showed, on average, that the estimation of crop damage in May exaggerated the loss by 58% compared with

Table 2. Distribution of the number of farmers, number of fields, area damaged (ha) and area replanted (ha) relative to the Regional Park and Natura 2000 perimeter.

Year		Regional Park	Outside Regional Park	Natura 2000	Outside Natura 2000	Total
2007	Farmers	10	8	10	8	18
	Fields	67	24	67	24	91
	Area damaged	28	16	28	16	44
	Area replanted	15.9	26	15.9	26	41.9
2008	Farmers	25	7	25	7	29
	Fields	126	21	130	17	147
	Area damaged	180.4	84.2	203.4	61.2	264.6
	Area replanted	1369	196.5	1419	146.5	1565.5
2009	Nb Farmers	8	3	8	3	11
	Nb Fields	37	16	37	16	53
	Area damaged	27.7	9.75	27.7	9.75	37.45
	Area replanted	17	11	17	11	28

the real crop damage found in June. The extent of damage caused by flamingos varied from 8 to 85% of the area of the forayed fields with 30.5 ± 9.8% of the field area damaged on average.

Plant establishment

Model selection retained field effect not farmer effect as a random factor . This suggests greater variations between fields than between individual farmers. For fixed effects, the best model explaining plant establishment retained the effect of rice variety, the type of area (damaged/undamaged) and their interaction (AIC$\omega = 0.98$). In undamaged areas, p_z was $>180.8 \pm 13.0$ plants/m^2 while it could drop to 55.6 ± 9.3 plants/m^2 in damaged areas. There were 2.3, 3.2 and 3.5 times fewer plants/m^2 in damaged areas than in undamaged areas for the varieties *Brio*, *Augusto* and *Selenio*, respectively. The establishment of rice plants was highly variable even among fields that did not suffer from flamingo forays (range 68–568 plants/m^2).

Tillering

As for the previous analysis, model selection retained field effect as a random factor. Regarding the fixed effects, the number of stems/m^2 was best explained by the effects of rice variety and the type of area (damaged/undamaged) (AIC$\omega = 0.72$). Despite tillering, the number of stems/m^2 remained lower in damaged areas than in undamaged areas just as for plant establishment. The number of fertile stems per plant was higher in damaged areas ($s_z = 2.21$, 4.09 and 3.19 for *Augusto*, *Brio* and *Selenio*, respectively) than in undamaged ones ($s_z = 1.56$, 2.65 and 1.47 for *Augusto*, *Brio* and *Selenio*, respectively).

Grain maturation and weight

Fresh grain weight did not vary with either variety or the type of area (damaged/undamaged), and was 2.54 ± 0.17 g of grain per stem (the best model retained fields as a random factor but this did not have a fixed effect AIC$\omega = 0.40$). Similarly, dry grain weight was independent of the type of area and of rice variety (the best model retained the random effects of farmer and field but not a fixed effect) and was 1.70 ± 0.11 g of grain per stem on average. Finally, maturity varied between varieties (the model retaining this fixed effect having the best support (AIC$\omega = 0.38$) but not with the type of area. Hygrometry was 31 ± 2% for *Augusto*, 37 ± 3% for *Brio* and 27 ± 2% for *Selenio*.

Yield and economic loss

The yield difference between damaged and undamaged areas varied from 1.35 to 2.56 and 3.06 t/ha for *Selenio*, *Brio* and *Augusto*, respectively (Table 3). Area and variety-specific yield estimates of the 26 fields considered indicate yield losses in forayed fields from 0 to 1.94 t/ha (i.e. 45.8% of the expected variety-specific yield) depending on the area damaged, with an average of 0.69 t/ha (11 ± 3.9% of the expected variety-specific yield). Replanted yield loss ranged from 0.06 to 7.9% for an average of 1.4 ± 0.9% of the expected variety-specific yield. Taking into account the extent of the areas damaged, the mean yield was estimated at 5.72 ± 0.32 t/ha ($n = 9$) for the sample of forayed fields, 6.00 ± 0.20 t/ha ($n = 8$) for the replanted fields and 6.03 ± 0.23 t/ha ($n = 9$) for the unforayed fields.

In 2009, the average price of round rice (*Brio* and *Selenio* varieties) was 320€/t, and 350€/t for long rice (*Augusto*). Hence, income loss in our sample of forayed fields varied

Table 3. Estimated mean yield ± SE (t/ha) of rice fields cultivated with the *Augusto*, *Brio* and *Selenio* rice varieties in areas damaged and undamaged by flamingos in the Camargue, southern France.

