Designing grassland landscapes for economic or ecological priorities: application to livestock farming and birds

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Abstract: *Grassland birds are facing increasing threats due to the intensification of agricultural practices. Grazing or mowing can have negative and positive effects on wader dynamics at field scale and land use distribution influences these dynamics at landscape scale. The aim of this study was to assess the ecological and economic performances of several agricultural landscapes composed by different farm types. Based on a database from the Marais Poitevin (France), farm types were characterised using several indicators of management intensity and were used to generate several hypothetical landscapes which were compared to the current landscape according to their ecological and economic performances. A stage structured stochastic model was developed to asses the long term effects of grazing and mowing practices on ground nesting birds on contrasted landscapes. A simplified version of the meta-population model made it possible to asses the importance of the mowing/grazing ratio on bird dynamics in a grassland landscape. Stocking rate per hectare of main fodder area proved itself to be a good indicator of farm management intensity and four farm types were identified. Landscapes comprising either large or small extensive farms were the most efficient on an ecological viewpoint but small extensive farms had on average the poorest economic performances. From these results it was inferred that landscapes made off large extensive farms were more likely to reconcile economic and ecological priorities. However, accounting for the social aspects of farming calls attention to the potential role of small extensive farms in sustainable management of grassland landscapes.*

Keywords: *grassland birds, grazing, landscape, mowing, sustainable farming*

Introduction

Recent changes in European agriculture have led to increasing threats on farmland biodiversity (Donald et al., 2006). Decline is particularly obvious concerning specialized farmland birds (Julliard, 2003). Grassland birds have also undergone severe population decline mainly due to the loss of grassland areas through conversion to arable land (Duncan et al., 1999) and the degradation of grassland habitats through intensification of agricultural practices (Vickery et al., 2001). Assuring suitable habitat quality for remaining grasslands in agricultural landscapes is of key concern in order to counteract biodiversity decline.

In grasslands, grazing and mowing practices implemented by livestock farms are important drivers of habitat quality for grassland birds at field scale (Tichit et al., 2005a). Although grazing can have negative direct effects on ground nesting birds through nest trampling (Watson et al., 2006), it is however necessary in order to generate suitable grass height for the long term maintenance of bird populations (Tichit et al., 2007). Connectivity between fields with suitable habitat quality is also important as it can facilitate or impede movement of birds among resource patches during chick rearing (Redfern, 1982). At a landscape scale, connectivity varies with the level of intensification of farming systems (Baudry et al., 2003) and factors such as land cover distribution and internal farm rules of land allocation play an essential role in determining connectivity. In grassland areas, the share of mowing in the landscape affects the spatial configuration of a habitat mosaic and the proportion of different habitats (suitable and unsuitable) determining the carrying capacity for several species. Several kinds of data suggest that the link between management and habitat quality at field scale is driven by factors acting at upper scale (Durant et al., in press). For instance, farm characteristics, such as size and intensity of main fodder area, are likely to be important drivers of habitat quality, notably if small or large farms do not implement the same management intensity at field scale and do not generate at landscape scale the same types of habitat mosaics (Tichit et al., 2006). Ecological performance of a landscape is thus driven by complex interactions between agricultural practices at the field scale and agronomical and economic constraints at the farm scale (Durant et al., in press). However, the question whether biodiversity may benefit from a few large versus several small farms is still unclear.

In a grassland landscape, with high priority for bird species conservation, we tackle this question in a long term perspective by developing a dynamic modeling framework to predict viable strategies for the management of two ground nesting bird species (lapwings and redshanks) on a grassland landscape. This model should help us to predict how biodiversity friendly livestock farming is likely to shape an agricultural landscape and to asses to what extend economic and ecological priorities can be conciliated.

Material and methods

Using several indicators, we qualified the degree of management intensity in the main four farm types found in a marshland area (marais Poitevin, France). We generated different hypothetical landscapes based on different proportions of these farm types. These landscapes were used to compare contrasted scenarios of landscape change over time reflecting a specialisation of the landscape with each farm type. We added a reference scenario (denoted “marshland”) where each farm type kept its present share in the landscape so as to test a landscape that would not evolve from current situation. For each landscape, economic and ecological performances were assessed. Economic performance was qualified by the economic size of the farm and ecological performances were based on a model of population dynamic of ground nesting birds.

