Cost-benefit analysis of red deer conservation in Sardinia

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Biodiversity provides important ecosystem services and economic benefits to local communities and is globally considered a key resource for sustainable development. Here, we attempt to measure costs and benefits of the conservation of Sardinian red deer, a subspecies endemic to Sardinia and Corsica. At the beginning of 1980 the Corsican red deer, Cervus elaphus corsicanus, was seriously threatened to extinction. A series of conservation measures and reintroductions allowed the population to recover, and more than 1000 rutting males and 5000 individuals are present in Sardinia. The population is still very localised and fragmented but in some areas local populations reach very high densities (up to 26 deer/Km2). Such densities are reassuring from a conservation standpoint. On the other hand, in these localities local communities are starting to experience the economic cost of red deer conservation as direct damages to agriculture and forestry, and road collisions. It is likely that in the future red deer management in Sardinia will have to take into account for higher costs and harvesting could be a valid management option. Based on time series data, we estimated red deer population growth parameters according to a logistic function. Different hypotheses about population growth were evaluated by model selection based on AIC. Costs of deer conservation were estimated based on resources employed in reintroduction and monitoring program, and in managing damages caused by the species (refunding). Potential benefits were estimated quantitatively from potential meat value and qualitatively from the ecological and recreational function of deer. Parameters taken from the best model selected were used to predict population growth of red deer in Sardinia. Based on this predictions future and by simulating population trajectories with and without harvesting, we predict related temporal variation of costs and benefits. Overall, this study shows that deer population could be an important economic resource and conservation efforts aimed at repopulating 30% of Sardinian surface, if properly managed, could allow economic benefits to be shared among local communities.

Key words: agriculture, forestry, natural resources, sustainable development,

Introduction

Biodiversity provides important ecosystem services and economic benefits to local communities and is globally considered a key resource for sustainable development (Millennium Ecosystem Assessment 2005). However, conserving and improving biodiversity implies both direct and indirect cost and benefits. In order to value the economic and social importance of biodiversity it is therefore important to find tools to perform a comprehensive cost-benefit analysis of conservation objectives.

Here, we attempt to measure costs and benefits of the conservation of Sardinian red deer, a subspecies endemic to Sardinia and Corsica (Skog et al. 2009), listed in the Italian International Red List. At the beginning of 1980 the Corsican red deer, Cervus elaphus corsicanus, was seriously threatened to extinction with an estimated population of few hundred individuals and a strong negative trend mainly due to unregulated hunting and habitat loss. A series of conservation measures and reintroductions allowed the population to recover (Kidjo et al. 2007; Puddu et al. 2008; Mandas et al. 2008), and more than 1000 rutting males and 5000 individuals are present in Sardinia (Mandas et al. 2008). The population is still very

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localised and fragmented but in some areas local populations reach very high densities (up to 26 deer/Km2) (Mandas et al. 2008). Such densities are reassuring from a conservation standpoint. On the other hand, in these localities local communities are starting to experience the economic cost of red deer conservation as direct damages to agriculture and forestry, and road collisions.

The most widely used method of reducing deer damage is by harvesting (Ward et al. 2004), which should be properly planned and interpreted as a sustainable use of a natural resource. In Sardinia, plans to reduce damages from deer populations started recently, underlining local request to manage the cost of red deer conservation. These plans do not consider harvesting red deer, which is not allowed in Sardinia as a consequence of its former and present conservation status. In fact, the population is still of small size and severely fragmented, and it would be probably unwise to harvest the population at this stage of conservation. However, harvesting might become a valuable option in the future.

Here, costs of deer conservation and reintroductions are estimated based on resources employed in implementing conservation (e.g. reintroduction program and monitoring) and in managing damages caused by the species (refunding), whereas potential benefits are estimated quantitatively from meat value and qualitatively from the ecological and recreational function of deer. A simulation of population trajectories with and without harvesting is also performed to predict related temporal variation of costs and benefits.

