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Conservation of the Montagu's harrier *(Circus pygargus)* in agricultural areas

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Abstract

The Montagu's harrier *(Circus pygargus)* is a ground-nesting raptor that breeds mainly in cereal crops in western Europe. We evaluate how the use of agricultural habitats may affect population sustainability in this species, based on simulation analyses, and explore how conservation measures could be optimized. Probability of extinction increased with decreasing harrier productivity, and this trend was accentuated when the carrying capacity (maximum number of breeding pairs) decreased. Harrier productivity in agricultural habitats is strongly affected by harvesting activities. An average of 60% of nestlings in agricultural areas of France and the Iberian Peninsula would perish in the absence of conservation measures. These losses would make populations unsustainable, if no immigration occurred. Simulation analyses showed that connectivity between populations through natal dispersal could allow persistence of threatened populations even in the absence of conservation measures. The probability of extinction of four hypothetical populations connected through natal dispersal would be lowest if one of those populations were fully protected (or fully productive), even if the other ones were unprotected. Montagu's harriers are semi-colonial, and populations could be considered as a compound of subpopulations (the colonies). Additionally, Montagu's harriers bred more frequently in areas where food abundance was high, and where the number of fledglings produced in the previous reproductive attempt was high. These factors could be used to develop sustainable and efficient conservation plans, identifying and protecting the most productive and stable colonies in agricultural areas, and further exploring experimentally factors that are likely to attract and maintain harriers in protected areas.

INTRODUCTION

The Montagu's harrier *(Circus pygargus)* is a ground-nesting raptor which may build nests within crops, mainly in winter cereal fields (wheat and barley), sometimes rye-grass or alfalfa (Cramp & Simmons, 1980). Use of crops by harriers as a nesting habitat was first described early in the twentieth century in southwestern Europe (Frionnet, 1925), but the frequency of this has increased rapidly in recent decades. The proportion of Montagu's harrier nests in crops reached 70% in France (Salamolard, Leroux & Bretagnolle, 1999) and 90% in Spain and Portugal (Ferrero, 1995), countries which hold about 80% of the European population excluding Russia (Tucker & Heath, 1994). Thus, cereal crops now appear to be the commonest nesting habitat of this species in western Europe.

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The dependence on such a man-made environment makes this species particularly exposed to all potential changes occurring in this habitat. Indeed, the conservation status for the species in France and the Iberian Peninsula, the stronghold of western Europe, is 'vulnerable' (SNPRCN, 1990; Blanco & Gonzalez, 1992; Salamolard *et al.,* 1999). It may thus be critical to predict how these changes will affect this species, to avoid negative consequences on its persistence.

The relationship between agricultural practices and Montagu's harrier conservation may be twofold. First, modifications in agricultural practices, increasing use of pesticides or herbicides, and reduction of field margins have produced in many areas decreases in insect and bird abundance in recent decades (Potts, 1991; Tucker & Heath, 1994; Pain & Pienkowski, 1997; Newton, 1998). The Montagu's harrier feeds on a variety of prey types, including mammals, birds and insects (Arroyo, 1997). As in other raptors, Montagu's harrier reproduction is strongly influenced by food abundance (Arroyo, 1998; Salamolard *et al.,* 2000; Millon *et al.,* 2002). Impoverished food supplies in agricultural areas may thus have detrimental consequences for Montagu's harriers.

Additionally, because nests are placed on the ground, if harvesting (or mowing) occurs before the nestlings are able to fly, harvesting may kill nestlings. Nestling mortality due to this factor has been quoted to be very high in some areas (e.g. Pérez Chiscano & Fernández Cruz, 1971; Martelli, 1987; Pandolfi & Pino d'Astore, 1990). Furthermore, these losses have been shown to make population persistence unsustainable in the absence of conservation measures, at least in some cases (Arroyo & Bretagnolle, 2000). This problem has mobilized conservationists for a long time to protect nests at harvest time (Berthémy, Dabin & Terrasse, 1983; Pacteau, 1999; Millon *et al.,* 2002), and important amounts of resources, either human or economic, are used every year. Given that resources for conservation are limited, insight on the efficacy of potential conservation measures would be useful in order to optimize the use of those resources, and the need for such analysis has been expressed (Arroyo & Bretagnolle, 2000).