Farm types

We used a database comprising 893 fields belonging to 46 farms involved in agri-environmental schemes, 687 of which were located in a marshland area. This database included several descriptors at the farm scale and data on grazing and mowing practices at field scale. In a former study Tichit et al.(2006) classified these farms in four different types on the basis of two criteria. The first one traduced the level of intensity of main fodder area (MFA), it is expressed by the ratio between average stocking rate (expressed in livestock units, LU) and main fodder area (expressed in ha). It made it possible to classified farms in extensive (<1.4 LU/ha MFA) and intensive ones (>1.4 LU/ha MFA). The second one corresponded to useable farm area (UFA), with three levels of farm size (100, 170 and 220 ha of UFA respectively). Combining both criteria led to four types of farms referred to as “*small intensive*”, “*small extensive*”, “*medium extensive*” and “*large extensive*”.

In addition to previous criteria, five additional criteria were defined in order to qualify the degree of management intensity on the different farm types. They corresponded to the following ratios: maize silage area / main fodder area (MS/MFA), temporary grassland area / main fodder area (TG/MFA), permanent grassland area / main fodder area (PG/MFA), main fodder area / useable farm area (MFA/UFA), livestock units / area of permanent grasslands (LU/PG). These ratios gave a more accurate distinction between farm types in terms of management intensity of the different components of the fodder system. For each ratio, we ranked farm types from the most extensive to the most intensive one. Then we calculated the average ranking value for each farm type so as to classify them according to an intensity gradient.

In a second step, we used economic data to assess the economic performance of the four types of farms. We relied on the economic size (ES) which is a good indicator of the farm gross margin. Combined with ecological performance (see below), this enabled us to discus potential changes over time of landscapes under ecologic or economic priorities.

Suitability of marshland fields for birds

We qualified all fields on the basis of grazing and mowing impacts on the dynamic of the two wader species. For each bird species, we distinguished suitable and unsuitable fields on the basis of the status of its population after 15 years. A given field was qualified as unsuitable if the population probability of quasi-extinction (population reduced by 80% after 15 years) exceeded 0.05 on an homogeneous landscape composed of this type of field only. We relied on a stage structured stochastic population model previously developed by Tichit et al. (2007) to assess bird dynamics. We used a Population Viability Analysis (Ferriere et al., 1996) to assess the effects of grassland management on each wader population. On this basis mown fields could be qualified as unsuitable. To qualify grazed fields, we incorporated the effect of nest trampling by cattle on wader fecundity in Tichit et al. (2007) model. High stocking densities during nesting month have negative effects on ground nesting birds. Beintema et al. (1987) predicted the effect of one livestock unit on the daily survival rate of eggs for four waders species including lapwings and redshanks. Bareiss et al. (1986) modelled the relationship linking stocking density, grazing duration and nest trampling. Based on both studies, we assessed the effect of stocking density on the fecundity of lapwings and redshanks. The suitability of grazed fields was therefore defined by stocking density during nesting months. We computed the fecundity threshold leading to a probability of quasi extinction of 0.05. These thresholds were then linked to the corresponding cattle density to define maximal cattle density ensuring the suitability of grazed fields for each wader species. Combining the effects on each wader, fields were then classified in five types: mowed (M), grazed and unsuitable for both waders (G), grazed and suitable for lapwings (GL), grazed and suitable for redshanks (GR) and grazed and suitable for both waders (GLR).

Ecological performance of marshland landscape

To assess ecological performances of marshland landscape, we built a meta-population model of redshanks and lapwings (*Fig 1*). For each wader species, three populations corresponding to three habitats (mown, grazed suitable and grazed unsuitable) were defined. Demographic parameters of each wader were defined in relation with grazing and mowing practices in these habitats. Fecundity was assumed to be higher in mown grassland as nests are not affected by cattle trampling and mowing operation occurs after egg hatching. On grazed fields, juvenile survival was assumed to be higher than that in mown grassland so as to reflect the positive effects of grazing on habitat structure (grass height and sward heterogeneity). In suitable grazed grassland, reduction in fecundity was defined by the effect on wader fecundity of a cattle density equal to the threshold of suitability. In unsuitable grazed grassland, fecundity took the value defined by the average cattle density of these fields (*Tab 1*).

Population dynamic was defined by the following relationship

$N_i(t+1) = L_i\, N_i(t)$

Where L_i is the stochastic matrix of bird dynamics and N_i the population size of species i. This matrix includes adult survival, reproduction (fecundity and juvenile survival) and movements among habitats.