Materials and Methods

Study system: red deer conservation and management in Sardinia

The Corsican red deer (Cervus elaphus corsicanus Erxeleben, 1777) is reported as 'endangered' in the IUCN Red Data Book (2004) and classified as "particularly protect" by the Italian law. It is strictly protected under the Appendix II of the Bern convention and Annexes II and IV of the EU Habitats and Species Directive. It is also considered as "high priority for conservation and research" under the European Mammal Assessment (2007).

Corsican red deer was referred to as a commonly hunted species until the XIX century (Casalis 1835; D'Austria D'Este 1812; Fara 1838; Lamarmora 1868). The species was heavily hunted until 1930, with hunters coming in Sardinia from all over Europe (Mantegazza 1869; Legré 1881). In 1930, following a period of decline, the Corsican deer was protected by the Italian law, but poaching and land-use change drove the sub-species to its historical minimum of 100 individuals in Sardinia (Jenkins 1972; Mattioli et al. 2001), and to extinction in Corsica in 1970 (Gauthier and Thibault 1979). By 1980 three completely separated sub populations remained in the south of Sardinia (Sulcis, Sette Fratelli, Monte Vecchio). Presently, the species is enlarging its distribution but still localised in the three isolated areas mentioned above. In the last years, distribution and abundance of the Sardinian red deer have been annually monitored by a joint effort of the Ente Foreste della Sardegna (EFS), WWF Italia and Provincia del Medio Campidano. Apart from conservation measures exerted with legislation and control, there are also 10 corrals managed by the EFS for reintroduction and/or ex-situ conservation. Moreover, reintroductions have been already implemented by the EFS in several areas of Sardinia, such as Montimannu (started in 1980), Monte Lerno (2003), Pabarile (2007), and Montarbu – Su Marmuri (2009).

Population dynamics

Population data

Data on population density of red deer in Sardinia were taken from literature (Boitani et al. 2003; Kidjo et al. 2007; C. Murgia et al. 2005), personal communications (Antonello Loddo, WWF Italia) and census based on rutting males performed by the EFS (Mandas et al. 2008). Data are relative to different areas (South Sardinia, SS; Monte Arcosu, MA, Monte Lerno, ML). The population SS represents most of the red deer population present in Sardinia (362 Km²). The other two series of data are relative to much smaller regions, one within the SS range (MA; about 36 Km²; however, data were separated from SS and taken from independent observers), and the other located in northern Sardinia (ML, about 30 Km²).

Model set

Given the scarcity of data on population structure and survival of individuals, population dynamics is modelled here by using the following phenomenological logistic model (Hassell 1975):

$$N_{t+1} = \frac{N_t \lambda}{\left(1 + a N_t\right)^b}$$

where the relationship between population density at time t+1 and t depends on the maximum population growth rate (λ), and two scaling factor, a and b, that relates population growth with density, giving the shape of the logistic curve. This model assumes that population growth is density dependent and at high density population growth equal zero. By assuming a=b=0, this model can be simplified to an exponential growth.

From the general model above, a set of models specifying hypotheses about red deer population dynamics in Sardinian locations was developed (Table 1). The general model was indicated as follows:

$N(s) \lambda(s)a(s)b(s)\sigma(s),$

where initial population size, N, maximum population growth rate, λ , the logistic parameters, *a* and *b*, and standard deviation, σ , differ among locations and data series (s, strata=location). In search of more parsimonious models, parameters were then constrained to be equal among locations or set to zero (e.g. a=b=0 to specify an exponential growth). Model simplification was indicated in parenthesis: for example, λ (.) means that growth rates do not vary among locations; $\lambda(SS;MA=ML)$ means that growth rates in the MA and ML populations are equal but differ with SS; a(=0) means that the parameter has been set to zero.

Table	1: Model	describing	population	dynamics of	f red deer	in Sardinia.

