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Analysis of a prey-predator model with prey refuge in infected prey and strong Allee effect in susceptible prey population	S. Saha, **A. Maiti**, G.P. Samanta	Mathematics	Discontinuity, Nonlinearity and Complexity	2022	2164-6414
A Competition Model with Herd Behaviour and Allee Effect	P. Sen, **A. Maiti**, G.P. Samanta	Mathematics	Filomat	2019	0354-5180
Analysis of a predator-prey model for exploited fish populations with schooling behavior	D. Manna, A. Maiti, G.P. Samanta	Mathematics	Applied Mathematics and Computation	2018	0096-3003
A Michaelis–Menten Predator–Prey Model with Strong Allee Effect and Disease in Prey Incorporating Prey Refuge	S. Saha, A. Maiti, G.P. Samanta	Mathematics	International Journal of Bifurcation and Chaos	2018	0218-1274
Deterministic and stochastic analysis of a predator–prey model with Allee effect and herd behaviour	D. Manna, A. Maiti, G.P. Samanta	Mathematics	Simulation: Transactions of the Society for Modelling and Simulation International	2018	0037-5497
Effects of Fear and Additional Food in a Delayed Predator–Prey Model	S. Mondal, A. Maiti, G.P. Samanta	Mathematics	Biophysical Reviews and Letters	2018	1793-0480

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Analysis of a predator-prey model for exploited fish populations with schooling behavior

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ABSTRACT

In this paper, a predator-prey model for exploited fish populations is considered, where the prey and the predator both show schooling behavior. Due to this coordinated behavior, predator-prey interaction occurs only at the outer edge of the schools formed by the populations. Positivity and boundedness of the model are discussed. Analysis of the equilibria is presented. A criterion for Hopf bifurcation is obtained. The optimal harvest policy is also discussed using Pontryagin's maximum principle, where the effort is used as the control parameter. Numerical simulations are carried out to validate our analytical findings. Implications of our analytical and numerical findings are discussed critically.

1. Introduction

It is a fact that many fish species live in groups. They enjoy many benefits from living in groups, such as higher success in finding mates, reduction in the risk of predation, increase in the foraging success, protection from bad weather, etc. Such collective behaviors are of two types, one is *shoaling* and the other is *schooling*. When members of a group swim independently in such a way that they stay connected, then this behavior is known as *shoaling*. If all members are swim in the same direction in a coordinated fashion with same speed then such a behavior is called *schooling*. Schooling fishes are usually of the same species and of the same size. Again shoalers and schoolers are of two types. *Obligate* shoalers or schoolers exhibit shoaling or schooling behavior all the time. *Facultative* shoalers or schoolers show collective behavior for finding mates or some other reasons [25]. Schools that are traveling can form thin lines, or squares or ovals or amoeboid shapes.

Usually interactions of different species take several forms, depending on whether the influences are beneficial or detrimental to the species involved. Among these interactions, predator-prey relationship is considered to be an extremely important one. It is true that the preys always try to develop the methods of evasion to avoid being eaten. However, it is certainly not true that a predator-prey relationship is always harmful for the preys, it might be beneficial to both. Further, such a relationship often plays an important role to keep ecological balance in nature. Mathematical modeling of predator-prey interaction was started in the 1920s. Interestingly, the first predator-prey model in the history of theoretical ecology was developed independently by Lotka (a US physical chemist) and Volterra (an Italian mathematician) [17,29]. Subsequently,

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A Michaelis–Menten Predator–Prey Model with Strong Allee Effect and Disease in Prey Incorporating Prey Refuge

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Here, we have proposed a predator–prey model with Michaelis–Menten functional response and divided the prey population in two subpopulations: susceptible and infected prey. Refuge has been incorporated in infected preys, i.e. not the whole but only a fraction of the infected is available to the predator for consumption. Moreover, multiplicative Allee effect has been introduced only in susceptible population to make our model more realistic to environment. Boundedness and positivity have been checked to ensure that the eco-epidemiological model is well-behaved. Stability has been analyzed for all the equilibrium points. Routh–Hurwitz criterion provides the conditions for local stability while on the other hand, Bendixson–Dulac theorem and Lyapunov LaSalle theorem guarantee the global stability of the equilibrium points. Also, the analytical results have been verified numerically by using MATLAB. We have obtained the conditions for the existence of limit cycle in the system through Hopf Bifurcation theorem making the refuge parameter as the bifurcating parameter. In addition, the existence of transcritical bifurcations and saddle-node bifurcation have also been observed by making different parameters as bifurcating parameters around the critical points.