We evaluate how the use of agricultural habitats may affect population sustainability in this species, and explore how conservation measures could be optimized, based on the characteristics of the species. First, we evaluate potential effects of a decline in food supply on population sustainability. The effect of food abundance is mainly observed in parameters related to breeding performance (laying date, clutch size or, particularly, breeding success), but breeding density may also be influenced if fluctuations in food abundance are strong enough (Salamolard *et al.,* 2000). We thus evaluate whether a decline in breeding success may have an impact on population sustainability, on its own or when associated with a decline in carrying capacity of the environment. We then explore how the characteristics of the species (connectivity between populations through natal dispersal, and its colonial habits) may influence the efficiency of conservation programmes. Finally, in many raptors, when nest sites are not limiting, food abundance is important in determining nest location. In addition, in colonial species, conspecific attraction and conspecific breeding success may be important to determine nest area choice (Boulinier & Danchin, 1997). We evaluate the relationship between these factors and the use of nest areas, and discuss whether such a relationship may influence conservation management.

METHODS

Study species

Montagu's harriers breed semi-colonially: some nests are isolated, but the majority of pairs breed in small colonies of 2-30 pairs (mean 7 ± 4 pairs in our study areas). The average between-nest distance in colonies is 202 ± 125 m (mean ± SD, n = 202 colonies). Given, among other things, the variability of the agricultural habitat between years, the location of the colonies is not fixed between years. However, certain areas may be used persistently over years, if conditions for breeding are favourable.

The species is highly mobile, particularly in relation to natal dispersal. Data from wing-tagged juveniles showed that at least 15% of juveniles disperse > 50 km in all directions from their natal site (Arroyo & Bretagnolle, 2000). This figure is without doubt an underestimation, because the probability of detecting wing-tagged harriers away from the natal areas (where no strong monitoring exists) is low. Observations of wing-tagged juveniles showed that, even for the 5% or so of juveniles that came back to breed in the natal area, the majority of them did not breed in their colony of origin (authors' unpubl. data).

Average productivity in natural vegetation, or in the absence of harvesting mortality, is two nestlings per breeding pair (Krogulec & Leroux, 1993; Garcia & Arroyo, 2001).

Demographic simulations

Demographic parameters (breeding rates, age of first breeding, adult and juvenile survival) were used to model population dynamics using Vortex 7.0, a stochastic simulation program (Lacy, Kimberly & Miller, 1995). Age of first breeding was set at 2 years for females, and 3 years for males, the average observed for the species (authors' unpubl. data). Adult survival was estimated at 80 ± 7% from wing-tagged birds (A. B. A. Leroux & V. Bretagnolle, unpubl. data). No accurate measures of juvenile survival were available, because the species is not very philopatric (see above). However, out of 426 fledglings wing-tagged in western France between 1988 and 1997, 70 (16%) were observed at least once in subsequent years. This percentage varied between 9 and 27% according to cohort (A. B. A. Leroux & V. Bretagnolle, unpubl. data). Similarly, in Madrid Province, central Spain, out of 476 fledglings wing-tagged between 1992 and 1998, 12-16% of nestlings were observed in subsequent years (the range is due to some observations not being individually identified), the percentage varying from 5 to 44% among cohorts (B. Arroyo, unpubl. data). Probability of observation of non-breeding wing-tagged birds in the study area depends on observation effort in the pre-laying period (B. Arroyo & J. T. Garcia, pers. obs.), and 30-50% of birds passing through the study areas did not breed (B. E. Arroyo, J. T. Garcia, V. Bretagnolle & A. B. A. Leroux, unpubl. data). Probability of observation of a wing-tagged bird outside the study areas is probably very low, as most breeding areas are not monitored, and observation effort for wing-tags in monitored areas is usually very low (not all areas are monitored by people trained to look for wing-tags), particularly early in the season (when even monitored areas are rarely covered). We therefore assume that survival must be much higher than observation rate (possibly two or three times higher). We subjectively fixed juvenile survival at 50 ± 20% (SD) for the simulations, which we think is a plausible figure. With observed values of productivity (in the absence of harvesting problems) and adult survival, this level of juvenile survival is associated with stable population numbers, if immigration equals emmigration. Populations in areas with no harvesting problems have been shown to be stable or increasing (Jiménez & Surroca, 1995; Garcia & Arroyo, 2001). In any case, we also repeated simulations with 40 ± 20% juvenile survival, and all results were similar (in terms of the relative value of each option).