		Model selection diagnostics			Maximum likelihood estimates of model parameters									
#	Model structure	QAICc	∆QA/Cc	wi	К	<u>Çi</u>	λSS	λMA	λML	а	b	σCA	σMA	σML
M1	$N(s)\lambda(s)a(s)b(s) \sigma(s)$	106,604	21,279	0,000	14	1,6668	1,1731	1,3299	1,2976			0,5806	0,8747	0,9789
M2	N(s))(s)a(.)b(.)σ (s)	97,278	11,953	0,002	12	1,5801	1,2266	1,3290	1,2975	0,0008	12,681	0,6409	0,8539	0,9789
M3	N(s))(s)a(.))(,)g (.)	89,159	3,835	0,128	10	1,4668	1,2266	1,3290	1,2975	0,0008	12,681	0,7974	= CA	= CA
M4	N(s)λ(CA;MA=ML)a(.)b(.) <u>σ</u> (.)	85,325	0,0000	0,870	9	1,4119	1,2266	1,3289	= MA	0,0008	12,681	0,7991	= CA	= CA
M5	Ν(\$),λ(.),a(.),b(.),α (.)	104,946	19,621	0,000	8	1,3395	1,3214	= CA	= CA	0,0008	12,681	1,2911	= CA	= CA
M6	$N(s)\lambda(CA;MA=ML)a(=0)b(=0)\sigma(.)$	126,495	41,170	0,000	7	1,2503	1,1000	1,0679	= MA	-	-	2,1766	= CA	= CA

Data analysis

Models were confronted with the three series of data described above (South Sardinia, SS; Monte Arcosu, MA, Monte Lerno, ML) by using likelihood based methods. Given the different localities and observers, the three series of data can be considered independent. In these cases, likelihood theory can easily incorporate multiple type of observations: the likelihood of the joint model is the sum of the log-likelihood of each series of data (G. C. White & Lubow 2002; Hobbs & Hilborn 2006). Estimates of parameters from the joint models were obtained by maximizing the sum log-likelihood of the three series of counts (n=35).

The normal distribution was used to specify the error structure in the data (Neter et al. 1996; Hilborn & Mangel 1997). Maximum likelihood estimation of model parameters was achieved by numerical search (Neter et al. 1996), using the Newton search implemented in Microsoft Excel solver tool.

Model selection was achieved through the calculation of quasi-likelihood adjustments for overdispersion of the corrected Akaike's Information Criterion, QAICc, which is a modified version of the AIC used when the number of the estimable parameters in the model (K) is large relative to sample size (i.e. when n/K < 40) and data are overdispersed (Burnham & Anderson 2002). Specifically, overdispersion was estimated as

$$\hat{c}_i = \frac{Deviance}{n-K_i}$$

where *n* is sample size and K_i is the number of estimated parameters of model *i*. QAICc values were calculated by using a weighted estimate of overdispersion. This approach is fundamentally an application of model averaging (Burnham & Anderson 2002) to the estimation of overdispersion. In practice, the weighted average of overdispersion was obtained by using Akaike model weights,

$$c = \sum w_i c_i^{\prime} .$$

Support for each model *i* was assessed by using $\Delta QAIC_c = QAIC_c(i)$ -Lowest QAIC_c and the proportional likelihood of the model, the Akaike weight, w_i , (Burnham & Anderson 2002).

Model selection allows to select the hypothesis about red deer population growth in Sardinia best supported by the available data. Subsequently, based on model structure and parameter estimates taken from the best model selected, predictions about future population densities and costs can be done.

Costs of deer conservation

The cost of conservation measures is estimated from translocations and monitoring programs already carried out by the EFS. Considering that environmental control (patrolling from Corpo Forestale e di Vigilanza Ambientale della Sardegna) is targeted at numerous objectives, the cost of control was not evaluated here.

The cost of deer damage to agricultural crops, private forestry and road collisions are estimated from official data on compensation requests (Assessorato Difesa dell'Ambiente, Sardinia, 2001-2007). Increasing damages are related to increasing deer density by a simple linear regression. Estimated regression parameters are used to predict increased cost of damages resulting from increased deer density.

Prevention activities to protect agricultural crops started in Sardinia very recently, and data about cost/effectiveness of measures implemented are not available or very sparse. Given that available data (2001-2007) on damage cost result from virtually no prevention activity, and assuming that prevention would be cost effective in reducing damages, we decide not to add the extra cost of prevention in this analysis. However, the cost to reduce damages to public forestry activities (damages to public forestry cannot emerge from data on compensation requests) was considered and estimated as the extra cost of fences (commonly used in Sardinia to protect plantations from sheep, cows and goats) suitable for protection against deer.