Philopatry of waders is not well known. It seems that waders usually come back to the same area to breed each year (Thompson et al., 1994). But at a smaller scale (field scale), philopatry of waders is still poorly understood. Several hypotheses about the movement patterns of waders among habitats were therefore examined

- No movement for both adults and chicks
- Philopatry: chicks can move during rearing period but adult always breed on their birth place
- No philopatry: chicks can move during rearing period and adults breed on a random site

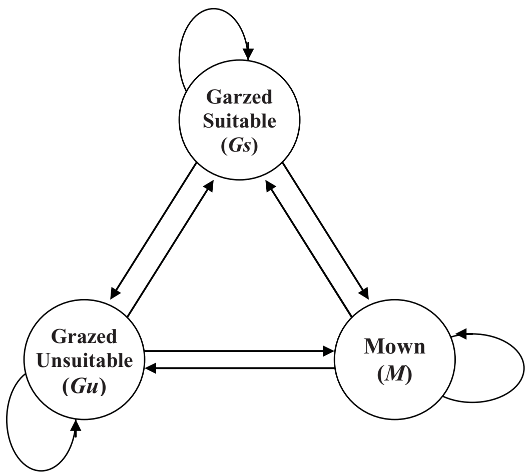

Figure 1. Schematic representation of the meta-population model. Circles stand for sub-populations corresponding to the habitat mentioned; arrows correspond to transitions between two sub-populations or within a same sub-population from year n to year n+1. Each arrow stands for adult transitions (probability of movement and survival) and reproduction (fecundity, chick survival and probability of movement of chicks).

Tab 1. Values of demographic parameters depending on wader species and type of field (fi being the optimal clutch size of species i, with flapwings = 4.2 and fredshanks = 4.2

		Lapwing		Redshank	
Type of field	**Code**	**Fecondity**	**Juv. survival**	**Fecondity**	**Juv. survival**
Mown	MG	f i	0.1	f i	0.1
Grazed unsuitable	G	0.4 * f i	0.45	0.15 * f i	0.35
Grazed suitable for Lapwings	GL	0.7 * f i	0.45	0.15 * f i	0.35
Grazed suitable for Redshanks	GR	0.4 * f i	0.45	0.5 * f i	0.35
Grazed suitable for both waders	GLR	0.7 * f i	0.45	0.5 * f i	0.35

Influence of the proportion of mown grassland

Both grazing and mowing can have negative effects on the demography of birds. Grazing affects fecundity through nest trampling and mowing affects juvenile survival because in such habitat the continuous development of vegetation height throughout spring generates tall vegetation cover impeding chick movements and increasing foraging costs (Devereux et al., 2004). As rearing areas differ from nesting ones, juvenile survival depends on the proportion of habitats in the whole landscape and not only in the nesting habitat. To asses the effect of the proportion of mowed fields in the landscape on wader populations, we used a simplified version of the meta-population model including two habitats only: mown and suitable grazed fields. We considered juvenile movement and reproduction on the site of birth i.e. philopatry hypothesis.

Results

Description of farm types

The five new indicators of management intensity showed a positive correlation with LU/MFA in all farm types excepted in medium extensive ones (Fig 2.a). Medium extensive farms showed a less obvious correlation and seemed to be farmed in a different way than the others. Indeed, the low proportion of maize silage tended to indicate an extensive management but stocking rate was quite high and livestock feeding system was highly dependent on grassland resources (both temporary and permanent). Consequently, permanent grasslands were managed more intensively than in large extensive farms. However the average ranking value of each farm type still classified them in the same order as the ranking based on the LU/MFA indicator only (Fig 2.b). Consequently, the previous classification of farms seemed to be a good assessment of management intensity.

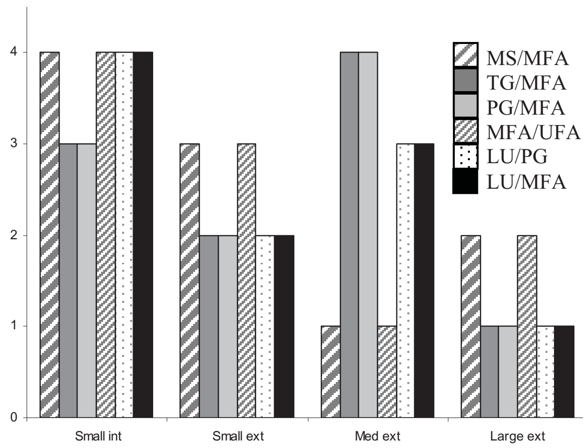

Figure 2.a. Ranking of the four farm types according to different indicators of management intensity of the fodder system. For each indicator a ranking value of one stands for the most extensive management and a ranking of 4 stands for the most intensive one.