Simulations were run for 100 years, and we performed 100 iterations per simulation. For the simulations, we used the following premises: no inbreeding depression, environmental variation in reproduction not correlated with environmental variation in survival, reproduction not density dependent, monogamy, sex ratio at hatching 0.5, only juveniles migrate between populations. Except when otherwise stated, simulations were performed starting from an initial population size of 50 pairs, as this is the average population size for a 200 km^2 area in our study sites. For the evaluation of the effect of distribution of conservation effort in the probability of extinction of four populations connected by natal dispersal (Fig. 4), we used subjectively a value of 1% connectivity (1% of fledglings produced in each area would settle in each of the other three areas each year) for the simulations. We use 1% as a conservative figure. To verify that results were consistent with varying values of connectivity, we repeated the simulations using 5% connectivity. The results were similar (in terms of the relative value of each of the options, even if the probability of extinction varied): the probability of extinction of the metapopulation when distributing resources was twice as high as when concentrating conservation effort in one single population.

Harrier death by harvesting activities

We summarized available information to calculate mean values of the percentage of harrier chicks potentially dead (unfledged at harvest time) because of harvesting activities in different areas of France and the Iberian Peninsula. This included published papers, and unpublished information arising from a national conservation campaign carried out in Spain in the last 3 years (see the Iberian Working Group on Harriers webpage, http://www.ucm.es/info/zoo/Vertebrados/webgia/GIA.html). Several published papers (e.g. Perez Chiscano & Fernández Cruz, 1971; Berthemy *et al.,* 1983) present very high failure rates (> 90%) but are based only on data from 1 year. The risk of nestling death at harvest time may vary strongly between years depending on factors such as food conditions and weather (e.g. Castaño, 1995; Arroyo & Bretagnolle, 2000; Millon *et al.,* 2002). Consequently, to avoid over-representing cases in which reported data belonged to particularly bad years, we used only information from areas for which at least 2 years' data were available.

Relationship between food, productivity and nest area use

Data collection to evaluate this part of the study was carried out in Deux-Sèvres, western France (46° 11' N, 0°28' W), in an area that covers 340 km^2, from 1995 to 1999. All harrier nests were located each year, and were visited regularly to collect data on breeding parameters (e.g. breeding success, timing of egg laying). Land-use was monitored and classified in the field each year and incorporated in a Geographical Information System (ArcView 3.0). The location of each nest was also plotted in the GIS. The main prey of Montagu's harriers in western France is the common vole, *Microtus arvalis,* which forms up to 90% of the diet in biomass (Butet & Leroux, 1993; Salamolard *et al.,* 2000). Montagu's harriers in this area show strong numerical and functional responses to vole abundance (Salamolard *et al.,* 2000). Vole density was estimated annually using line-trapping: 80-96 lines of 51 traps each were placed every April throughout the study area in different crop types. Traps in each line were placed every 2 m. Lines were located in non-contiguous fields, and separated by 500-1500 m. Traps were checked and removed 24 hours after setting (see Salamolard *et al.,* 2000 for more details). The extensive vole-trapping set-up, together with the mapping of land-use each year, allowed us to estimate vole abundance in 1 km^2 quadrats throughout the study area: vole abundance in each field (as number of captures per 100 traps) was estimated by extrapolating the number of voles trapped in the nearest field with the same crop type; and the abundance in each quadrat was estimated by adding the estimates of each field in a quadrat, correcting the abundance in each field for its area. We then performed generalized linear models, with number of harrier nests in each quadrat each year as the dependent variable (with Poisson distribution and a log-link function), and vole abundance estimates and number of fledglings produced in the previous year in that quadrat as the explanatory variables. Type III results are presented.