Benefits from deer conservation

Benefits from deer conservation are evaluated here quantitatively and qualitatively. We focus our quantitative analysis on the potential benefits coming from deer harvesting, a reasonable option for red deer management if conservation keep resulting in population increase, with consequent changes in conservation status and legislation. Other benefits such as increased tourism income, recreation, ecosystem functioning and so on, are at this stage of the investigation evaluated qualitatively.

Results and discussion

Population dynamics of red deer in Sardinia

Table 1 shows model selection results. Six models were developed and confronted with time series data on red deer density to evaluate whether population growth rates differ among locations (M1 vs M4 and M5) and to define the shape of the growth curve (logistic vs. exponential; model M4 vs. M6). Also, the parameters a and b have been soon set equals to the MA population based on the assumption that the growth curve of the Sardinian red deer is of one type and the only time series that provides enough information to test whether the shape is exponential or logistic is that from Monte Arcosu (MA, n=19 years).

The best model selected is model M4, $N(s)\lambda(SS;MA=ML)a(.)b(.)\sigma(.)$, which compared to the other models has rather strong support ($w_i = 0,870$). This model states that: a) initial population density differs among locations, N(s); b) population growth rates differ between MA-ML and SS, λ (SS;MA=ML), i.e.

the two small populations of MA and ML have a higher growth rates than the larger population of south Sardinia (SS; see parameter estimates in Table 1); the parameter a and b do not change between locations, a(.)b(.); the standard deviation has similar value for the three time series, $\sigma(.)$. The only other model with some support, M3 - $N(s)\lambda(s)a()b()\sigma()$ - is identical to the best model apart from the assumption that population growth rates changes among all locations, showing a small difference between MA and MI, which is however very weakly supported by the data ($w_i = 0,1279$). It also important to note the very high $\Delta QAIC_c$ of models M5 and M6, assuming respectively that population growth rates do not change among locations, $\lambda(.)$, and that population growth follows an exponential curve, a(=0)b(=0). This hypotheses have fundamentally not support, and available data are therefore sufficient to provide good information about population growth rates can be explained by the much higher landscape heterogeneity of the extended area of southern Sardinia which is likely to be of general poorer quality than the two areas of MA and MI, specifically selected for environmental suitability.

The good support found for the best model selected encourage us to make prediction about population density in the future. A visual inspection of model fit will perhaps reinforce this belief. Figure 1 shows observed data on population density relative to the three study areas and relative good fit of theoretical predictions based on parameters estimated from the best model selected. Figure 2 shows theoretical predictions of deer density variation through time in southern Sardinia (SS), Monte Arcosu (MA), Monte Lerno (ML), and two more sites subject to reintroduction in 2009 (Seui and Ulassai). In these two more sites, about 16 deer will be released by the end of 2009 (8 and 11 already released). Preliminary GPS-GSM positioning data (15 collars; Tellus GPS System, Followit) taken from the individuals already released (February 2009), show that the two deer populations distributed over different extensions (respectively 9 and 20 Km²). Based on this, we estimated two different densities and made predictions about population growth. From the figure appears that by 2030 virtually all populations will have reached equilibrium. We assumed that all small populations have growth rate similar to MA, reaching therefore equilibrium at the same density (about 27 deer/Km²), whereas the larger population SS, having smaller growth rate, reach equilibrium at lower densities (about 20 deer/Km²).



Figure 1. Observed data on red deer population density (Obs) and theoretical predictions based on the best model selected (Exp).



Costs of deer conservation

Costs of deer conservation carried out by the EFS.

In the last 20 years, the EFS implemented 12 corrals for reintroductions and ex situ conservation. The overall cost for corrals implementation (manpower, materials, and translocations) has been estimated in 1,130,650 euros. The cost of translocations for four more reintroductions implemented by the EFS is estimated to be 106,128 euros. Monitoring programs based on rutting males censuses covering about 362 Km², with the involvement of 40 workers per 10 days, cost 47,445 euros/year. The annual cost of all these actions amount at about 110,000 euros. However, whereas the annual cost of translocations and reintroductions is likely to decrease, the cost of monitoring program should increase with the extension of deer distribution. Indeed, if species management is to be based on sound information about deer abundance, extended monitoring programs should be implemented. In particular, if monitoring programs were extended over 30% of Sardinian surface, a reasonable objective for deer conservation in Sardinia, an overall cost of translocations and monitoring of approximately 1 million euros/year should be taken into account. By creating a monitoring network based on volunteers and local knowledge (Anadón et al. 2009; Schmeller et al. 2008) this cost could be reduced.

