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Conserving Iberian Lynx in Europe: Issues and challenges

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ABSTRACT

The world's most endangered feline species; the Iberian Lynx has suffered severe population decline and is now on the verge of extinction despite recovery plans. In this paper, an attempt has been made to understand the extinction dynamics of this endangered cat species. The paper focuses on the spread of rabbit haemorrhagic disease in the European rabbit population and its effect on the survival of the Iberian Lynx. A qualitative analysis of an eco-epidemiological model with simple law of mass action and Holling type II functional response is carried out.

Existence and uniqueness of solutions are established and shown to be uniformly bounded. The basic reproduction number R_0 is obtained and the occurrence of a backward bifurcation at $R_0 = 1$ is shown to be possible using central manifold theory. The global stability of endemic equilibrium is established using a geometric approach. Criteria for diffusion-driven instability caused by local random movements of European rabbits and Iberian Lynx are obtained. Detailed analysis of Turing patterns formation selected by the reaction-diffusion system under zero flux boundary conditions is presented. We found that diffusion coefficients and transmission rate have appreciable influence on spatial spread of the epidemic. Numerical simulation results confirm the analytical finding and generate beautiful patterns that are consistent with the field observations and suggest that Iberian Lynx might have become extinct from Portugal and neighbouring countries. Suggestions for disease eradication and its control which in turn may increase the population of Iberian Lynx are discussed.

1. Introduction

Life on Earth is dying at an unprecedented rate and the world is possibly heading towards sixth mass biological extinction (Dirzo et al., 2014). The Iberian Lynx, a vertebrate predator, has suffered severe population declines in the 20th century and is now on the brink of extinction (Palomares et al., 2011; Fordham et al., 2013). There are mainly four Lynx species in the northern hemisphere: European Lynx or Iberian Lynx (*Lynx Paradinus*), Eurasian Lynx (lynx lynx), Canadian Lynx (*Lynx canadensis*) and Bobcat (Lynx rufus). The Iberian Lynx, the largest wildcat in southern Europe, is exclusively found on the Iberian Peninsula (Palomares et al., 2005). The major decline of Iberian Lynx is closely associated with sharp reduction in European rabbit (*Oryctolagus cuniculus*) abundance (Rodriguez and Delibes, 2002), caused by *myxomatosis* virus in 1950s and more recently by Rabbit Haemorrhagic disease (RHD) (Delibes-Mateos et al., 2009). The Iberian Lynx and the European rabbit are closely related at broad spatial and temporal scales. Both originated in the Iberian Peninsula at approximately the same time and are linked to the western European Mediterranean environments (Branco et al., 2000; Johnson et al., 2004). The dramatic decline in rabbit population caused by RHD in 1980s, had a direct impact on Lynx numbers. Rabbit haemorrhagic disease is an infectious viral disease caused by the RHD virus (RHDV) (a member of the genus *Lagovires* and family Caliciviridae), and is mainly transmitted by direct contact with infected animals and kills up to 90% of infected rabbits more than 2 months old (Xu and Chen, 1989). This disease affects rabbits of the species *O. cuniculus*.

Rapid population declines and extinctions of animal and plant species have spurred ecologists and conservation biologists to consider the consequences of widespread destruction of natural habitats which have been reported across the globe (Brook et al., 2003) and suggest plans for conserving them. Our understanding of dynamics and causes of extinction remains incomplete even as the number of endangered and extinct species grows (Brook et al., 2008). The loss of species is expected to result in the loss of other species that depend on it (referred to as co-extinction), leading to cascading effects across trophic levels (Dunn et al., 2009) and may be the most common form of biodiversity loss. There are many causes that can contribute directly or indirectly to the extinction of a species or group of species. Diamond (1989) suggested that there

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are five drivers of extinctions. They are climate change, habitat loss, species invasion, overkill and cascades of extinctions or co-extinctions. Koh et al. (2004) defined co-extinction as the loss of one species as a result of extinction of a species it depends on and also estimated the frequency of co-extinction. It is a manifestation of the interconnectedness of organisms in complex ecosystems. The loss of species through co-extinction represents the loss of irreplaceable evolutionary and co-evolutionary history (Nee and May, 1997; Purvis et al., 2000). Examples of co-extinction are—Haast's Eagle may become extinct because its food source Moa becomes extinct; the extinct passenger pigeon (*Ectopistes migratorius*) and its parasitic louse (*Columbicola extinctus*) (Stork and Lyal, 1993); Iberian Lynx and European rabbit (Ferrer and Negro, 2004).