RESULTS

Harrier productivity and population sustainability

The results of the simulations evaluating the effect of variations in harrier productivity on harrier sustainability are presented in Fig. 1. When productivity decreases, the probability of extinction of harrier populations increases. Additionally, for any value of harrier productivity, extinction probability was higher when the carrying capacity of the environment (i.e. the maximum number of pairs being able to breed) decreased by as little as 1 or 2% annually.

Harvesting activities, harrier productivity and population sustainability

The proportion of nestlings in agricultural areas that might be potentially at risk from harvesting activities

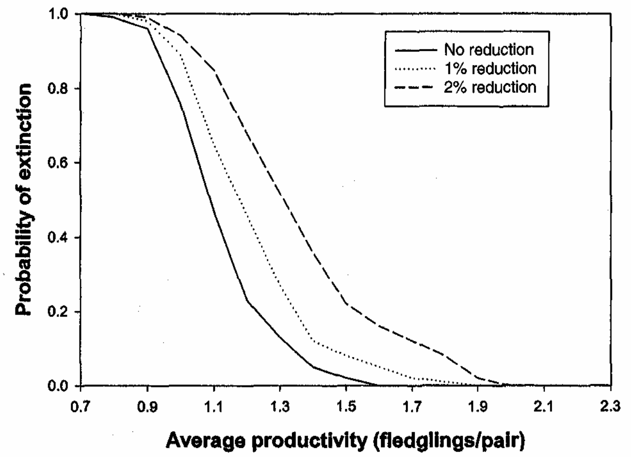

Fig. 1. Probability of extinction within 100 years of a population of Montagu's harrier (initial population size: 50 pairs) according to variations in average harrier productivity, and according to reductions in carrying capacity of the environment

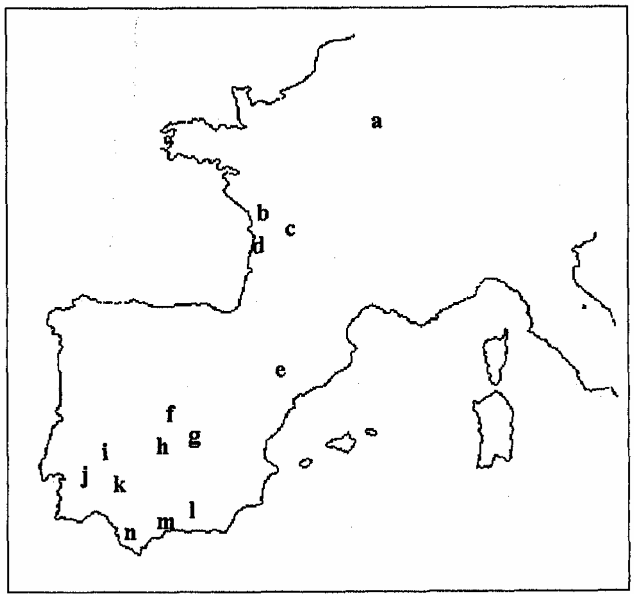

Fig. 2. Location of the study areas where mean percentage of nestlings at risk has been measured (see Table 1)

(i.e. those unfledged at harvest time) is indicated in Table 1. Values ranged between 30 and 95%, with the highest values being observed in the southwestern Iberian Peninsula, and also in areas where barley is the predominant culture (e.g. c and h in Fig. 2). The average observed was 60%. In other words, average productivity could be reduced by up to 60%, assuming that all unfledged nestlings would die as the fields are mechanically harvested if unprotected. Such a reduction would make harrier populations unsustainable (Fig. 1).

