From a conservation trap to a conservation solution: lessons from an intensively managed Montagu's harrier population

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Abstract

Many threatened species in human-dominated systems are managed through conservation programs. Such programs are sometimes designed based on intuition or short-term results rather than assessing their long-term biological and economic sustainability. The current conservation program for Montagu`s harriers (*Circus pygargus*), a ground-nesting bird of prey, in Lleida (Catalonia, NE Spain) aims to protect nests located in farmlands by promoting crop harvest delay around the nest and compensating farmers for their economic loss. This program has been flagged as a "conservation trap" as its costs have been increasing over time, possibly compromising the long-term sustainability of the program and associated consequences to the local harrier population. In the present work, population viability analyses (PVA) were used in order to find a conservation management scenario that decreases the risk of the conservation trap, or at least minimizes the medium-term expenditure on conservation. PVA simulations suggest that the current nest-protection program is financially unsustainable at the medium-term. Cost-effectiveness analyses suggest that it would be impossible to fully avoid the conservation trap if the conservation goal is to maintain Lleida's current population size. Alternative management scenarios that minimize the medium-term expenditure of scarce conservation funds are presented. The results suggest that selecting a conservation program based only on short-term biological or cost-effective targets might not be the most appropriate, and demonstrate the relevance of having clear medium-term conservation targets.

Key words: *Circus pygargus, population viability analysis, conservation programs, conservation goal, cost-effectiveness.*

1. Introduction

Species conservation in human-dominated systems, such as agro-ecosystems, commonly aims to revert the negative anthropogenic impacts on wildlife through financial incentives (Ferraro and Kiss 2002). This approach is too often grounded on experts' opinion and intuition rather than sound scientific evidence (Sutherland *et al*. 2004; Duke, Dundas and Messer 2013), and usually seeks to reduce species' extinction risk by maximizing biological benefits **(**in terms of, e.g. increasing survival or productivity) as fast as possible. This is partly also a consequence of the very short-term nature (typically a few years) of conservation funds. Conservation programs might thus appear biologically effective in the short-term, however their long-term biological efficacy in reverting population trends, their economic sustainability as well as its subtle negative biological repercussions (e.g. possible maladaptations to management; Massaro *et al.* 2013) after the program is terminated are often neglected (Ferraro and Pattanayak 2006; Kleijn and Sutherland 2003). When these factors are not properly considered, conservation strategies may need recurring management and increasing funds to achieve long-term impacts (De Snoo *et al.* 2013). In the cases where long-term economic sustainability cannot be ensured, maintaining the conservation program might not be feasible. As a consequence, some conservation programs may ultimately turn into conservation traps (Cardador *et al.* 2015).

Cardador *et al.* (2015) defined a conservation trap as a costly conservation strategy in human-dominated landscapes that needs to be perpetually applied to have an effect; in such cases, even if the species extinction risk may be reduced (e.g. by increasing its survival and/or reproduction) in few generations, the program's high costs may render it financially unsustainable in the long-term, and the species would return to its endangered status after management actions are terminated. Cardador *et al.* 2015 suggest shifting conservation actions from its reactionary short-term vision towards a long-term self-sustainable system. In this sense, to avoid a conservation trap, species-specific conservation programs must be based on actions that i) prevent the species long-term dependence on intensive management or ii) have high likelihood of being financially maintained in the long-term (Cardador *et al.* 2015).

Here we use the Montagu´s harrier (*Circus pygargus*) as a study species to explore, using population viability analyses (PVA) coupled with cost-effectiveness evaluations, alternative conservation scenarios in their potential to minimize the risk of falling into a conservation trap while protecting the species with limited resources. The Montagu´s harrier, a ground-nesting raptor highly impacted by mechanical harvesting causing nest loss, is subject to intensive nest protection programs in farmlands of Europe (Arroyo, García, Bretagnolle 2004). Although these programs have been effective in increasing harrier productivity and enhancing population persistence (Santangeli, Di Minin, Arroyo 2014; Santangeli *et al.* 2015), they may only represent short-term solutions. Most Montagu's harrier populations in Western Europe would locally go extinct in absence of protection (Arroyo, García, Bretagnolle 2002, Koks and Visser 2002, Santangeli *et al.* 2014).

