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Review paper

A matrix system using quality classes can be applied for managing sustainable wild ungulates populations: Convergence below optimum capacity

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ABSTRACT

During last decades ungulates have increased their populations and distribution areas, this widespread has made habitat damage appear and some conflicts with human interests, for these reasons the development of an ecological sustainable control is necessary. This study introduces a mathematical matrix model for managing wild ungulate populations through a quantitative method, describing the steps for the complete managing process,

This work describes and applies the method to a population of red deer (*Cervus elaphus*) in central Iberia (Spain), through a matrix system model organized by quality classes, based on physical characteristics and biological behavior, and it results in an improvement much more useful for wildlife managers than previous matrix methods The output provides essential information for the management, as the population density evolution by quality classes twice a year: after the reproductive season and the extraction season, population growth rate, stable population distribution and extraction rate to guarantee a heathy and sustainable population. The model describes a method to reach a stable Optimum Capacity, reducing conflicts with human societies and environment deterioration, giving meaning to two different concepts: Optimum capacity and Carrying capacity. The study simulates a real management case with the density below Optimum Capacity where there are no density dependent growth restrictions, and how to achieve and maintain the Optimum Density.

The method allows a successful optimum management, improving a quantitative sustainable control of the population, and preserving ecological natural habitat characteristics, given an advantage over alternative models and management trends.

1. Introduction

Ungulates are one of the most extended medium-large animals in the world, among them, deers with many different species, have increased their population size in many areas of Europe and North America (Skonhoft et al., 2013), where their habitat is often shared with humans, and are being increasingly fragmented due to their territorial activities (Zuberogoitia et al., 2014). This coexistence causes problems, as forestry and agriculture damage (Putman and Moore, 1998; Renaud et al., 2003) and traffic accidents as the most widespread and persistent human-wildlife conflict in the world (Snow et al., 2015). Also, large deer population densities endanger the natural ecosystem conservation, browsing and damaging the natural vegetation (Trdan and Vidrih, 2008; Carpio et al., 2014). The protection of the ecosystem, human impact on the environment and the necessary exploitation of natural resources, demand a wildlife management (Gordon et al., 2004).These aims permit managers to integrate ecological processes, social, cultural and political values, as well as economic feasibility (Tremblay et al., 2004) with the target of global sustainability, and in particular to reduce conflicts and illnesses related to high wildlife population densities.

These management actions are necessary and they would have significant impacts on the broader plant, animal communities and biodiversity (Zipkin et al., 2010), although in many parts of the world large herbivores are managed inefficiently (Austin et al., 2013). The new developed models allow to simulate a population behavior throughout time, and is useful to compare alternative management practices (Jensen, 2000), even to know how many individuals should be extracted to guarantee sustainability and stability of the population under optimum control. In this theoretical position, the studied matrix model is described and applied for this purpose (Mayle, 1996).

Population projection matrix models (Leslie, 1945), later modified

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(Lefkovitch, 1965) by grouping organisms in terms of stage categories, rather than age categories, have been widely applied to analyze the evolution, management, harvest, etc., for wildlife populations (Caswell, 2000). These kinds of models have been used in several ungulates as wild boar and fallow deer (Focardi et al., 1996), moose (Lopatin and Rosolovsky, 2002) and American deer, with an age structure by years (Jensen, 1996) or age classes, considering only the female population and their productivity (Jensen, 1995; Walters, 2001; Gilbert et al., 2007), or males and females in the same model (Jensen, 2000) permitting a more detailed system of a vectoral variable, with a higher dimension. These studies based on transition matrix present several disadvantages to use them as an efficient tool to simulate real deer populations, due to an unrealistic way to simulate the logistic curve appeared over values or population next to ecosystem carrying capacity. These studies have solved this divergence between models and empirical knowledge, introducing density-dependent factors without a reliable ecological sense, as mathematical limiters, to simplify the explanation. Also, none have a view of the population differences between the reproductive season and after the next managed season, quantifying the extractions for every case that could arise.

This model avoids working with age categories, because they present a huge difficulty for a wild animal, it is impossible to know exactly the age without capturing the animal, and even when capturing the animal, it is still difficult without killing them. The quality classes have been created for this reason, attending to traditional management systems for this species, detectable in field work without captures.