Connectivity and population sustainability

The likelihood of extinction given in Fig. 1 applies to populations considered as isolated units, i.e. to populations where no emigration or immigration occurs (or in cases where immigration equals emigration). Simulation analyses showed that connectivity through juvenile dispersal between two populations, one of them having normal productivity (two fledglings per pair) and the other one suffering 50% mortality because of harvesting activities, would allow persistence of the second population, even in the absence of conservation measures (Fig. 3).

These results imply that conservation measures applied to a given area also affect all other areas connected to it through juvenile dispersal. Therefore, if resources are limited and they do not allow full protection of all breeding areas, the choice exists as to how to distribute those resources in the most efficient way. We explored whether it would be more efficient to concentrate resources in a given area, or to share them among as many areas as possible, with simulation analyses. We evaluated the probability of extinction of four hypothetical populations of Montagu's harriers connected bilaterally through juvenile dispersal (1% connectivity). Each population held initially 80 breeding pairs, had a

Table 1. Mean ± SD percentage of nestlings at risk (PNR; i.e. nesting in agricultural habitats and unfledged at the moment of harvesting) in different areas of France and the Iberian Peninsula. 'Site' refers to the location of the study areas in Fig. 2

Site	Location	Mean ± SD PNR	Years of study	Reference
a	Champagne-Ardenne, France	48 ± 16	1993-2000	Millon *et al.,* 2002
b	Vendée, France	41 ± 14	1995-98	Arroyo & Bretagnolle, 2000
c	South Deux-Sèvres, France	59 ± 17	1994-98	Arroyo & Bretagnolle, 2000
d	Charente-Maritime, France	43 ± 42	1992-98	B. Arroyo, V. Bretagnolle & A. Leroux, unpubl. data
e	Lleida, Spain	98*	1988-94	Pomarol *et al.,* 1995
f	Northern Madrid, Spain	30 ± 20	1991-98	Arroyo & Bretagnolle, 2000; J. T. García, unpubl. data
g	Southern Madrid, Spain	64 ± 13	1999-2000	GREFA, unpubl. data
h	Ciudad Real, Spain	72 ± 4	1988-94 and 1999-2001	Castaño; 1995; ESPARVEL, unpubl. data
i	Central Extremadura, Spain	62 ± 38	1987-91	Corbacho *et al.,* 1997
j	Evora, Portugal	76*	1997-98	Claro, 2000
k	Badajoz, Spain	61 ± 32	1999-2001	AMUS & J. M. Traverso, unpubl. data
l	Malaga, Spain	62 ± 53	1997-99	J. Rivas Fernández, unpubl. data
m	Granada, Spain	58 ± 56	1999-2000	F. Cabello de Alba, unpubl. data.
n	Tarifa, Spain	35 ± 7	1999-2000	COCN (Colectivo Ornitológico Cigüeña Negra), unpubl. data

* Data were not presented on an annual basis, so it was not possible to calculate SD

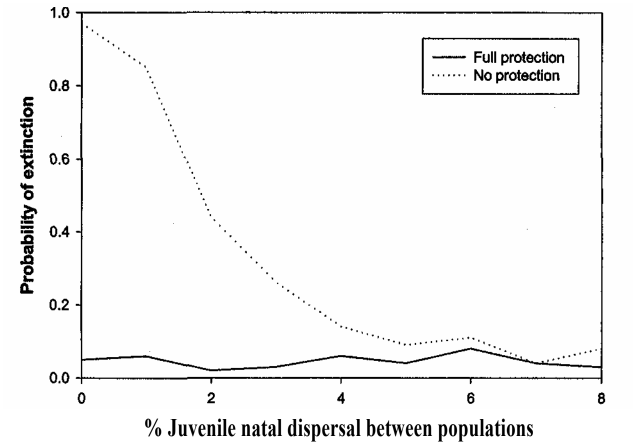

Fig. 3. Effect of connectivity through natal dispersal on population sustainability of a fully productive population and another one loosing 50% of its nestlings because of harvesting activities in the absence of conservation measures