In Lleida (Catalonia, NE Spain), conservation actions based on paying farmers for delaying harvest of at least half a hectare around a harrier nest have been effective in reversing the negative population trend (Martínez and Such 2013, Cardador *et al.* 2015). In 2005, a strong drought rendered cereal crops too sparse and low to be attractive for breeding harriers, and harriers started nesting in irrigated crops, including fodder (Cardador *et al.* 2015), which they have continued doing ever since. Because delaying harvest in irrigated crops is more expensive than in dry cereals, the recent shift in harriers nesting habitat, coupled with an expanding harrier population, has increased the overall annual protection costs. The current program is thus potentially economically unsustainable for the regional administration, and may represent a conservation trap (Cardador *et al.* 2015). An evaluation of alternative management scenarios would allow practitioners to guide management decisions and optimize conservation investments. In collaboration with local practitioners, we assessed realistic alternative scenarios for the allocation of conservation resources to protect Montagu's harrier nests in Lleida. The scenarios vary in terms of costs and demographic benefits according to the number of nests protected in each crop type (i.e. dry cereal, irrigated cereal, fodder). Our main aim was to quantify the overall biological benefits (i.e. final projected population size using PVA) and costs in order to compare the cost-effectiveness of alternative management scenarios targeted to protect Montagu`s harriers in Lleida. We identify the best scenario in terms of its capacity to avoid falling into a conservation trap in the medium-term (i.e. a few harrier generations, here set as 30 years). Finally, we discuss the implications of the approach and study findings towards avoiding a conservation trap in species-specific conservation programmes beyond the study species considered here.

2. Methods

2.1 Study area and populations

The study took place within the Catalonian province of Lleida (NE Spain). The current Montagu´s harrier conservation program started in early 1980's following a sharp population decline. The program has been successful in increasing the number of nesting pairs from five to more than sixty breeding couples (Cardador *et al.* 2015). Nowadays, harriers nest in fodder fields (40%), irrigated cereals (27%) and dry cereals (27%), where they are subject to nest protection (Cardador *et al.* 2015), while only few (6%) breed in natural vegetation (see Table S4). Each breeding crop type is associated with different harrier productivity (number of fledglings per nest) in the absence of protection (due to different harvest dates per crop type). At present, all nests found in agricultural fields are protected, with costs for nest protection through payments for delaying harvest varying between 360 to 700€ / nest depending on the breeding crop type (see details below).

2.2 Alternative conservation management scenarios

We simulated the demographic effects of applying nine alternative nest protection scenarios for the harrier population in Lleida (see Table S1).

The first scenario assumes business-as-usual, where protection of all nests in crops (irrigated cereals, dry cereals and fodder) continues as currently done and for the next 30 years (this scenario is hereafter named *All Prot*). A second contrasting scenario simulates that nest protection stops across all crop types (*All Unprot*).

We also simulated six alternative scenarios in between the two above extremes. These included protecting nests in only one crop type (fodder (*F*), dry cereal (*Dc)* or irrigated cereal (*Ic*)), or in combinations of two crop types (fodder and dry cereal (*F+Dc*), fodder and irrigated cereal (*F+Ic*), or dry and irrigated cereal (*Dc+Ic*); see Table S1). All these scenarios were built by changing the relative fecundity value for Lleida’s population (see below for further details). We assumed that the proportion of individuals breeding in each crop type remains constant over time irrespective of the protection status. This is a somewhat simplistic assumption (see also discussion), but it was not possible to estimate the likelihood of variation in breeding habitats and incorporate this into our analyses.