Keywords: Allee effect; Michaelis–Menten functional response; prey refuge; global stability; extinction.

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Effects of Fear and Additional Food in a Delayed Predator–Prey Model

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A field observation on a terrestrial vertebrate has shown that the fear of predators can affect the behavior of prey populations and it can greatly reduce their reproduction. On the other hand, it has been observed that providing additional food to the predator decreases the predatory attack rate and increases the growth rate of the predator. In this paper, we have investigated the dynamical behavior of a predator–prey model incorporating both the effects of fear and additional food. Positivity, uniform boundedness and extinction criteria of the system are studied. Equilibrium points and their stability behaviors are also discussed here. Existence of a Hopf-bifurcation is established by considering the level of fear as bifurcation parameter. The effect of time-delay is discussed, where the delay may be considered as gestation time of the predator. Numerical simulations are performed using MATLAB to verify our analytical findings.

Keywords: Predator–prey interaction; fear effect; additional food; time-delay; Hopf-bifurcation.

1. Introduction

The effect of fear has an important role in ecology and evolutionary biology. The fear of predators may affect the physiological condition of the prey and it may cause

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Deterministic and stochastic analysis of a predator–prey model with Allee effect and herd behaviour

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Abstract

This paper aims to study the dynamics of a predator–prey model, where both prey and predator show herd behaviour. Due to this behaviour, predator–prey interaction occurs only at the outer edge of herds formed by the populations. Positivity and boundedness of the system are discussed. A criteria for the extinction of prey is established. A steady-state analysis has been performed. Some criteria for Hopf bifurcation are derived. The stochastic version of the model is formulated to take into account the effect of fluctuating environment. A criterion of asymptotic mean square stability of this model is derived. Numerical simulations are carried out to validate our analytical findings. Implications of our analytical and numerical findings are discussed critically.

Keywords

Prey–predator system, stability, herd, stochastic, Hopf bifurcation

1. Introduction

Interaction between a prey and its eater has always received substantial attention from ecologists. Explaining such interaction in mathematical terms is still a fascinating area of research today. The persons who first kindled the discussion were the great Italian mathematician Vito Volterra (1860–1940) and the renowned US physical chemist Alfred James Lotka (1880–1949), and it is really interesting that Volterra and Lotka independently developed the first predator–prey model. Lotka proposed the model in 1925 to describe the ineraction of a plant population and a herbivorous animal that feeds on it.[1] On the other hand, Volterra derived the same model in 1926 to describe the interaction between sharks and fishes in the Adriatic sea.[2] Their model is known as the *Lotka–Volterra model*.

If $X = X(t)$ denotes the density of the prey population and $Y = Y(t)$ the density of the predator population at time t, then the Lotka–Volterra model can be described under the framework of the following system of ordinary differential equations:

$$\frac{dX}{dt} = rX - \alpha XY$$
$$\frac{dY}{dt} = -dY + \beta\alpha XY$$

where $r, \alpha, \beta, d > 0$. Here r is the growth rate of the prey in the absence of the predation, d is the mortality rate of the predator, α is the search efficiency (attack rate) of the predator, and β is the conversion factor (for converting prey biomass into predator biomass).

In the Lotka–Volterra model, it is assumed that the prey population has ample food resources and will grow exponentially in the absence of the predator (as seen from the first equation that $X'(t) = rX(t)$, so that $X(t) = X_0e^{rt}$). However, it is well known that the resources are limited in nature. Therefore, a model with *logistic growth* in prey is thought to be logically justifiable.