potential productivity of two fledglings per pair, and suffered 50% nestling mortality through harvesting activities in the absence of conservation measures. The simulation presents four potential scenarios, assuming that we have resources to save only 40 nests per year: (1) these resources would be used equally among all areas, thus saving 25% of affected nests in each area; (2) resources would be distributed among only two of the populations, saving 50% of affected nests in each population or (3) saving 75% of affected nests in one, and 25% in the other; (4) all resources would be concentrated in only one of the four populations, saving 100% of the affected nests there, but leaving unprotected all other three areas. Figure 4 represents the probability of extinction of each of the populations and the whole metapopulation in each of these scenarios. The most effective strategy in terms of maximizing persistence would be the one in which one of the populations is fully protected. The results were similar (in terms of the relative value of each of the options, even if the actual probability of extinction varied) when using 5% connectivity.

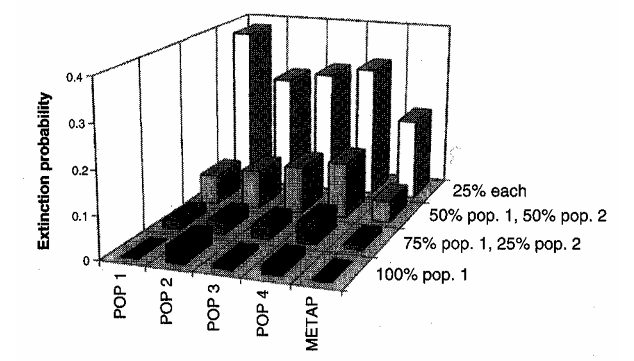

Fig. 4. Probability of extinction of four hypothetical populations (initial population size: 80 pairs) and the whole metapop-ulation of Montagu's harriers connected bilaterally through juvenile dispersal, and each suffering 50% nestling mortality because of harvesting activities, according to the percentage of nests saved in each population (all scenarios represent the same amount of resources used)

Colonies as subpopulations

We may consider each harrier population as a compound of subpopulations (the colonies) connected through dispersion in a metapopulation. Figure 5 shows the results of simulation analyses for a theoretical population of Montagu's harriers composed of 12 colonies connected between them through 1% juvenile dispersal, each one holding 7-15 pairs, with an average productivity of two fledglings per pair, but suffering 50% nestling loss because harvesting activities if unprotected, when a varying number of these colonies would be protected. Results show that, in such circumstances, the whole metapopulation would persist (and to a level at least 70% of initial population size) with as few as five (40%) colonies protected.

Choice of breeding areas

In western France, where voles represented the bulk of harrier diet, harriers more frequently used areas with high vole abundance (Table 2). In addition, the presence of harrier nests in given quadrats was significantly related to the number of nests in that area the previous year, but also to the total number of fledglings produced in that quadrat in the previous breeding season (Table 2). In other words, harriers breed in areas where most young harriers are produced each year, and which contain good food supplies.

DISCUSSION

Food, productivity and harrier sustainability

Simulation analyses showed, unsurprisingly, that decreased productivity had an important effect on population

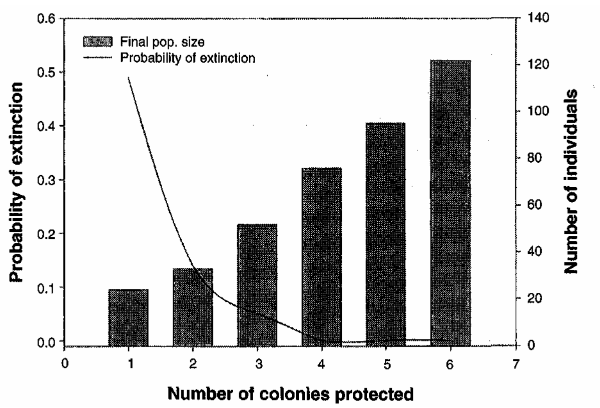

Fig. 5. Probability of extinction and final population size of a hypothetical population of Montagu's harriers, distributed in 12 colonies each with 7-15 pairs, and suffering 50% nestling mortality because of harvesting activities in the absence of conservation measures, according to the number of those colonies protected