Additionally, we tested the effect of decreasing nest protection at different temporal rates (in the event of a decision to stop protection) on population trajectories in the medium-term. Hence, for each of the above scenarios we considered four different protection reduction rates in crops assumed to be left unprotected: i) instantaneous rate, where nest protection is halted after the first year; ii) 5% reduction in nest protection annually, thereby all nests in that crop will be left unprotected after 20 years (hereafter called “slow” rate); iii) 10% (“moderate” rate); and iv) 20% (“fast” rate).

2.3 Demographic parameters used for all scenarios

All scenarios were simulated in RAMAS GIS 5.0 (Akçakaya 2005). The simulation period was set to 30 years (ca. 5-8 harrier generations) with 1,000 replications for each scenario. This simulation time allowed the investigation of medium-term effects of each scenario and decreased the uncertainties of major landscape changes expected in agricultural systems over longer timeframes.

We used three stage classes for females and four for males, and the same survival values used for a previous PVA study on the species in Spain (Santangeli *et al.* 2014; Table S2).

Fecundity was calculated as the product of the portion of breeding females, times productivity (Table S3), times nestling sex ratio. As Santangeli *et al.* (2014), we assumed that only adults attempt to reproduce, 10% of adult females do not breed and an even nestling sex ratio (50:50).

Initial population size (n=279) was based on survey data gathered during 2012 (Table S4). Sub-adult abundances within each age and sex class were assumed to follow a stable age structure, and juvenile abundance was estimated after breeding but prior to migration as the product of adult abundance times average female productivity (set at 0.75).

Environmental and demographic stochasticity were included following Santangeli *et al.* (2014). To account for factors (*e.g.* food abundance) that limit population growth, we used a ceiling model that affects population dynamics only when total population abundance exceeds the carrying capacity (Akçakaya 2005). The ceiling was set at 10% (±15% SD) higher than the total initial population size, following Santangeli *et al.* (2014). Although somewhat arbitrary, this threshold for the carrying capacity was chosen because, according to our knowledge, the population has never been higher than currently, and food availability appears to be limited (Guixé and Arroyo 2011). However, we also present results of simulations where the ceiling was set at 50% (±15% SD) higher than the total initial population size (see Figure S1).

We also ran multiple analyses (see support material Table S5 and Figures S1-S6) to quantify the sensitivity of the PVA results to key parameters (survival of different life stages, fecundity, carrying capacity).

2.4 Cost-effectiveness of different conservation scenarios

We calculated the overall costs for each scenario where protection in any crop type was applied. We considered compensation costs per nest as 360€/nest in dry cereals, 500€/nest in irrigated cereals and 700€/nest in fodder as reported by Cardador *et al.* (2015). Overall costs per scenario were calculated by multiplying the total number of nests to protect across the 30-year period by the cost to protect a nest in each crop type. Conservation benefits were measured as the difference between the final population size (after 30 years) of each scenario with that of *All Unprot* scenario. Cost-effectiveness of each scenario was then derived as the ratio costs / benefits. Conservation programs with cost-benefit ratio of zero or close to zero are highly cost-effective.

3. Results

3.1 Population consequences of alternative management scenarios

Given the demographic parameters used, the harrier population of Lleida is expected to remain stable within the next 30 years under a business-as-usual scenario where all nests are protected as currently done (Figure 1a, thick upper line). Conversely, if all nests were instantaneously left unprotected (*All Unprot)* the population is expected to decrease by about 80% in 30 years from its initial size (Figure 1a-f, thin bottom line). All intermediate scenarios considering an immediate reduction in nest-protection at any one or a combination of crop types lead to a decrease in population size compared to the situation where all nests in all crops are protected (*All prot* scenario; Figure 1). However, results indicate that nest protection of each crop type yields different biological benefits in the medium-term.

Among the scenarios where protection is only applied to nests in one single crop type, nest protection in fodder only (scenario *F*) yields 80 more individuals than that of the *Dc* scenario), and 149 more than the *Ic* scenario (Figure 1a). Population decreased in all cases compared with current population size, by 23%, 48% or 76% if nests were protected in fodder, dry or irrigated cereal respectively.

