Identifying rice fields at risk from damage by the greater flamingo

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Summary

1. Since the early 1980s, greater flamingos Phoenicopterus ruber roseus have been reported to cause damage to the rice fields of the Camargue, south-eastern France.

2. We tested whether some rice fields had landscape features that were more attractive to flamingos than others, using data from the period 1993–97 and from 1978 different paddies. Discriminant function analysis (DFA), logistic regression (LR) and artificial neural networks (ANN) were used to identify the environmental variables best explaining flamingo incursions.

3. The most accurate models (LR) gave 75% prediction success and used as predictors the surface area of rice fields, the presence of contiguous damaged fields, the presence of wooded margins and the distance to natural marshes.

4. Our study suggests that it is possible to identify accurately fields at risk from damage in order to concentrate scarifying methods. We also suggest that planting hedges should be promoted, and wood cutting discouraged, in high-risk areas. Following our study a programme of planting of hedges by the Natural Regional Park of the Camargue started at the beginning of 2000.

5. Our work reveals how presence–absence modelling can have clear applications in managing important species that sometimes cause negative impacts locally.

Key-words: bird pest, cultivated fields, environmental variables, predictive model.

Introduction

Growing on 11% of the world's arable land, rice Oryza sp. is the most cultivated crop in the world, and 40% of the human population depends on this primary food (Fasola & Ruiz 1997). In countries where rice fields cover large areas, crop damage by birds has been well documented. Seed depredation by birds causes losses of millions of dollars annually (Decker, Avery & Way 1990, Lane, Azuma & Higushi 1998).

Until recently, rice crop damage by birds had been less prevalent in Europe, where rice cultivation is restricted to a few parts of the Mediterranean region. Nevertheless, ducks, geese and shorebirds were reported damaging rice crops in the Banhalma region of Hungary as early as the 1950s (Sterbetz 1960). Incursions of greater flamingos Phoenicopterus ruber roseus Pallas in paddies were first noticed in the Camargue, south-eastern France, in 1978 (Hoffmann & Johnson 1991) and in the Ebro delta, north-eastern Spain, in 1993 (Jimenez & Soler 1996). Since then, the presence of flamingos in rice fields has been reported almost annually in both regions (Jimenez & Soler 1996, Johnson & Mesléard 1997). In the Camargue, around 1000 ha of rice fields, about 5% of the total rice surface area, need to be partially or totally resown every year. Damage to rice crops was estimated at approximately 200 000 US dollars in 1997 for the whole Camargue (Johnson & Mesléard 1997). Flamingos are strictly protected in Europe (Hoffmann, Hafner & Salathé 1996) and are not rice-dependent for their survival. As a symbol of the 'wild' Camargue for thousands of tourists, their image is used...
in promoting regional products, including rice. Therefore flamingo damage constitutes a potential conflict between nature conservation, tourism and agricultural production. Ecologists were thus asked to find a method to scare the birds off the fields.

Huge efforts have been made world-wide to prevent birds from damaging rice crops, including both non-lethal and lethal techniques (Mealey 1971; Elliot 1979; Decker, Avery & Way 1990), but few studies have investigated the behavioural processes involved (but see Brugger, Labsiky & Danzke 1992). In the Camargue, scaring programmes (i.e. gas exploders, rotating firing devices and Very® pistols) have been used since 1981 (Hoffmann & Johnson 1991). However, no precise knowledge exists on the flamingo’s response to these scaring techniques, some of which may be efficient while others only induce movements of flamingos to other fields.

Instead of searching for short-term control methods that are ethically problematic and possibly inefficient (Caughley & Sinclair 1994), we investigated the landscape characteristics of the rice fields selected by flamingos in order to provide new insights to help predict and prevent damage. As some paddies are visited each year by flamingos and others never, we hypothesized that some were more attractive than others with regard to landscape parameters (Sourribes 1993; Durieux 1997). For this purpose, we used discriminant factorial analysis (DFA), logistic regression (LR) and artificial neural networks (ANN) to identify the most explanatory environmental variables of paddies visited by flamingos.

Materials and methods

STUDY AREA

The Camargue lies in the Rhône river delta on the Mediterranean Sea coast, south-eastern France (Fig. 1). This deltaic complex, covering an area of about 14 500 km², is renowned for its apparently pristine habitats and as one of the most important wintering and breeding grounds for waterbirds in Europe (Thibault et al. 1998). Natural habitats cover some 60 000 ha (41% of the total surface) and salt works some 25 000 ha (17% of the total surface), in the southern part. Some 24 000 ha (16% of the total surface) are devoted to rice farming and 26 000 ha to dry crops (Chauvelon 1996).