Table 2. Results of the four Generalized Linear Models of the relationship between number of Montagu's harrier nests in 1 km^2 quadrats each year of the study, vole abundance estimates within each quadrat, number of nests in the previous year, and previous reproductive success (total number of fledglings produced within that quadrat). Poisson errors and a log-link function were specified. Type III results are presented. n = 296 quadrats

Year	Effects	X^2	P
1996	Vole abundance in 1996	16.02	0.0001
	Number of nests in 1995	1.05	0.30
	Reproductive success in 1995	6.31	0.012
1997	Vole abundance in 1997	3.18	0.07
	Number of nests in 1996	7.30	0.007
	Reproductive success in 1996	13.20	0.0003
1998	Vole abundance in 1998	3.34	0.07
	Number of nests in 1997	54.53	0.0001
	Reproductive success in 1997	3.78	0.052
1999	Vole abundance in 1999	6.94	0.008
	Number of nests in 1998	12.62	0.0004
	Reproductive success in 1998	6.38	0.011

sustainability, particularly if linked to a decrease in carrying capacity (maximum number of breeding pairs). Both factors are linked to food abundance in all areas studied (Arroyo, 1998; Salamolard *et al.,* 2000; Koks, van Scharenburg & Visser, 2002; Millon *et al.,* 2002), despite the variability of harrier diet among areas (Corbacho, Muñoz & Bartolomé, 1995; Arroyo, 1997; Salamolard *et al.,* 2000; Koks *et al.,* 2002; Millon *et al.,* 2002).

Insect, farmland passerine and vole abundance have declined in agricultural habitats in recent decades (Potts, 1991; Delattre *et al.,* 1992; Tucker & Heath, 1994; Pain & Pienkowski, 1997). Such changes are associated with agricultural intensification and land-use changes. Therefore, agricultural habitats are associated with impoverished food supplies for the harriers, and this trend may continue, particularly in countries like Spain or Portugal (or those of eastern Europe) which have entered more recently into intensive agricultural markets.

Harrier productivity observed in agricultural areas, when deaths due to harvesting activities are insignificant, averaged two fledglings per pair (e.g. Underhill-Day, 1990; Biljsma *et al.,* 1993; Corbacho, Sanchez & Sanchez, 1997; Garcia & Arroyo, 2001). Therefore, in current conditions, harrier populations could be sustainable if values of fledgling production were maintained. However, if food abundance further decreases in agricultural environments, both average productivity and breeding numbers (i.e. carrying capacity) may decline. In the long term, therefore, impoverishment of food supplies caused by changes in land-use and intensification of agriculture may render harrier populations in agricultural areas unsustainable.

Harvesting activities and harrier sustainability

Nestling deaths due to harvesting activities have been described since the 1970s (Perez Chiscano & Fernandez Cruz, 1971), but the incidence has been accentuated in recent years because of the increased mechanization and intensification of agriculture.

Data presented in this paper showed that at present 60% of nestlings in the Iberian Peninsula and France would die because of harvesting activities if unprotected, assuming that all unfledged nestlings are killed by combine harvesters if unprotected. The latter is not strictly true, as some (5-25%) nestlings survive by chance even in the absence of conservation measures, at least in some areas (Castaño, 1995; Arroyo, 1996). Nevertheless, even a 40-50% reduction in productivity makes harrier populations unsustainable in the absence of conservation measures (Arroyo & Bretagnolle, 2000; Fig. 1). Therefore, harvesting activities represent a threat for harrier sustainability even in the short term, and there is a need for global thought on the conservation plan for the species. This is particularly necessary as the high mobility of this species and connectivity between populations mean that conservation efforts in one area influence viability in others.