Protecting nests in two crop types simultaneously yields generally higher final population size than if nests in only one crop type are protected (Figure 1b). Moreover, if nests in fodder and dry cereal are protected, a nearly stable population is achieved.

The results also show that reducing the rate at which protection is terminated in each scenario has little impact on population trajectories, as it only results in a delay in the population decline (Figure 1c-f).

3.2 Cost-effectiveness of protection in farmland scenarios

Protecting nests in dry cereal, in fodder, or in both appear as the most cost-effective alternative scenarios (Table 1). However, in terms of final population size and population persistence, only scenarios that include protection in fodder, alone or in combination with protection in dry or irrigated cereal, appear capable of leading to a stable population over 30 years (Figure 2). Conversely, protecting nests in irrigated cereals, either alone or in combination with protection of nests in another crop type, always leads to the least cost-effective solution (Table 1) and typically to a decline in the final population size. In fact, protection in *Ic* alone is five times more expensive than the *All unprot* scenario, but its expected benefit, in terms of final population size, would only be marginally higher than if all nests are left unprotected (Figure 2).

3.4 Sensitivity analyses

Sensitivity analyses suggest high sensitivity of the results to changes in adult survival in particular, but also survival of other age classes, as well as to changes in fecundity and carrying capacity (Support figures S1-6 and Table S5).

4. Discussion

Our results confirm that increasing investment in nest protection for Montagu´s harrier in farmland results in increased populations, which in turn will increase costs for protection. However, costs and effectiveness of nest protection vary among the different crop types considered, and this variation allows choices to be made between several alternative scenarios. Our PVA exercise provides empirical evidence of what different options entail in terms of economic sustainability and species persistence, and highlight that the best scenario would depend on conservation goals.

4.1 Trade-offs between population persistence and economic sustainability

Continuing Montagu's harrier conservation efforts in Lleida as currently implemented will allow achieving the conservation objective of ensuring the persistence of the harrier population in farmland. However, protecting all farmland nests every year (currently around 60) might not be the best choice as it is among the least cost-effective solutions (Table 1). Therefore, some of the alternative scenarios could help managers improve the cost-effectiveness of their resource allocation in farmland.

Under present conditions, the most cost-effective scenarios include protection in dry cereal, fodder or both, but a stable population size is only achieved when nests in fodder are protected. This however represents a suboptimal solution in terms of cost-effectiveness due to its high cost, and one that may be financially unsustainable.

Moreover, Montagu's harriers probably select fodder in Lleida because the crop is taller and with denser vegetation than other breeding habitats early in the breeding season (Claro 2000; Arroyo, García, Bretagnolle 2004). This pattern might be enhanced by previous successful breeding attempts, e.g. as a result of nest protection. Thus, continuing conservation in fodder might not only be financially unsustainable but might increase the species dependence on the conservation program. At the same time, productivity of unprotected nests in fodder is close or equal to zero, indicating that fodder is a strong candidate for representing both an ecological and a conservation trap.

This situation highlights a potential conflict between the need to achieve regional/local conservation goals, and the need to ensure long-term sustainability of the program.

Ultimately, managers may opt to apply the scenario where only nests in dry cereal are protected, as this represents the most cost-effective option. This would allow retaining a good proportion of the initial population in the farmland of Lleida while limiting the conservation expenses to a large extent compared to the business-as-usual condition where all nests are protected. We caution that even the application of this latter scenario has a risk of representing a conservation trap. In fact, this risk cannot be completely avoided if nests in farmland are to be protected with some associated costs in order to achieve the conservation objective.

On the other hand, decreasing protection in fodder crops might not be as detrimental as our simulations show. It is possible that after failed breeding attempts due a decrease in nest protection in fodder, individuals may relocate themselves into respectively more successful breeding sites during following years. We could not incorporate this possibility in our simulations, but it is worth considering it for future studies.