Variety	Damaged areas (t/ha)	Undamaged areas (t/ha)	Yield loss (t/ha)
Augusto	2.55 ± 0.43	5.61 ± 0.21	3.06
Brio	3.92 ± 0.23	6.48 ± 0.28	2.56
Selenio	5.50 ± 0.36	6.85 ± 0.36	1.35
All varieties	4.33 ± 0.22	5.88 ± 0.19	1.55

Table 4. Estimated total economic loss (€) caused by flamingo forays in rice fields of the Camargue, southern France, from 2007 to 2009.

Year	Area cultivated (ha)	Area damaged (ha)	Expected income in area damaged (€)	Observed income in area damaged(€)	Total Economic loss (€)	Economic loss per ha cultivated (€)
2007	17,274	117.5	231,767	170,646	61,121	3.5
2008	16,640	768.8	1,516 450	1,116,536	399,913	24.0
2009	21,100	207.7	409,686	301,645	108,041	5.1

from 0 to 622€/ha, for an average loss of 228€/ha in forayed fields, providing an average expected income of 1,861€/ha in forayed fields compared with 2,041€/ha in unforayed fields and 2,023€/ha in replanted fields.

Assuming that our sample is representative of the whole Camargue, the extrapolated damage for rice cultivated area in the Camargue ranges from 117 to 768 ha, with 2008 showing the highest levels of damage (Table 4). The extrapolated total economic loss reached 399,913€ in 2008, averaging 24€/ha of cultivated rice (Table 4).

Table 5. AES code, objective, amount of financial subsidy provided and number of agreements signed from 2007 to 2009 by rice farmers in the Camargue area, southern France.

Type of agreement	AES code	Objectives	Financial support	Number of agreements
Rice fields	PA_CA13_GC1	Water management in rice fields (primarily linked to levelling)	37€/ha	39
Rice fields	PA_CA13_GC2	Water management in organic rice fields (primarily linked to levelling)	74.42€/ha	1
Canals	PA_CA13_F01	Canal management and drainage in rice fields (dredging, mowing and clearing)	1.70€/m	26
	PA_CA13_F02		1.70€/m	19
Canals	PA_CA13_F03	Canal management and drainage in natural habitats (dredging, mowing and clearing)	0.56€/m	1
Hedges	PA_CA13_HA1 (1 side)	Hedge management in rice fields (biological corridors)	0.094€/m	6
	PA_CA13_HA2 (2 sides)		0.172€/m	4

AES agreements uptake

The spatial limitation of AES to Natura 2000 zones is an insurmountable obstacle for 25% of farmers affected by the flamingo forays (Figure 2).

The agri-environmental measure for hedge maintenance was available within a portfolio containing much more lucrative measures (e.g. the financial support for simple canal maintenance is 10 times higher than for hedge management, Table 5) and the total financial support for an individual farmer was limited to 10,000€. There were 15 AES available in the Camargue, seven of which related to rice farming activities. In 2008 and 2009, 40 farmers signed agreements for AES for levelling rice fields, 46 farmers for canal management and only 10 farmers for hedge maintenance (Table 5). Uptake rate for hedge-related AES was less than 5% (10 contracts for 200 rice farmers) compared with >20% for levelling and canal management.

Discussion

Extent of damage and yield loss

This 3-year study suggests significant damage caused by flamingo forays. The 2008 estimate of the damaged area (4.62% of the rice field area) is close to the 5% estimate reported earlier from visual estimates and aerial photographs of the turbid area caused by flamingo forays (Mathevet *et al.* 2002). The proportion of damaged rice yield is of the same order as other crop and crop pest systems, such as Brent geese (*Branta b. bernicla*) in England, ranging around 7% yield loss per year (Summers 1990). We estimated almost 400,000€ net yield loss in 2008. This estimate is of the same order of magnitude as yearly crop loss estimates from other crop pests such as geese foraging on 60,000 ha on Islay, Great Britain (i.e. 387,770€; Lilley 1997) or for millet crop loss due to elephants in southern India (i.e. 375,250€; Sukumar 1989) but much lower than Dicksissels *Spiza Americana* damage to rice fields in Venezuela (i.e. >1 M€; Basili and Temple 1999). Despite these similarities which allow emphasizing the extent of the problem, the estimates are hardly comparable since they have been established in a particular socio-economic context, with great economic differences between yield gains and losses.

Although tillering partially compensated for low plant establishment caused by flamingo trampling (though differently depending on varieties) it did not offset the entire damage. Full compensation may be constrained by the low number of degree-days available for rice in this region at the edge of its growing range. In contrast, in Asia, rice could compensate up to 100% after a 50% loss at the tillering stage. However, cuts simulating rate consumption at later stages could not be compensated due to insufficient time remaining for stems to produce mature panicles at harvest time (My Phung *et al*. 2010).