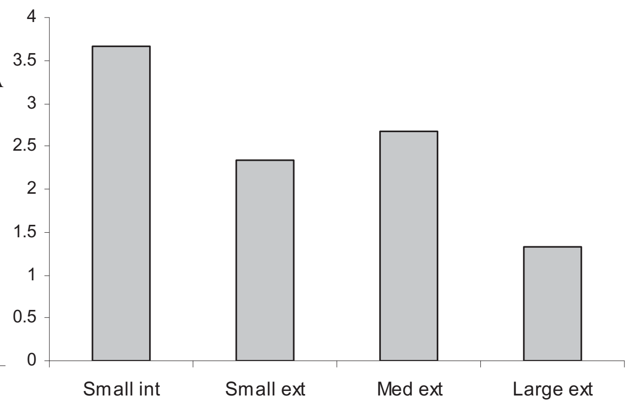

Figure 2.b. Average ranking of the four farm types according to different indicators of management intensity of the fodder system

Economic performances of defined farm types

The database allowed us to compute the economic performance of each farm type (*Fig 3*). Small intensive farms were still close to medium extensive ones but the economic performance of large extensive farms was higher than that of small intensive ones. Small intensive farms had a large variability between maximal and minimal economic performances. They had the highest maximal economic performance. On average, large extensive farms had the best economic performances whereas small extensive ones only reached poor performances, with the highest variability.

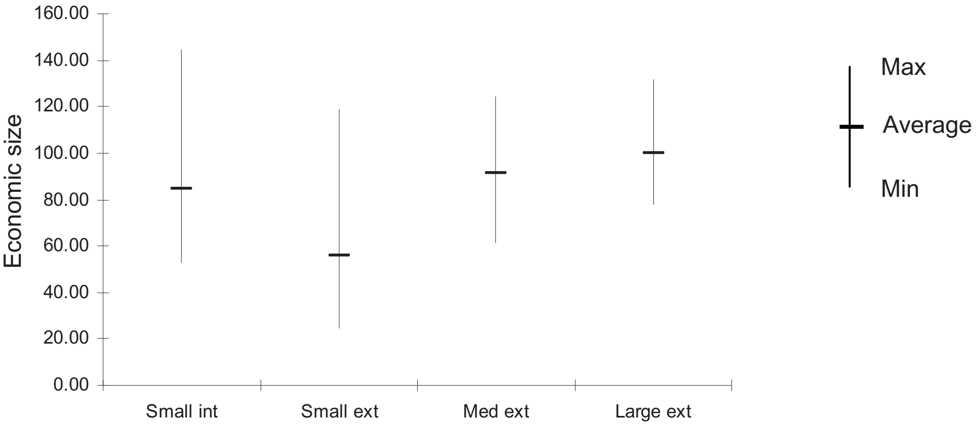

Figure 3. Economic sizes of the four farm types.

Comparison of different landscapes involving varying proportion of farm types

The actual marshland landscape included one third of suitable fields (Tab 2.). More fields were suitable for lapwings than for redshanks whatever the landscape. Landscapes composed of only one type of farm could be divided in two categories. Landscapes of small extensive and large extensive farms seemed to be more suitable for both waders species while landscapes composed of small intensive and medium extensive farms appeared to be less favourable. Landscape composed of small and large extensive farms showed similar proportions of suitable and unsuitable fields. Small intensive and medium extensive farms differed in the composition of unsuitable grasslands. Landscape with small intensive farms had a high proportion of mown pastures and half of their grazed grasslands were suitable for waders. Those with medium extensive farms had a lower proportion of mown grasslands but most of their grazed grasslands were not suitable for waders. Landscapes with medium extensive farms only were the less suitable ones. This situation was likely to be linked with the general intensive use of permanent grasslands.