The discrepancy between the medium-term biological benefits and low self-sustainability of scenarios including nest protection in fodder raises the question whether is best to pursue: a) the largest biological benefits; b) an increase in medium-term economic sustainability while decreasing the species risk of dependence on the program (and thus of suffering after it terminates) –i.e., decreasing the magnitude of the conservation trap; or c) a combination of these two scenarios.. To this end, we share the view of Cardador *et al*. (2015) for an urgent need to find fresh solutions that emphasize the self-sustainability or durability of conservation programs.

4.2 Achieving a self-sustainable population

Our results demonstrate that achieving a self-sustainable breeding population in the agro-ecosystem of Lleida would be impossible. In other words, it may be impossible to fully avoid the conservation trap. However, our findings show the potential role of irrigated cereal as a candidate for maintaining a small but self-sustainable population.

Our findings suggest that protecting nests in irrigated cereal is not cost-effective. Late harvest time of this crop type allows some harrier chicks to fledge before being killed even at unprotected nests (Manel Pomarol, pers. comm.). Protecting nests in irrigated cereal thus results in only marginal improvements in the species productivity (as shown by the similar trends between *All unprot* and *Ic* scenarios in Figure 1a). Nonetheless, this does not mean that contribution of irrigated cereals to the final population size is unimportant; it only means that it is not worthwhile paying for nest protection in this crop type given its high costs. In fact, actions leading to an increase in number of breeding pairs in irrigated cereal over the other crop types would potentially increase the program's self-sustainability. Not only would it reduce the economic expenditure at the medium-term, but also the dependency of the program on financial incentives which are not always effective as a mean to change human behaviour (Kleijn *et al.* 2009, De Snoo *et al.* 2013). It is currently difficult to estimate how likely it is to increase the proportion of individuals nesting in irrigated cereal. The species is more likely to move places if they have failed in previous breeding attempts, and it is also known that the nest is located in places in relation to vegetation height and density (Arroyo et al. 2004). It is thus possible that stopping protection in fodder, or cutting the vegetation in those crops at arrival time, would lead to an increase in the harrier population breeding in irrigated cereal, at least within the limits imposed by the carrying capacity of that habitat in the area. In that sense, the projected change in climate may also play an important role in the future management of this species in Lleida. Drought events are projected to become more frequent in the Mediterranean region, and this may render dry cereals less attractive for breeding harriers, triggering the harrier population in Lleida to further move to breed in irrigated crops, similarly to what happened in 2005 (Cardador *et al*. 2015). This could represent an opportunity for the local practitioners to apply a scenario whereby fodder nests are left unprotected, whereas nests in irrigated cereal, which are cheaper to protect than fodder, are protected.

4.3 Decreasing nest protection over time

Montagu´s harrier population persistence is only marginally affected by the rate of nest protection reduction in Lleida. This means that, at least theoretically, conservation programs that differ exclusively on their rate of protection reduction might achieve similar population sizes at the medium-term. In this sense, if a decision is made about stopping nest protection in a given crop, practitioners should not consider the rate of protection decrease and simply reduce costs by stopping nest protection instantaneously. However, we recognize that if the scenarios allowed for the movement of individuals between different crop types, slower rates of protection decrease could yield higher population sizes compared to stopping protection instantaneously.

4.3 Study limitations

Given that results of the simulations depend entirely on the demographic and environmental information we inputted, we call for caution when interpreting the results. Sensitivity analyses confirm that, as expected for this long-lived species, results are mostly sensitive to changes in survival, less so for changes in fecundity and carrying capacity (Santangeli *et al.* 2014). Moreover, the density-dependence threshold used in the model could be determining the ultimate abundances for scenarios limited by carrying capacity (*e.g. All Prot* and *F+Dc*). Nevertheless, we deem it unlikely that one parameter would change differently among scenarios; therefore cross-scenario comparisons (i.e. in terms of cost-effectiveness) should be reliable. Our models also assume a stable proportion of nests in each crop type or natural vegetation, which is an oversimplification. Harriers are flexible in their choice of nesting habitat, and in the same way they started using irrigated crops in 2005, they may favour one or other crops at any given time, which may modify the final outcome, as explained above. Additionally, we only considered compensation costs to the farmers for delaying harvest, and ignored costs related to fieldwork for detecting nests. Thus, the real costs per scenario are higher than the values presented here. However, inclusion of fieldwork costs would not affect the relative cost-effectiveness of each scenario as fieldwork costs are similar across crop types. In Lleida, harrier nest monitoring (regardless of intervention) is performed as part of the species regional conservation programme. Finally, we caution that the costs for harvest delay in each different crop considered here might be subject to unpredictable changes over the coming years dictated by global market trends in prices for cereals as well biofuel crops.