The *logistic growth function* was derived by the Belgian mathematician Pierre Francois Verhulst (1804–1849) in 1838. Unfortunately, the work of Verhulst went unappreciated during his own lifetime and he died in relative obscurity.[3] In 1920, the logistic growth function was rediscovered by the American biologists Reymon Pearl and

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A Competition Model with Herd Behaviour and Allee Effect

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Abstract. In this work we have studied the deterministic behaviours of a competition model with herd behaviour and Allee effect. The uniform boundedness of the system has been studied. Criteria for local stability at equilibrium points are derived. The effect of discrete time-delay on the model is investigated. We have carried out numerical simulations to validate the analytical findings. The biological implications of our analytical and numerical findings are discussed.

1. Introduction

In many situations, two or more species live in proximity and share the same basic resources (such as food, water, habitat, or territory). As these resources are not unlimited, therefore it is quite obvious that these species might have to fight for these. *Competition* among organisms or species can be defined as an interaction in which the fitness of one is diminished by the presence of the other [10]. Competition among individuals of the same species is called *intraspecific competition*. On the other hand, *interspecific competition* is the competition between individuals of different species. The so called *Competitive exclusion principle* (or *Gause's law of competitive exclusion* [26]) states that stronger (or best suited) species will always dominate the weaker (or less suited) leading to either the extinction of the weaker or an evolutionary or behavioral shift toward a different ecological niche. But there are many evidences where this principle fails, the best known example being the *paradox of plankton* [31].

So far as the growth of a single-species population is concerned, it has long been recognised that the famous *logistic growth function* is a logical choice. The function is introduced in 1838 by the Belgian mathematician Pierre Francois Verhulst [57] and later it is rediscovered in 1920 by American biologists Reymon Pearl and Lowell Reed [43]. If $X(T)$ denotes the population density at time T, then the logistic growth equation is given by

$$\frac{dX}{dT} = rX\left(1 - \frac{X}{K}\right), \tag{1}$$

where r is the intrinsic per capita growth rate and K is the carrying capacity of the environment. The logic behind this is very simple. As the resources (e.g., space, food, essential nutrients) are limited, every

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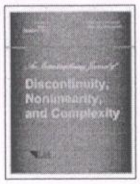

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Analysis of a Prey-predator Model with Prey Refuge in Infected Prey and Strong Allee Effect in Susceptible Prey Population

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Abstract

An eco-epidemiological predator-prey model with Holling type-II functional response is proposed in this work. In the presence of disease, the prey population has been divided into two subpopulations: susceptible and infected prey. The predator can access the full healthy prey population for hunting but a predator is provided with a fraction of the infected prey as infected prey refuge term is incorporated here. Also, a strong Allee effect in susceptible population is introduced to make the model more realistic. Boundedness and positivity of the system strengthen that the proposed model is well-posed. The strong Allee threshold and the infected refuge parameter have been taken as the key parameters to control the system dynamics. The numerical simulation gives that regulating the refuge parameter can turn an oscillating state into a stable coexistence state. Also, the system changes its dynamics from two interior equilibrium points to no interior point when this refuge parameter crosses the saddle-node bifurcation threshold. Besides, the strong Allee threshold can also change the dynamics of a system from oscillating state to steady-state through Hopf bifurcation.

1 Introduction

Nowadays, Mathematical Biology is one of the popular research fields. Malthus, in early 19^{th} century, first initiated to present dynamics of the population through mathematical models by developing Malthusian (or exponential growth) model. Later, in the situation when the per-capita population growth rate is positive, Verhulst modified this model by introducing an inhibiting term to take into account the competition for resources among members of the population and this model is called a logistic model. The first predator-prey model was introduced by Alfred James Lotka, an American biophysicist and Vito Volterra, an Italian mathematician [1,2]. Later, an enormous number of mathematical models have been refined from the Lotka-Volterra model to overcome its weakness and many factors have been incorporated to make it more realistic [3–9].

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