Similar to elephants (Hoare 1999), geese (Owen 1990) and starlings (Somers and Morris 2002), crop loss is not equally spread over the entire region, but is spatially heterogeneous, more specifically affecting some fields or farms. Given the in-farm and in-field heterogeneity, our sampling and statistical approach was appropriate and could be adapted to estimate damage and yield loss for other crop pests. Our results also confirm previous studies concluding that flamingo forays target certain types of fields with specific conditions, that is, large open fields with no natural hedges (Tourenq *et al*. 2001a, 2001b). In the Camargue, yield loss affects only a small number of farmers, with more or less intensity (Figure 2). In 2009, one farmer incurred damage due to flamingo forays (10.5 ha damaged), representing a loss of approximately 2,536€. Interviews also confirm that farmers pay an additional cost linked to the time spent scaring flamingos at night. This can cause psychological stress as reported by farmers fighting Dicksissels damage to their rice fields (Basili and Temple 1999). These results indicate that flamingo forays do cause important economic damages to individual farmers.

Finally, there were important temporal variations in damage which may be related to yearly fluctuations of flooded wetland surface areas that are used as the main foraging habitats for flamingos. Extremely dry years, such as 2008, could cause the wet rice fields to be forayed more intensively to compensate for the lack of resources available in natural marshes. Hence, as in other crop pest systems, favourable climate conditions decrease damage intensity (Mangnall and Crowe 2002) probably preventing the long-term investment of farmers in reducing rice field attractiveness.

AES failure to trigger long-term landscape response

Replanting and maintaining hedges using native tree varieties has been promoted as a long-term landscape-change response by the Natural Regional Park of the Camargue because it had been demonstrated that this could reduce flamingo forays in rice fields (Tourenq *et al*. 2001a, 2001b). While the Park initiated publicity campaigns and offered free seedlings to plant hedges only two farmers took part in this activity in 2009. Similarly, while hedges are an efficient way to reduce damage, our study showed that <5% of the rice farmers adopted the hedge maintenance AES. This is a much lower uptake rate than the mean uptake rate published elsewhere (73% for France and from 16 to 98% in the other European Union countries; Falconer 2000). This demonstrates the weakness of the AES scheme proposed, and supports Bocacci *et al*.'s (2009) conclusions that the measures most frequently contracted do not provide meaningful long-term landscape changes. The financial incentives for 'business as usual' are more attractive and solicit the farmer's interests. Farmers tend to select the most lucrative AES (such as levelling and canal management) with the least amount of constraints (Ruto and Garrod 2009), discarding AES for hedges. Furthermore, similar to compensation schemes set up for damage caused by tigers in India (Karanth *et al*. 2012), the AES in the Camargue have not been designed properly to address the problem as geographical limitations prevented 25% of the farmers from benefiting from the scheme. Our results show that the financial and geographical limitations placed on AES do not incite farmers' engagement in maintaining hedges. The mechanism is thus inadequate to support long-term mitigation efforts.

Despite empirical evidence demonstrating that hedges do not reduce agricultural productivity (Martinez-Ghersa *et al*. 2001, Marshall and Moonen 2002), farmers' perceptions of hedges remain negative due to the constraints they add to farming practices, including the use of large agricultural machinery, reduced use of pesticides and increased water management (Martinez-Ghersa *et al*. 2001). The financial cost of establishing and maintaining hedges does pose a real constraint for intensive rice farming as water management and pesticide application schemes would need to be modified to promote healthy and productive hedges. If real HWC mitigation is to be effective in the Camargue and around the world, we suggest a change from short-term prevention methods to longer term sustainable conflict mitigation. Promotion of hedges and other landscape changes require that the relative incentives compared with other measures be reversed (Marshall 2002, Tattersall *et al*. 2002). This may imply cutting incentives related to price support policies which are unconditional to environment-friendly practices. Incentives should then be redirected to new AES that could cover the loss caused by these cuts and encourage investments needed by farmers willing to shift to agro-ecological and environment-friendly practices. New AES should be established by a thorough evaluation of practices which promote sustainable agriculture, wildlife mitigation and biodiversity. In particular, if AES are to be maintained in the new Common Agricultural Policy for Europe, we recommend that they be modified to provide a balance between short-term (maintenance) and long-term (creation) objectives and that the eligibility for the AES be extended beyond administrative zones to encompass ecological territories in a better manner. This strategy would be in line with the agro-ecological intensification strategy promoted by Tscharntke *et al*. (2012) as a way to resolve the land sparing versus wildlife-friendly farming debate. HWC may be resolved through agricultural management practices that would maintain actual yield to meet the demand for agricultural products while retaining biodiversity and the services it provides.

In the case of the Camargue, further research could also be conducted on short-term alternative responses such as: (i) Are certain rice varieties more resistant to flamingo forays (such as *Selenio* variety) a feasible agronomic choice for the Camargue? and (ii) What are the financial implications related to rice replanting and harvest grain quality? The pursuit of similar empirical studies on the acceptance of existing incentive-based schemes could give new alternatives to implement cost-efficient strategies aimed at minimizing human wildlife conflict.

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