Table 2. Share of the five grassland fields in different landscapes composed of different farm types and in the actual marshland landscape

	Small int	Small ext	Med ext	Large ext	Unclas. farms	Marshland
Grazed (Lapwing)	19.35	20.73	12.66	25.57	10.94	19.94
Grazed (Redshank)	4.30	2.91	0.00	5.11	0.00	3.06
Grazed (Lap. Red).	5.38	18.18	10.13	12.50	15.63	13.83
Total suitable	***29.03***	***41.82***	***22.78***	***43.18***	***26.56***	***36.83***
Grazed	23.66	25.09	37.97	22.73	9.38	24.31
Mown	47.31	33.09	39.24	34.09	64.06	38.86
Total unsuitable	***70.97***	***58.18***	***77.22***	***56.82***	***73.44***	***63.17***

Ecological performances of landscapes types

The actual marshland landscape showed relatively good ecological performances (Tab 3). If the hypothesis chosen for the movement of birds had an influence on the absolute population sizes, it had little impact on the relative abundance of waders. As expected, the ecological performance of landscapes was mainly driven by the proportion of suitable and unsuitable grasslands. Landscapes could be grouped in two types. The first one was composed of large and small extensive farms reaching the best ecological performances. Their ecological performances were close to that of the marshland landscape. The second group was composed of small intensive and medium extensive farms with lower ecological performances.

Table 3.a. Lapwing population size after 15 years for the five scenarios and for three movement patterns of bird

	Small int	Small ext	Med ext	Large ext	Marshland
No movement	34	39	33	39	38
Philopatry	28	35	32	34	32
No philopatry	25	31	26	31	29

Table 3.b Redshank population size after 15 years for the five scenarios and for three movement patterns of bird

	Small int	Small ext	Med ext	Large ext	Marshland
No movement	18	21	17	20	20
Philopatry	41	46	44	45	44
No philopatry	27	26	25	26	27

Influence of the proportion of mown grasslands

The effect of the proportion of mown grassland on wader population sizes at 15 years did not show a linear relationship with bird population sizes at 15 years (*Fig 4*). On the ecologic viewpoint, there was an optimal proportion of mown grassland in the landscape which differed between lapwings and redshanks. This optimum was reached with 10% of mown pastures in the landscape for lapwings and 20% for redshanks. This was due to differences in waders' demographic parameters. Under the philopatric hypothesis, juvenile survival was the same for every chick, independently from their birth place. Movement of chicks made the juvenile survival only dependant of the proportion of different habitats at the landscape scale. Waders nesting on mown grasslands had thus an optimal fecundity and their juvenile survival took an average value between grazed and mown grassland survival whereas waders nesting on grazed grassland had a lower fecundity but the same average survival. The optimum proportion of mown parcels in the landscape illustrates the trade off between a large carrying capacity for waders on mown grasslands and a good average juvenile survival (penalized by a too high proportion of mown grasslands). To define the trade-off between conservation of redshanks and lapwings, we defined the proportion of mown grasslands leading for each wader to a population of 95% of their maximal population. The best strategies for the conservation of both waders were those with a proportion of mown grasslands varying between 10% and 20%.

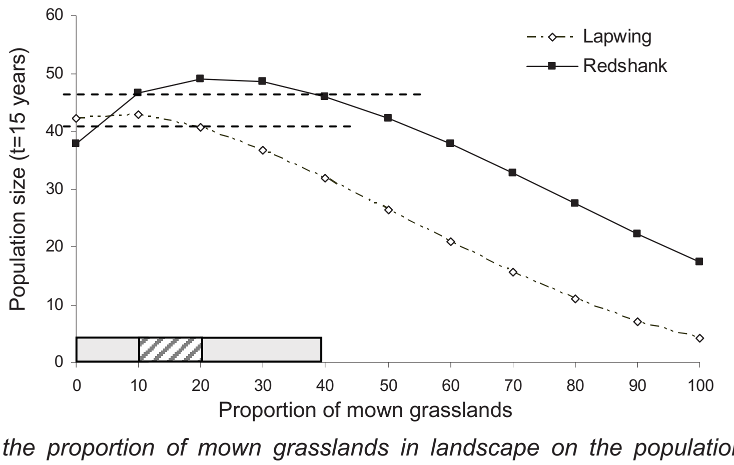

Figure 4. Effects of the proportion of mown grasslands in landscape on the population size of lapwings and redshanks after 15 years. Strategies leading to 95% or more of the maximal population of each wader are shown with dotted lines. The hatched box corresponds to the proportion of mown grasslands leading at least to 95% of the maximal population of both waders, grey boxes to this proportion concerning one wader species only.