5. Conclusions

Our study clearly shows that conservation practitioners may face hard decisions. In the case of Montagu´s harriers in Lleida, a practitioner may be lured towards implementing the most cost-effective options that would nevertheless be financially unsustainable and ultimately increase the species dependence on active management in the medium and long run. Our results call for greater caution when setting conservation objectives based on biological outcomes, and that a long-term vision including financial sustainability and the species’ potential risk of becoming dependent on management should be considered. In our case, refining conservation objectives towards maintaining a population that would be financially sustainable but ecologically viable seems appropriate, even if this carries the risk of reducing the population size. Our findings reinforce the need for explicitly setting conservation goals and account for biological benefits as well as costs of conservation programmes (Bottrill *et al.* 2008).

The implications of this study span far beyond the system considered here. As most of the land on Earth has been altered and put under some forms of production regimes, practitioners are often faced with managing species in complex socio-ecological contexts (Knight *et al.* 2010). Although most emphasis has been rightly placed on assessing the cost-effectiveness of management options (Ferraro and Pattanayak 2006), our study highlights that this may not always show the whole picture. A species becoming dependent on costly conservation actions implemented on land under intensive production regimes may turn an apparently cost-effective program into a costly conservation trap in the long term (Cardador *et al.* 2015). We show here that alternative solutions can be sought through a combination of PVA and cost-effectiveness analyses. Implementing solutions will inevitably require making hard choices while refining conservation objectives. However, when provided with scientific evidence, practitioners are often willing to use it in their decision-making (Walsh *et al.* 2014). Therefore, we believe that studies designed in collaboration with local practitioners will make a real contribution towards improving the long-term sustainability of conservation programs. Such studies can produce solution-oriented science with high impact for implementation, which is still too rarely done in academia (Smith *et al.* 2009).

Acknowledgements

We are grateful to those who participated in harrier population monitoring, particularly, J. Bonfil, A. Varea, F. Pont, and Cos d'Agents Rurals. A. S. was supported by a Kone Foundation grant. We also thank three referees and the editor for insightful comments that helped improve this study.