The inadequacies of the current management systems for endangered species become apparent when one considers the following fact. In the early 19th century, the Iberian Lynx was found in Spain, Portugal and southern France. It has continuously declined since then, falling to the dangerously low levels. IUCN's assessment in 2007 stated that the numbers were not sufficient for the survival of the species in the long term, putting this wildcat on the verge of extinction (Platt, 2011). The latest survey results from Spain suggest a minimum of 84 and maximum of 143 adults surviving in two breeding populations: in the Coto Doñana and near Andújar in the eastern Sierra Morena. The most recent evidence of the presence of Lynx in Portugal comes from the discovery of a scat in the Guadiana area in 2001, which was identified by molecular analysis (Pires and Fernandes, 2003). During the 1990s, a national survey based on personal interviews and dead animal records suggested a population of about 40–53 Lynxes fragmented in small subpopulations which spread over throughout 2400 km^2 in five different areas: Algarve mountains, Sado valley, Guadiana valley, Sera de Sao Mamede and Sera da Malcata. However, further local field surveys indicated the absence of resident animals, pointing to a pre-extinction scenario (Pinto, 2000; Fernandes et al., 2001; Sarmento et al., 2009). Such an unaffordable level of extinction calls for an in-depth study of the conservation strategies and plans. As a first step, it is necessary to study the basic principles on which these efforts are to be designed. In this paper, we design a deterministic eco-epidemic model to study the co-extinction dynamics of susceptible and infected rabbit population and Iberian Lynx, a specialist predator. A specialist predator dies out when its favourite food is absent or is in short supply while the generalist predator switches to an alternate food option as when it faces difficulty to find its favourite preys (Upadhyay and Iyengar, 2013). Therefore, the specialist predator is more prone to extinction as compared to the generalist predator. Upadhyay et al. (2001) have attempted to answer the intriguing question faced by the conservation biologists whether it is genetic or ecological factors responsible for the extinction of a species.

The main objective of this article is to understand the extinction dynamics of Iberian Lynx population caused by deadly rabbit disease in prey population. We also emphasize that the force of infection has an important contribution to the dynamics of this designed eco-epidemiological system. We explore the value for predator conservation by addressing the bio-geographical relationship between a species of great conservation concern, the Iberian Lynx, and its staple prey, the European rabbit. The paper is structured as follows. In next Section 2, we present the basic assumption for designing the model system. Section 3 presents the analysis of non-spatial model. Numerical simulation for non-spatial model is also presented in this section. Section 4 presents the stability analysis and diffusive instability of spatial model system. Simulation results for model with diffusion are presented in Section 5. Finally, Section 6 summarizes the main contributions of the work.

2. Basic assumptions and mathematical model

Calvete (2006) showed the impact of RHD on the dynamics of different classes of rabbit population (susceptible, infected, chronically infected and recovered class). Reddiex et al. (2003) studied the impact of predation and RHD on population dynamics of rabbits. In the present work, we have considered only the susceptible and infected rabbit populations and studied their impact on the dynamics of Iberian Lynx population. The primary goal of the model is to identify the mathematically viable conditions that determine whether the predator population, Iberian Lynx will be able to survive or becomes extinct. The model considers the fact that rabbit is the only food for Iberian Lynx and it depends on it for its survival. We also assume that the predators cannot distinguish between infected and susceptible populations, so that predator species consumes the prey species (susceptible as well as infected) according to the Holling type II functional response. However, in the absence of prey, the predator population decays exponentially as it is a specialist one. Under the above assumptions, the model is governed by the autonomous non-linear differential equations.

$$\frac{\mathrm{d}S}{\mathrm{d}t} = rS\left(1-\frac{S}{K}\right) - \beta SI - \frac{\omega_1 SP}{S+d_1} - \eta S = Sg_1(S,I,P) = f_1(S,I,P), \tag{1a}$$

$$\frac{\mathrm{d}I}{\mathrm{d}t} = r_1 I\left(1-\frac{I}{K}\right) + \beta SI - \frac{\omega_2 IP}{I+d_2} - \gamma I = Ig_2(S,I,P) = f_2(S,I,P), \tag{1b}$$

$$\frac{\mathrm{d}P}{\mathrm{d}t} = \frac{\omega_3 SP}{S+d_1} + \frac{\omega_4 IP}{I+d_2} - cP = Pg_3(S,I,P) = f_3(S,I,P), \tag{1c}$$

with $S(0) = S_0 > 0$, $I(0) = I_0 > 0$ and $P(0) = P_0 > 0$.

All parameters involved in the model system are positive. The infected class suffers loss through disease induced mortality. Virus transmission causes loss of susceptible (S) and gain in infected (I) population. We assume vertical virus transmission; hence reproduction by infected yields infected and reproduction by susceptible yields susceptible offspring (see Fig. 1). Further, we also assume that both prey and predator populations perform active movements in x and y directions which have been ignored in previous researches and is biologically relevant. Random movement of animals occurs because of various requirements like, search for better food, better opportunity for social interactions such as finding mates (Okubo and Levin, 2001) etc. Food availability and living conditions demand that these animals migrate to other spatial locations. In the proposed model, we have included diffusion term to assume that the animal movements are random and uniformly distributed in all directions.

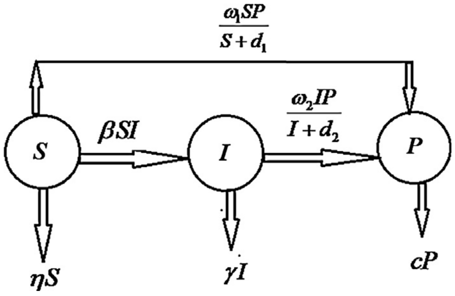

Fig. 1. Schematic diagram for the eco-epidemic model (1).