Costs resulting from damages to agriculture, private forestry and road collisions

Simple linear regressions show that there is an increasing trend in the number of road collisions and compensation requests relative to damages in agriculture and private forestry (Figure 3 and 4). Related increase of cost was calculated by using the average cost of compensation requests or damages. The increase with time of both costs is evident and is also rather steep.

Damage costs related to future deer densities with and without harvesting is shown in Figure 5 and 6. Harvesting was assumed to consist in 1 deer harvested per Km^2 each year. Population density was calculated based on parameters of population dynamics of the southern Sardinian population, which were considered more likely in large populations. The figures show that this level of harvesting drastically reduces damages by reducing population density at about 12-13 deer per Km^2 . If the whole suitable landscape for red deer in Sardinia, about 30% of the total surface (Puddu et al. 2008), were populated by deer at equilibrium, overall cost due to road collisions and damages to agriculture and private forestry

could be estimated in 1,893,600 (damages) + 345,600 (collisions) and 662,400 + 93,600 for no-harvesting and harvesting respectively.









Costs to public forest management

Deer cause damage by browsing, stripping bark and fraying trees (or tall scrubs) with antlers. Locally or when density is high, soil compaction might occur. However, in an area with particularly high red deer

density in Sardinia (WWF Natural Reserve of Monte Arcosu), no damages by bark stripping and limited fraying were recorded (Lovari et al. 2007). The same appears in other locations in Sardinia where, workers the EFS involved in monitoring deer populations found no evidence of bark stripping activity and low frequency of fraying, occurring mainly in coniferous plantations. In Mediterranean ecosystems such as those in Sardinia, bark stripping might not occur because of the presence of green parts of plants throughout the year. Bark stripping is also prevented by some structural features of the maquis: high density and persistence of living branches inserted close to the stem base.

Even if the impact of red deer on forest or pre-forest ecosystems in Sardinia seems to be low despite the very high densities, it is important to highlight that red deer population in Sardinia is recently recovering after having come close to extinction. It is thus possible that the present density has been established for too short a time to be sure that, as no impact is occurring now, the same would be in the future. Also, there is lack of knowledge about the carrying capacity of different ecosystems so that only speculations can be made in order to explain the higher deer densities and lower damages reported for Mediterranean ecosystems compared to temperate and temperate-boreal ones.

The public agency EFS manages about 220,000 ha of land covered mainly by Mediterranean forests, maquis, and low scrubland. It is thus reasonable to consider all of the land area managed by the EFS as suitable areas for red deer populations (sensu Puddu et al, 2009). By averaging the planted area in 2008 with the programmed area for plantations in the 2009-11 period, the mean afforestation rate in Sardinia by the EFS is about 460 ha/year. Incidentally, most of the new plantations presently lie outside the actual area covered by the species. Nevertheless they have to be fenced against other animals including trespassing livestock. This means that a possible expansion of red deer in the suitable but not yet exploited area would imply additional costs due to the need for adequate fencing. Thus, the presence of deer would be accountable only for the difference between specific and normal fencing.

Assuming an average area of the single plantation around 7 ha with an average perimeter of 1200 m, 78,429 m of fencing per year are estimated to be necessary. The average unit cost of a normal fence (not specific for cervidae) is 20 Euro m-1 (based upon the price list adopted by EFA for project cost calculation), while the cost of specific fences for Cervidae are reported to be 32 Euro/m (internal technical report of the RFA). These figures include installation costs. Therefore, an additional cost of 12 Euro m-1, that is ca. 940,000 euros/year, may be accounted for by red deer in Sardinia for public forestry.