Nowadays, red deer is widely distributed all over the Iberian Peninsula, except the farther North West and the east coast. The distribution is usually focused on areas with very high densities surrounded by others with very low or even absent ones. The population of red deer in the Iberian Peninsula is estimated to be above 500.000 individuals (Carranza, 2007), where the Mediterranean habitat with a mixed forest and grassland is the perfect landscape for the Iberian red deer, covering the principal needs for this animal: food and protection (Caballero García De Arévalo, 1985). This study takes place in an estate called "Quintos de Mora" located in central Iberia, specifically in the southwest of the province of Toledo, in a region called Los Yébenes, belonging to the river Guadiana's basin. The climate, that characterizes this area is typical Mediterranean weather with an average of 702 mm/year rainfall and an average annual temperature of 16,7 °C. The elevation is between 735 m on the valley floor that is surrounded by two mountain ranges slightly sloping reaching 1.265 m above sea level (Navarro Millas-Prendergast and Martín Fernández, 2015). The area has a natural red deer population which serves to obtain biological data to carry out the model, and has been used to simulate the behavior and management of a natural Iberian red deer population, which is increasing density through time from a lower value until reaching carrying capacity.

2. Objectives

The first objective is to describe a useful model for the management of any ungulate population, taking its evolution to reach a stable distribution by classes, with an optimum density, leading to a healthy population and reducing social conflicts. The harvested individuals will be obtained as an output, to obtain a stable population (vectoral variable) that will be a factor of sustainability, using an iterative numerical method to calculate eigenvalues and associated eigenvectors. Under these conditions, the population distribution is considered to be stable if it increases without structure changes, that is, if the proportion of deer within each quality class remains constant over time. That stable population is closely dependent on births and natural deaths.

The second objective, is to develop a real density-dependent model which includes the population evolution depending on the competence. The total number of individuals over the years will be a sigmoid curve, which is usually followed by this kind of wild populations (Wang et al., 2002) using the carrying capacity (CC) and introducing the concept of Optimum Capacity (OC).

The third objective, is to describe a usable and easy method for field works, to identify the different groups to be controlled through the model, introducing quality classes for both sexes recognizable without capturing them, looking for a faster way to obtain data from a wild population, without reducing the efficiency and quality of the results.

In this context, the main purpose of the whole work is to estimate long-term evolution, sustainable harvest rates, and the optimum stable classes distribution, applied to an Iberian red deer population (*Cervus elaphus hispanicus*), all of this implemented through a density-dependent quality class projection matrix model, completing a tool for wildlife managers to guarantee sustainability when controlling deer populations.

3. Materials and methods

3.1. Study area and data

"Quintos de Mora" is a 6.864 ha fenced estate that keeps a classic Mediterranean vegetation cover, dominated by several species of *Quercus* sp. This vegetation is dominated, especially by holm oak (*Quercus ilex*) and Mediterranean scrub, co-existing with other tree species like oak (*Quercus pyrenaica*), (*Quercus faginea*) and pines (*Pinus pinaster*) (*Pinus pinea*), with an integration from an anthropic origin. Currently, the forest management has been carried out to improve the habitat for wildlife and to recover the natural ecosystem (Ministerio de Agricultura y Pesca and Alimentación y Medio Ambiente, 2017).The fence is not permeable to medium and large animals; and migration movements are not allowed. Despite the fence, this state has a great biodiversity and a huge variety of wildlife. Red deer is the most extended big game mammalian in the estate and the target of this study, but there are also other ungulates (Navarro Millas-Prendergast and Martín Fernández, 2015) like fallow deer (*Dama dama*), roe deer (*Capreolus capreolus*) and wild boar (*Sus scrofa*). Big predators are absent, only red fox could reduce the number of calves in the first few days, when they spend most of the time laying down in the underbrush (Montoya Oliver, 1999) as it has been studied in roe deer (Panzacchi et al., 2009).

The Biological values to carry out the model have been obtained from the actual management planning (Navarro Millas-Prendergast and Martín Fernández, 2015), and the data has been obtained through the staff working in the state during the last years. All this information includes population description as number of calves, yearlings, adults, and their death rates and birth rates which are required to complete the model. After processing all the compiled information, according to this study and supported by specialized bibliography (Soriguer, 1994; Montoya Oliver, 1999) and publications (Landete-Castillejos et al., 2004; Rodriguez-Hidalgo et al., 2010) an average biological values reference (Table 1), has been elaborated for a standard Iberian red deer population with density conditions below Optimum capacity, to introduce in the model.

The study's interest in the population is focused on densities below optimum capacity, where growth has no extra restrictions. Natality and mortality rates introduced in the model have been the highest real

Table 1
Biological values applied in the model below optimum capacity conditions.

Birth rate (Calves birth/Reproductive Female)	0.80
Birth sext ratio (M:F)	1:1
Females Calves death rate	0,12
Males Calves death rate	0,15
Young Females death rate	0,06
Young males death rate	0,10
Adult Females death rate	0,03
Adult Males death rate	0,05