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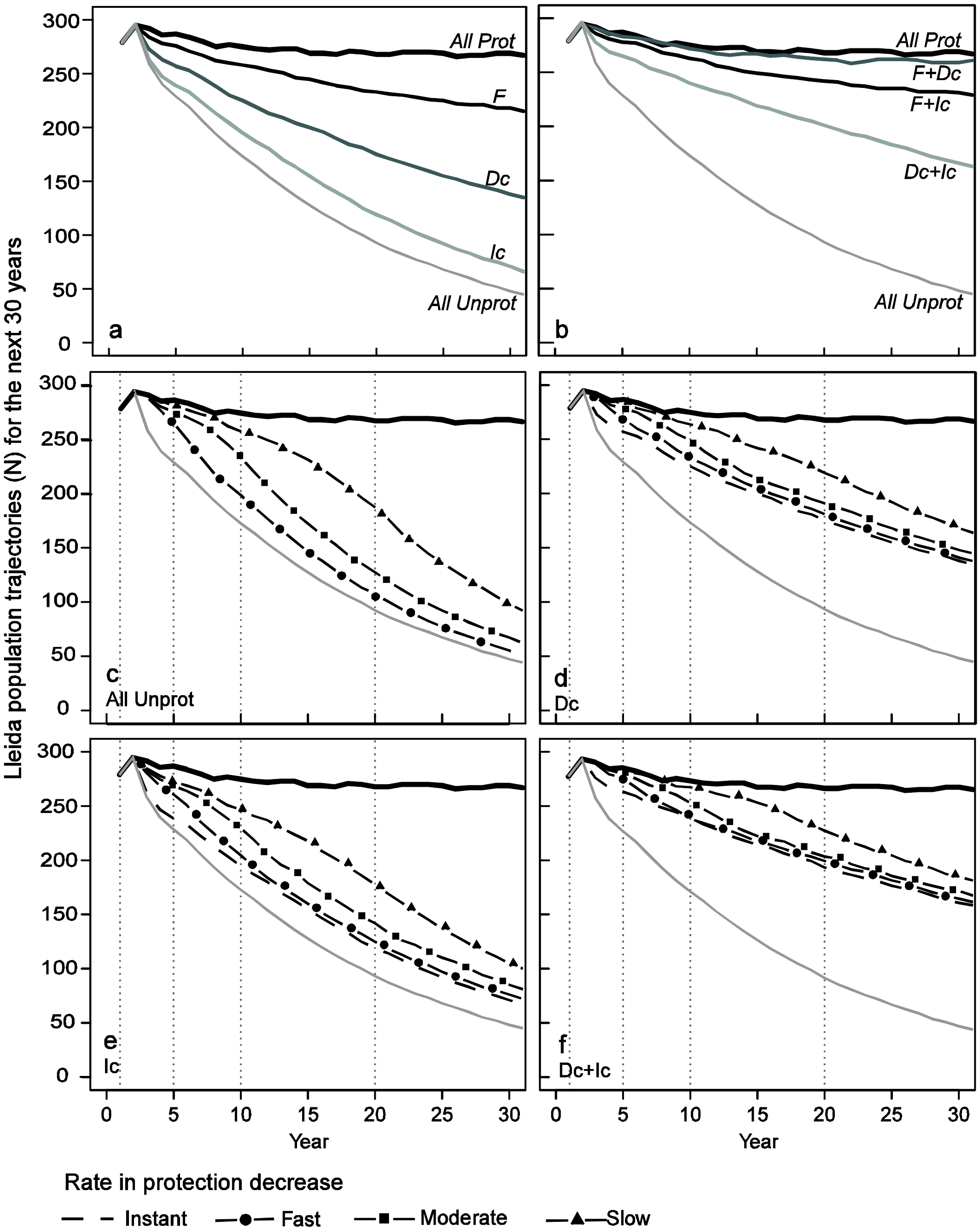
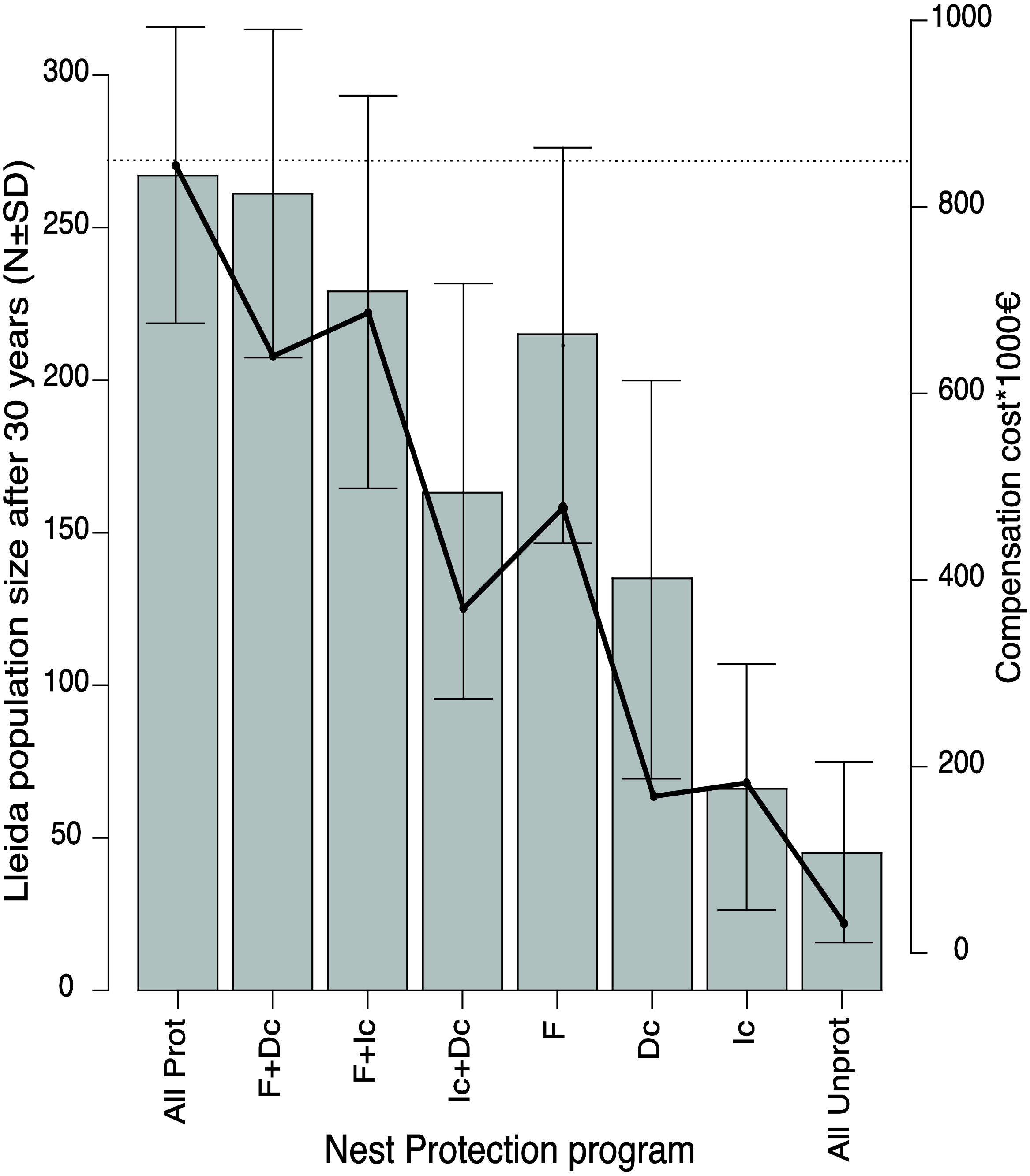
Table 1. Mean cost per nest, benefit (i.e. number of individuals gained relative to all unprotected program) and cost-effectiveness of applying each nest-protection program after 30 years in Lleida. The most cost-effective programs have small values of cost-effectiveness in the table. For more details on the conservation programs see Methods.

	cost per nest	benefit	cost-effectiveness
All Unprotected (*All Unprot)*	16	0	-
Dry cereal (*Dc*)	112	90	1.25
Fodder (*F*)	290	170	1.71
F+Dc	385	216	1.79
Dc+Ic	237	118	2.01
F+Ic	414	183	2.26
All Protected (*All Prot*)	510	222	2.29
Irrigated cereal (*Ic*)	141	21	6.63


Lleida population trajectories (N) for the next 30 years
a
b
c
All Unprot
d
Dc
e
Ic
f
Dc+Ic
All Prot
F
Dc
Ic
All Unprot
F+Dc
F+Ic
Dc+Ic
0
50
100
150
200
250
300
0
5
10
15
20
25
30
Year
Rate in protection decrease
Instant
Fast
Moderate
Slow

457

458


Lleida population size after 30 years (N±SD)
0
50
100
150
200
250
300
Compensation cost*1000€
0
200
400
600
800
1000
All Prot
F+Dc
F+Ic
Ic+Dc
F
Dc
Ic
All Unprot
Nest Protection program