Introduced in the Camargue after the Second World War, rice is traditionally cropped in flat areas that are usually flooded just before sowing (end of April–early May). The germination takes place 7–15 days later and rice plants emerge from water approximately 30 days after sowing. They develop stems in June and attain their maximum height in August. Harvesting takes place in September–October. Once seedlings are rooted, water levels (20–30 cm) are periodically reduced (5–10 cm) several times during the season for agricultural operations: herbicide and pesticide spraying or fertilization. Rice fields are drained some days before harvesting. Due to the salt load in the soil, growing of alternative species is restricted to a few parts of the delta, and because it requires flooded fields, rice remains the only crop possible in most areas of the Camargue (Barbier & Mouret 1992).

The rice farming area surveyed in this study was situated within the Fumemorte Basin (65 km²), one of the six independent drainage basins of the Camargue. In 1994, 1978 rice fields covered 61% of the agricultural land, equivalent to 31% of the total surface of the basin, while natural areas, such as freshwater marshes, salt ponds, woods and grasslands, covered a surface of 2 277 ha (32% of the total surface of the basin; Chauvelon 1996). The southern part of the basin is situated only 2 km from the Étang du Fangassier, the only site where flamingos breed in France (Fig. 1). With up to 20 000 breeding pairs, this colony is the most important in the Western Palearctic (Johnson 1997).

FLAMINGOS AND RICE FIELDS

Widely distributed in the wetlands of southern Europe, south-west Asia and Africa, the greater flamingo is most commonly found in extensive, shallow brackish or saline lagoons (Del Hoyo, Elliot & Sargatal 1992). The western Mediterranean population of about 80 000 individuals relies at present, to a large extent, upon two managed breeding sites: the Étang du Fangassier, situated in the industrial salinas of the Camargue, and the salt lake of Fuente de Piedra, southern Spain (Johnson 1997). Since 1977, the species’ biology, dispersal and survival have been the subject of long-term studies (Johnson 1997). Flamingos arrive on the breeding site in March and the first eggs are generally laid in early April. Chicks hatch 29 days later but do not fledge until the age of 70–75 days. Flamingos are partial migrants and up to 25 000 individuals winter on the French Mediterranean coast, including the Camargue, and others migrate in August–September to North Africa, Sardinia or Spain (Johnson 1997). Dispersed among about 85 000 ha of wetland habitats in the Camargue, flamingos usually feed in brackish or saline lagoons but are able to forage in freshwater marshes where aquatic invertebrates constitute their main prey (Johnson 1997). This might also be the case in rice fields where invertebrates are known occur (Suhling et al. 2000).

Flamingos visit paddies mostly between sunset and sunrise, soon after sowing (c. 20 April) until early June, this being the rice germination period. Flamingos visit the fields in small groups of less than 50 individuals but flocks of up to 200 individuals have been observed (André & Johnson 1981). When they are not disturbed, the birds usually stay all night in the same paddy. When they are scared off by farmers, they move to nearby fields or natural marshes. With their large
webbed feet, they trample the grain into the earth preventing germination of rice grain. Seeds may be uprooted and consumed; flamingos are also known to feed on vegetation, including seeds (Del Hoyo, Elliot & Sargatal 1992), and rice has been found in the stomachs of two individuals (Hoffmann & Johnson 1991).

**DATA COLLECTION**

**Occurrence of damage**

Visits by flamingos to rice fields were monitored in 1978 paddies between 1993 and 1997. From 1993 to 1995, records of visits (i.e. fields partially or totally resown) were extracted from internal reports of the Natural Regional Park of the Camargue, and collected by interviewing landowners. For the period 1996–97, specific methods of census were used during the critical period (May–June; Durieux 1997).

First, we undertook a bi-weekly aerial survey (at 150 m) of the Fumemorte Basin in the morning. Each field believed to have been visited by flamingos (turbid water, tracks) was checked by ground visits the same day to confirm that flamingos were really responsible (presence of pink coloured feathers, faeces, large footprints, pattern and extent of damage). Thus there was no confusion with other rice pests such as wild boar *Sus scrofa* L., coypu *Myocastor coypus* L. or ducks. Secondly, farmers were asked to plot the distribution of fields visited by flamingos on a map and to estimate the number of birds involved. During the whole period, farmers were asked to call the Centre Français du Riz or the Station Biologique de la Tour du Valat as soon as they noticed groups of flamingos in their fields. A visit to the property followed each telephone call to verify damage.