Benefits from deer conservation

Here, we discuss the qualitative benefits from deer conservation on nature conservation and ecosystem functioning and for tourism and recreation. We also attempted to estimate the economic value of a harvestable viable population of red deer in Sardinia, which can be thought of as a population occupying all suitable areas, estimated in covering 30% of Sardinian surface (Puddu et al. 2008) and at near-equilibrium density.

Nature conservation and ecosystem functioning

Mediterranean biodiversity evolved in highly disturbed environment, where fire and grazing were among the most powerful ecological factors shaping biological communities (Blondel & Aronson 2000). The striking heterogeneity that often can be observed in the Mediterranean arises from complex interactions between environmental heterogeneity and patterns of ecological and anthrop ogenic disturbance. A recent paper underlines the importance of rewilding landscapes by coupling fire and grazing (Fuhlendorf et al. 2008). Moreover, it has been shown that deer can be an important vector of plant dispersal (Myers et al. 2004). To fully appreciate benefits to nature conservation and ecosystem functioning from deer grazing, research should go beyond the simplistic concept of "game damage" (Weisberg & Bugmann 2003) and look for the effects on community dynamics. On the other hand, it is widely recognized that high density of deer does damage vegetation, reduce biodiversity and hinder forest regeneration. Unfortunately, we don't have much understanding on the effect of red deer grazing in Sardinian landscapes and for this reason we were unable to evaluate costs and benefits. At the same time, we believe that future research effort should aim at understanding

Recreation and Tourism

Given the attractiveness of red deer it is likely that red deer population increase will have a positive impact on recreation and tourism, which will benefit from high encounter rates of deer and from quality alimentary goods that can be derived from deer. Unfortunately, the economic benefit was not estimated

here but, given the increasing demand for wilderness, it is likely to be relevant and should be quantitatively evaluated in future efforts.

Harvesting and food

In the Italian market, deer meat cost approximately 20 Euros per Kg; the average weight of hunted deer in Sardinia can be estimated as 80Kg; about 50% of the animal can be used for food. Consequently, one deer value amount at about 80Kg x0.5x20E=800E. Results presented in previous sections show that 7200 deer (1Deer x Km² of suitable areas) could be hunted if 30% of Sardinia were populated by viable populations of deer near equilibrium density. Thus, 800 euros/deer x 7200 deer/year= 5,760,000 euros/year of potential meat value. However, deer harvesting provides additional travelling, recreational, tourist, trophy and alimentary values that are likely to increase this estimate.

Conclusions

Overall, deer conservation costs and benefits on annual scale are summarised in Table 2. As we have quantitatively considered only benefits coming from meat value, harvesting make clearly a big difference in the overall cost-benefit analysis of red deer conservation in Sardinia. However, this study shows that red deer could be a profitable resource for Sardinian communities, and if properly managed, costs could be reduce and important profits derived.

Local policy should therefore take apart the fear of dramatic damages and cost arriving without benefits, and encourage a conservation objective aiming at reaching a wider distribution of red deer in Sardinia, possibly targeting 30% of Sardinian surface, which has been suggested as the actual surface suitable for red deer in Sardinia (Puddu et al. 2008).

At the same time we have to underline that our model projections are based on few data taken from a few localities and we have little understanding of red deer population dynamics and economic impact in Sardinia. Before to plan any harvesting results presented here should be confirmed. Besides, a monitoring network that guarantee good data on population abundance, structure, dispersal and spatial distribution should be created.

We know that deer were once an important resource that got almost extinct as a consequence of overexploitation. Going beyond the obvious ethic and cultural duty of conserving biodiversity, we also hope that in the future this species could be seen of as a renewable economic resource.

Description	No Harvestin	ng	Harvesting		
	Costs	Benefits	Costs	Benefits	
Translocations, reintroduction and monitoring	1,000,000		1,000,000		
Road collisions	345,600		93,600		
Damages to agriculture and private forestry	1,893,600		662,400		
Damages to public forestry	940,000		940,000		
Meat value				5,760,000	
Difference	- 4,179,200			+1,580,800	

Table 2. Cost-benefit analysis of red deer conservation in Sardinia: synthesis based on annual costs.

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