The results of the simulations highlight the importance of maintaining fully productive populations for the conservation of Montagu's harriers. The first way to attain this in a sustainable and economic way would be to protect populations that are naturally productive and unaffected by harvesting problems, such as those breeding in natural vegetation. This conclusion is particularly important when considering that most conservation measures for the species have been based in protection of nests in agricultural areas, and that most populations in natural vegetation in Spain and France are unprotected. Second, results also suggest that, if resources are limited and do not to allow full protection of all breeding areas, it may be more efficient to concentrate conservation efforts in a given area, making sure that most nests are saved there, rather than working less intensively in larger areas. Efficient and economic ways of attaining this would be to concentrate conservation effort in areas where the impact of harvesting activities is relatively low, because fewer nests would have to be protected, to concentrate resources in areas where farmers are particularly sensitive to agro-environmental measures (for example, in areas where they are already subject to such measures for other species), or to concentrate efforts in areas where other special protection measures are already implemented, such as in Special Protected Areas (SPAs).

In any case, the most efficient and sustainable way of protecting Montagu's harrier nestlings from harvesting activity would probably involve habitat management, rather than nest management. Unlike nests of many other raptors, that are durable from one year to the next, nests of Montagu's harriers are not solid physical structures, and are built each year. Human resources used to locate the nests are therefore considerable, and have to be renewed each year. Habitat management, for example through agro-environmental measures (e.g. delaying harvesting until most nestlings have fledged), would allow protection of nestlings without the need of locating the nests. An analysis over 2 years in several areas in Spain of the relationship between timing of harvesting and timing of fledging showed that overlap in most areas would be avoided by delaying harvesting by only 7-10 days (Iberian Working Group on Harriers, unpubl. data).

However, it is not always easy to apply habitat measures (e.g. agro-environmental measures) over wide areas. The simulation results show that, if we consider colonies as sub-populations, and in the conditions applied for the simulations, conservation measures could be organized around the colonies in a network of small protected areas. Obviously, these results should not be taken literally, given that the premises used for simulation analyses are somewhat simplistic. To be able to evaluate exactly how many colonies should be protected in order to maintain a viable population we need to include factors such as the distances between colonies, as juvenile dispersal is likely to depend on such factors. Nevertheless, the simulation shows that, theoretically, a network of a relatively low proportion of small protected areas could be efficient. Such a possibility would indeed be interesting, given that it would be easier to manage, both logistically and economically.

However, colony location is not fixed in this species, and Montagu's harriers may move considerable distances between one reproductive event and the next. Knowledge about factors influencing nest area choice in this species may help to attract and maintain harriers in the protected areas. Results of the analyses presented in this paper showed that harriers are more likely to nest in areas that had been used productively in the previous year. Traditionally productive colonies should thus be protected as a priority, given that they are more likely to be used in subsequent years. The fact that 'number of young fledged' had a significant influence on harrier nest location even when controlling for number of nests suggests that, in some, circumstances, breeding success could even be artificially manipulated (e.g. boosted) in protected areas: in cases when egg or nestling recovery and subsequent release by hacking is necessary, because on-site protection is impossible or inefficient (Pomarol, 1994; Pomarol, Parellada & Fortia, 1995), there exists the option of where to release those birds, and such an option could be used in management programmes.

Other variables affecting nest area choice include food abundance (our results) and vegetation height (Claro, 2000), which thus could be used to attract and maintain harriers to protected areas. Experimental evaluations could be developed to determine the most attractive vegetation heights, or land-use that maximizes food abundance or availability in each area.

Conclusions

The Montagu's harrier is clearly dependent on conservation measures for its sustainability in the long term. There is therefore a need for developing sustainable and efficient conservation plans. Such measures should include ones directed to maintaining food supplies, as well as those directed to minimizing impact of harvesting activities on harrier productivity. Maintenance of biodiversity (thus food supply for the harriers) in agricultural areas is a highly important issue, not only for the Montagu's harriers. Large-scale agro-environmental measures should be implemented to achieve it. Protection of harrier nestlings from harvesting activity, in contrast, should be optimally implemented through a network of relatively small protected areas. Promoting protection of natural vegetation areas, identifying and protecting the most productive and stable colonies in agricultural areas, and experimentally testing factors that are likely to attract and maintain harriers in protected areas should be priorities in the short term.

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