The presence or absence of flamingo visits causing damage (dependent variable) was coded as 1 or 0, respectively (even when damage was repeated during several years). Flamingos visited 276 fields during the 1993–95 period, 60 in 1996 and 73 in 1997, all of the latter having been visited in 1993–95 (Fig. 2).
Landscape variables

We considered 11 environmental variables for each of the 1978 rice fields of the Fumemorte Basin: surface area of the rice field (SUR), distance from natural marshes (DNM), distance from the breeding site (DCO), distance from the closest wooded hedge or copse (DWO), distance from power lines (DTL), distance from habitations (DHA), distance from principal roads (DPR), distance from secondary roads (DSR),
height of hedges surrounding the paddy (HHS), number of wooded sides (NWS), and presence (1) or not (0) of contiguous damaged fields during the same year (CON). This last variable was introduced to consider spatial information according to Smith (1994).

Surface area was measured in ha and distances were considered from the geometric centre of the field (in km). Five classes of hedge height were retained according to the main vegetation occurring in the Camargue (Durieux 1997): < 50 cm (herbaceous plants or absence of vegetation), 50 cm–150 cm (mostly reed Phragmites australis (Cav.) Steudel), 150 cm–3 m (reed, tamarisk Tamarix gallica L., hawthorn Crataegus monogina (Jacq.), phillyrea Phillyrea angustifolia (L.), elderberry Sambucus nigra L.), 3 m–15 m (narrow-leaved ash Fraxinus excelsior L., laurel Laurus nobilis L., oleaster Elaeagnus angustifolia(L.), > 15 m (cork alder Alnus glutinosa (L.) Gaertn., downy oak Quercus pubescens Wild., italian cypress Cupressus sempervirens L., elm Ulmus campestris auc. non L., white poplar Populus alba L., false acacia Robinia pseudo-acacia L.).

STATISTICAL ANALYSIS

DFA, LR and ANN modelling

DFA is the statistical technique most commonly used to provide a classification that minimizes the probability of misclassification, but requires multivariately normally distributed variables and equal covariance matrices for all groups for the prediction rule to be optimal. The relative contribution of independent variables can be estimated by the standardized canonical coefficients (Norusis 1997; Manel et al. 1999).

LR, a type of generalized linear model, estimates directly the probability of an event occurring (Hosmer & Lemeshow 1989). LR is well adapted when the response variable is binary, for example the presence or absence of a species (Higgins et al. 1999). This technique requires far fewer assumptions than DFA, and even categorical variables can be used. The partial correlation between the dependent variable and each of the independent variables can be used. The contribution of independent variables can be estimated by the standardized canonical coefficients (Norusis 1997).

Due to their highest prediction scores over all classical methods in some cases, ANN applications have been given increasing interest in ecological modelling (Mastrorillo et al. 1997; Spitz & Lek 1999; numerous papers in Lek & Guégan 1999). Based on the initial work of Rumelhart, Hinton & Williams (1986), this method uses a classic multilayer feed-forward neural network with back-propagation algorithm. A more complete description of the methods and structure of the ANN models used in this study is given in Tourenq et al. (1999). Based on a non-parametric method, ANN have no assumptions on variables. The contribution of each environmental variable was determined using the Goh procedure (Garrison 1991; Goh 1995).

DFA and LR were computed using the SPSS-PC software package (SPSS Inc., Chicago, IL). The computational program of ANN was undertaken using Matlab™ software release on PC.

Data sets

In order to test the predictive quality of the three models, the global data matrix of 1978 different paddies (276 with damage and 1702 without) for the 1993–97 period was randomly decomposed into two sets. The first set was used to train the models (training set). The remaining individuals (testing set) were used to evaluate the quality of the predictions in a hold-out procedure (Geman, Bienenstock & Doursat 1992; Kohavi 1995).

In a preliminary study (Tourenq et al. 1999), we showed that ANN training needed an equal set of presences and absences to correctly predict events and two events. Ten different training sets of 414 records (207 presences–207 absences) and testing sets of 1564 records (69 presences–1495 absences) were randomly sampled to avoid particular input either in the training set or in the testing set. As a consequence of these balanced training sets, presence was accepted as a threshold probability of 0.5 in LR and ANN (Fieberg & Bell 1997).