This results explained why under the philopatry hypothesis, medium extensive farms (with 39% of mown grasslands) had better ecological performances than small intensive farms (47% of mown fields). Although ecological performances of both farm types were similar under the *No philopatry* or *No movement* hypothesis, differences in proportions of the two unsuitable grassland types (mown and unsuitable grazed) led to differences in ecological performances.

Discussion

Low ecological performances?

Ecological performances indicated a general decline in wader populations (*Tab. 3*). This result suggests that landscapes were not fully optimal for waders. Wader dynamics was calibrated in order to maintain each population to 100 individual in an hypothetical optimal habitat. However agricultural landscapes are not fully optimal as they are shaped by production constraints. It is therefore normal to observe such a declining trend. Such a population size is however likely to be important in a meta-population context where small populations can play a major role in recolonisation dynamics.

Moreover, reduction in fecundity in suitable grazed fields was set to the value of the maximum cattle density observed on these fields. This means that the effect of trampling by cattle is likely to be over valued, leading to a pessimistic view of population trends. This is coherent with a conservation approach, which aim is to avoid extinction of the studied population and therefore pays more attention to worst case situation.

Model limitations

Effects of agricultural practices on wader demography were assessed through their impact on juvenile survival and adult fecundity. We did not take into account their effects on nest site selection. Indeed a too high grass height early in spring can also be unfavourable during nest site selection. However, empirical data on grazing regimes in this area showed that grass height at this time mainly depends on late autumn grazing (Tichit et al., 2005b) and spring mowing is often associated with a few days of grazing in previous autumn. We therefore hypothesized that nest site selection is not under the influence of any factor. This point should be studied more precisely, notably when mowed fields are heavily fertilised, a situation which is likely to accelerate early spring grass growth and therefore generate unfavourable tall swards.

As for many PVA, the main weakness of this model still remains its lack of validation. Its strength lies in the qualitative results showing that the effect of cattle trampling on bird breeding success seems to be properly assessed as the predicted impacts are very similar to those predicted by (Green, 1986). Furthermore, the declining trend for both species in the marshland landscape is qualitatively congruent with trends reported for both species in France and the United Kingdom. It should be kept in mind that like with any model, results should be seen as a starting point for reflecting on complex trade-offs and not as an absolute truth.

Farm size and sustainable development

Large extensive and small extensive farms seem to be the most efficient on the ecological viewpoint. Large farms are the most efficient on the economic viewpoint. From this result, we argue that they are more able to reconcile economic and ecologic performances. Moreover large farms present several advantages in a conservation perspective. Farm size is often correlated with farmer participation to agri-environmental schemes (Wilson, 1997). This situation seems to be true in our case study as studied farms were all involved in agri-environmental schemes and had a higher UFA than that measured in national and regional statistics (Agreste, 2005). This correlation can be explained by several factors. First, transaction costs seem to be major drivers of agri-environmental scheme participation (Falconer, 2000) and large farms induce lower transaction costs. As each farm represents a wider total farmed area, a conservation policy focussing on large farms would imply fewer interlocutors, and therefore a better efficiency through a reduction in transaction costs. Secondly, farmers reaching the best economic performances are often better linked to professional networks and are more likely to take advantage of new regulations thanks to their better level of information. Conversely, farmers that do not follow the average behaviour (pluri-activity, small farms,…) are often cut from technical networks (Mundler et al., 2004). These different accesses to technical information are also leading to lower transaction costs with large farms. Finally, in large extensive farms low stocking rates and larger fodder area give more degrees of freedom and more flexibility in the management of grasslands. Such farms are likely to be less constrained to adopt management prescriptions. This situation may explain why farmers of large farms have been reported to accept changes more likely and to be often “happy” with agri-environmental schemes (Falconer, 2000). Therefore, environmental friendly policies seem to be more cost-effective in large farms.

Conclusion

Sustainability of an activity is defined by its ecological, economic and social performances. We studied here the ecological and economic aspects and showed that large extensive farms were the most efficient ones. On the social viewpoint, the situation shows a slightly different pattern. Small farms play an important part in integrating their owners in social networks. Farmers of small farms are often the poorest ones and would be cut from society without their activity. Farming allows them to share a common activity with other farmers and build links with them through trading and labour force exchange (Laurent et al., 1998). On our study, large extensive farms seem to be more likely to reach both ecological and economic priorities but they may not be efficient on a social aspect. Considering that economic function is not always a priority for farmers (Laurent et al., 1998) and that small extensive farms have good ecological performances and are expected to have better social performances, the role of small extensive farms in conservation policies should not be under valued.

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