Results

PREDICTION OF FLAMINGO VISITS

Correct classifications of the training data were similar between DFA and LR. Prediction success ranged from 71.5% to 81.2% for presences and from 73.4% to 80.2% for absences (Table 1). ANN always delivered better classifications; a maximum of 98.1% was obtained for presences when the minimum was 86.5% of absences for one model. However, this improvement of classification with ANN did not provide better predictions in the test set. In the tests set, DFA models predicted absences better (median 75.4%) than presences (median 71.8%) of damage (Wilcoxon paired test, $T = -1.98$, $P = 0.047$, $n = 10$). LR models did not show significant differences between predictions for absences (median 74.4%) and presences (median 71.7%) of damage (Wilcoxon paired test, $T = -1.27$, $P = 0.203$, $n = 10$). Predictions of ANN models equilibrated around 72% for both absence (median 71.4%) and presence (median 72.5%) of damage (Wilcoxon paired test, $T = -1.47$, $P = 0.154$, $n = 50$).

There were no significant differences between presence of damage predicted by the three techniques, but LR exhibited the highest scores (Wilcoxon paired tests, DFA/LR: $T = -1.81$, $P = 0.071$, $n = 6$; DFA/ANN: $T = -0.10$, $P = 0.919$, $n = 10$; LR/ANN: $T = -0.71$, $P = 0.475$, $n = 10$). The only significant difference was observed for predictions of absence of damage between DFA and LR (Wilcoxon paired tests, DFA/LR: $T = -2.81$, $P = 0.005$, $n = 6$; DFA/ANN: $T = -1.58$, $P = 0.114$, $n = 10$; LR/ANN: $T = -1.27$, $P = 0.203$, $n = 10$), DFA scores being higher than LR scores for all test sets.
damage by flamingos

For ANN models, contributions from the environmental variables varied considerably among models (Fig. 3). For example, DNM contributed strongly to model 3 of set 10 (17.96%) and was weakly implicated in model 1 of set 8 (7.86%). Moreover, variables generally displayed equilibrated contributions, so ANN were not adequate to identify the most relevant environmental variables involved in the frequentation of rice fields by flamingos.

Standardized canonical coefficients of environmental variables displayed few variations among DFA models (Fig. 4). In addition, fewer variations were recorded among partial correlations in LR models (Fig. 5). Two variables contributed strongly to every model with

**Table 1.** Results of discriminant function analysis (DFA), logistic regression (LR) and five models of artificial neural networks (NNN, NN2, NN3, NN4, NN5) to predict the presence–absence of damage in rice fields by flamingos. The values are the prediction success percentages from 10 randomly sampled data sets of presence and absence (207 presences and 207 absences in the training set, 69 presences and 1495 absences in the independent testing set). The mean and standard variation (in parentheses) is given for each method.

<table>
<thead>
<tr>
<th>Method</th>
<th>Training presence</th>
<th>Training absence</th>
<th>Testing presence</th>
<th>Testing absence</th>
</tr>
</thead>
<tbody>
<tr>
<td>DFA</td>
<td>74.36 (3.01)</td>
<td>77.59 (2.04)</td>
<td>70.88 (5.12)</td>
<td>75.65 (1.67)</td>
</tr>
<tr>
<td>LR</td>
<td>75.51 (2.67)</td>
<td>76.53 (1.82)</td>
<td>72.04 (6.11)</td>
<td>74.65 (1.46)</td>
</tr>
<tr>
<td>NN1</td>
<td>92.35 (3.73)</td>
<td>91.60 (2.37)</td>
<td>72.00 (2.14)</td>
<td>70.86 (3.28)</td>
</tr>
<tr>
<td>NN2</td>
<td>93.48 (1.62)</td>
<td>91.73 (3.20)</td>
<td>72.45 (5.89)</td>
<td>70.08 (4.47)</td>
</tr>
<tr>
<td>NN3</td>
<td>90.90 (6.78)</td>
<td>92.12 (2.04)</td>
<td>70.14 (11.57)</td>
<td>71.77 (2.40)</td>
</tr>
<tr>
<td>NN4</td>
<td>93.72 (1.57)</td>
<td>92.57 (2.00)</td>
<td>72.76 (4.90)</td>
<td>71.86 (2.30)</td>
</tr>
<tr>
<td>NN5</td>
<td>93.73 (1.54)</td>
<td>91.00 (3.44)</td>
<td>71.56 (3.50)</td>
<td>71.71 (3.71)</td>
</tr>
</tbody>
</table>

**Fig. 3.** Importance of the contribution of each environmental variable expressed as a percentage of the total contribution to the model, determined by Garson's algorithm (Garson 1991) in artificial neural network (ANN) models. Boxes represent the interquartile range of contributions and are bisected by the median values. Open circles indicate the value more than 1.5 box-lengths from the 75th percentile (outlier points). SUR, surface of rice fields; DNM, distance from natural marshes; DCO, distance from the breeding site; DWO, distance from the closest wooded hedge or copse; DTL, distance from power lines; DHA, distance from habitations; DPR, distance from principal roads; DSR, distance from secondary roads; HHS, height of hedges surrounding the paddy; NWS, number of wooded sides; CON, presence of adjacent fields with damage during the same year.

**Fig. 4.** Range of contributions of input variables expressed as standardized canonical discriminant function coefficients obtained with discriminant function analysis (DFA) models. Boxes represent the interquartile range of contributions and are bisected by the median values. Open circles indicate the value more than 1.5 box-lengths from the 75th percentile (outlier points). Abbreviations as for Fig. 3.

**Fig. 5.** Range of contributions of input variables expressed as R-values of logistic regression (LR) models. Boxes represent the interquartile range of contributions and are bisected by the median values. Open circles indicate the value more than 1.5 box-lengths from the 75th percentile (outlier points), stars represent the value more than three box-lengths from the 75th percentile (extreme values). Abbreviations as for Fig. 3.
both techniques: CON (0.167–0.281 for LR, 0.422–0.666 for DFA) and SUR (0.124–0.216 for LR, 0.334–0.539 for DFA). Thus, the presence of contiguous damaged fields and the large surface area of the rice field favoured visits by flamingos. Four variables were used with lower contributions than the two former ones: DWO (0–0.179 for LR, 0.156–0.501 for DFA), NWS (0 to –0.140 for LR, –0.462 to –0.069 for DFA), DNM (0 to –0.112 for LR, –0.338 to –0.089 for DFA) and DHA (0–0.089 for LR, 0.048–0.279 for DFA). Flamingos tended to visit fields far from wooded and urbanized areas, but close to natural marshes, while they tended to avoid fields with hedges.

**Discussion**

Each field visited by flamingos in 1996 and 1997 had already been visited by flamingos during the wintering period 1993–95. This repetition of damage from one year to the next should facilitate modelling, but our prediction scores did not reach 100%. Despite differences in prediction training performances among the three types of model in favour of ANN, prediction scores in testing equilibrated around 71–75% for the three techniques with slightly lower performances for ANN. These prediction scores can be considered high and variables chosen were able to explain well the visits to rice fields by flamingos. DFA and LR models predicted absence better than presence of damage, whereas ANN provided more balanced predictions for both absences and presences. Our results contrast with recent studies that suggested both models performed better than conventional modelling methods (Lek et al. 1996; Mastrorillo et al. 1997). As observed by previous authors (Manel et al. 1999; Tourenq et al. 1999), ANN models delivered better prediction for the largest occurrence (absences) but information was lost by decreasing the number of records in the training sets. Moreover, the nature of the input variables and causal relationships between them, which are specific to the species, may affect ANN performances (Mastrorillo et al. 1997; Manel et al. 1999). Thus, in some cases, ANN may not provide better scores and do not have major advantages over DFA or LR.

Contributions of environmental variables to the models using DFA and LR were quite similar. With both DFA and LR, the environmental variables that mostly influenced the visits to rice fields by flamingos were CON and SUR, and to a lesser extent DWO, NWS, DNM and DHA.

With high contributions, the influence of SUR, NWS and, to a lesser extent, DWO, may reflect the accessibility of these fields to large birds such as the greater flamingo. In this case, the presence of hedges appeared more critical than the height of the hedges (low scores of HHS in the three methods). Larger fields allow birds to detect predators at greater distances, and the absence of hedges increases all-round visibility, reduces the risk of surprise attacks from predators and facilitates take off (Barnard & Stephens 1981; Whitehead, Wright & Cotton 1995). Small paddies fringed by hedges have less risk of being visited by flamingos than large paddies with no hedges on the border, as flamingos prefer to forage in open wetlands (Del Hoyo, Elliot & Sargatal 1992; Johnson 1997).

Throughout the year, flamingos are commonly seen foraging in natural marshes within our study area (Johnson et al., personal observation). Paddies located far from these natural marshes are visited less frequently by flamingos (negative contributions of DNM). Paddies close to fields already visited by flamingos have a higher risk of being visited by flamingos (high positive contribution of CON). With a heterogeneous environment such as the Fumemorte Basin, flamingos may act as ‘prescient foragers’ (Valone 1991): they may be able to estimate where the good foraging places are on the basis of visual information and may remember where they found good foraging conditions formerly. However, the bright plumage of flamingos may be an attractive signal for congeners, as mentioned in Ciconiiform wading birds (Kushlan 1977; Caldwell 1986). This highly gregarious species (Del Hoyo, Elliot & Sargatal 1992) may be attracted by groups foraging in closed damaged fields or natural marshes.

Furthermore, this formerly shy species has been observed with increasing frequency in the vicinity of human beings, for example sewage ponds, lagoons near oil refineries, highways and suburbs (A. Johnson, unpublished data). This habituation to human presence is reflected by the low ranking of distances to human settlements (DSR, DPR, DTL and DHA). Such behavioural-based assumptions, i.e. food store memory, gregariousness and human habituation, are supported by the fact that some damaged fields were visited in several years during our study period. However, more data are needed to investigate the site fidelity of foraging flamingos between years, whether damage in two contiguous fields is simultaneous and caused by the same or by different birds during the same night. The low scores of the variable DWO are not surprising, as flamingos can travel up to 150 km from their breeding site to forage (Johnson 1997).

**TOWARDS ‘SOFT’ MANAGEMENT?**

The loss of natural wetlands throughout the world, and particularly in Europe, has been correlated with human population growth, urbanization and conversion of land to agriculture (Duncan et al. 1999). This has made rice fields attractive for waterbirds, some species of which are of national or international conservation concern (Fasola & Ruiz 1997). Even if their impact on rice crops was lower than currently estimated (Hobaugh, Stutzenbaker, & Flickinger 1989; Hohman, Stark & Moore 1996; Ezealor & Giles 1998), and in some cases possibly positive for rice cultivation (Bird, Pettigrove & Eadie 2000), some waterbird species have benefited from the increase in areas cultivated with rice and are now considered as serious pests by farmers (Bomford...
secular agriculture (less than 10,000 breeding pairs in 1980 and about 25,000 in 1995; Johnson & Mesléard 1997) and increasing economic pressures on rice farming. The invasion of paddies by flamingos may appear to be a trivial problem at an international or national scale, but at a regional or local scale the situation is more critical (Rogers 1995; Johnson & Mesléard 1997).

The exploitation of resources and the distribution of foraging animals are influenced by the habitat structure and, at a larger scale, by landscape (Carter & Abrahams 1997; Dooley & Bowers 1998). Our study reveals that reduced surface area of paddies, distance from natural marshes and of wooded marginals all act to reduce flamingo visits. Our results suggest that appropriate planting of hedges and preventing wood cutting in rice fields may significantly limit the incursions of flamingos in rice fields. In addition, hedges are likely to enhance local biodiversity in agro-ecosystems and offer agronomic advantages by acting as reservoirs of crop pest predators. They also reduce soil erosion and drift of fertilizers and pesticides to adjacent habitats (Baudry 1988; Jörg 1995; numerous papers in Sotherton et al. 1998).

However, most rice farmers do not perceive their positive value, because they slow down rice growth at the edge of the field and make aerial spraying of pesticides more difficult (Mañosa i Rifé 1997). However, in the case of rice cultivation, hedges may also act as a physical barrier against wind and thermal stress during the critical germination stage, as seeds are sensitive to any wave action and water temperature decrease (Sterbe 1960; Barbier & Mouret 1992, Mañosa i Rifé 1997; PNRC 1999a).

Even though our model prediction could be improved, our results can already be suggested as appropriate planting of hedges and to discourage wood cutting in high-risk areas. Restoration of hedges could limit flamingos incursions in the more threatened paddies. On the basis of our results, the Natural Regional Park of the Camargue has started to promote hedge planting. Trees and shrubs are provided by the Natural Regional Park at no cost to farmers whose fields are planted. Trees and shrubs are provided by the Natural Regional Park at no cost to farmers whose fields are planted.

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