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Conservation of degraded wetland system of Keoladeo National Park, Bharatpur, India

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ABSTRACT

The most common threats to wetlands and the Keoladeo National Park are water scarcity, changing biodiversity, increasing rate of contamination, uncontrolled growth of grass, urbanization and human intervention. In this paper, an attempt has been made to study the degradation and conservation of biotic part of the park through a reaction diffusion modeling. The biotic part of wetland is divided into three categories good biomass, bad biomass, and bird population. Good biomasses are those species that provide food for bird population and contain floating vegetation, fishses, waterfowl and useful species. Bad biomasses contain *Paspalum distichum* and its family that affect the growth of good biomass. The interaction between good biomass and bird population is considered to be Crowley–Martin type functional response. We have presented the theoretical analysis of stability and Turing instability. With the help of numerical simulations, we have observed spatial patterns for the wetland model system. This study demonstrates that spatial heterogeneity, diffusion coefficients and per capita availability of water to bad biomass play an important role on the dynamical behavior of the model system. Also, we have pointed out the parameters that are responsible for the bad health of wetland ecosystem and suggested enhancing the water supply, decontamination and optimizing the land use structure for sustaining ecological balance and socio-economic stability of a region.

1. Introduction

The ecological health of Keoladeo National Park (KNP) has been major concerns in India as it has figured in the list of Ramsar convention. The wetlands throughout the world and their ecosystems are suffering from environmental degradation like water scarcity, changing biodiversity, increasing rate of contamination, uncontrolled growth of grass, urbanization, pollution, disruption of breeding ground, imbalance in sediment load and nutrient filtration (Ramsar Convention Secretariat, 2011). According to the Millennium Ecosystem Assessment (MEA) (MEA, 2005), wetlands deliver a wide range of ecosystem services that contribute to human well-being, such as fish and fiber, water supply, water purification, climate and flood regulation, coastal protection, recreational opportunities, and, increasing tourism. The degradation of wetlands is more rapid than that of other ecosystems. Similarly, the status of both freshwater and coastal wetland species is deteriorating faster than those of other ecosystems. Wang et al. (2008) analysed the current status of Chinese wetland protection and utilisation and concluded that it will be necessary to develop a practical method for developing patterns of appropriate economic application of wetlands and establishing a rational and scientific assessment system. Nobre (2011) reviewed the scientific approaches to address challenges in coastal management and to restore wetlands in spite of urbanization and rapid industrialization which supports ecotourism. Junk (2013) discussed the current state of knowledge about the occurrence, structures, and functions of the different wetland types varies considerably between regions, but in many cases it is insufficient to contribute to the development of a modern policy for the sustainable use and protection of wetlands. Ramírez and Fennell (2014) examine the wetland utilization and protection through the lens of ecotourism and presented a comprehensive framework for ecotourism and wetland restoration in the case of Bogotá, Colombia. Xu and Wall (2007) studied the ecotourism in Yancheng wetland, China and suggested that the educational programmes should be provided for local people concerning the nature of ecotourism, its potential benefits, and the value of protecting the environment. Their main concern was how to protect ecotourism while paying due consideration to the interests of local inhabitants. Chatterjee et al. (2015) have made assessment of environmental factors causing wetland degradation using Fuzzy analytical network process.

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There must be a balance between available oxygen and the demand for it. Fishes, plants and aerobic bacteria all require oxygen for respiration. For the aquatic life, available oxygen means dissolved oxygen from the air plus oxygen produced by aquatic plants, algae, and phytoplankton as a by product of photosynthesis. *Paspalum distichum* and its family are the dominated species in Keoladeo National Park that deplete the oxygen (Patra et al., 2017) and affects the survival of other species of floating vegetation, fishes and waterfowl, etc. Sharma et al. (2015) studied the impact of hydrological changes on the biodiversity of KNP and their impact on ecotourism and suggested that some action should be taken by Government for maintaining the healthy and compatible ecological system for migratory birds. Species which are key players for an aquatic body are macrophytes, fishes and birds. The aquatic macrophytes are grouped into three categories, emergent, submerged and floating. Submerged aquatic vegetation (SAV) is an important source of oxygen which provides food and shelter for fish, shellfish and invertebrates. The DO, BOD and COD concentrations are varied in the ranges 3.3–4.8 mg/lt, 0.24–3.48 mg/lt and 7.5–34.16 mg/lt respectively. The physio-chemical and biological parameter for KNP such as the hydrogen-ion concentration (pH), turbidity, electrical conductance, salinity, TSS and TDS were found to be in ranges 7.6–7.9, 2.15–38.4 NTU, 867–1358 mg/lt, 160–205 mg/lt, 27.5–49.16 mg/lt and 492–674.66 mg/lt respectively (Choudhary and Nama, 2014).

Keoladeo national park (KNP) is one of the world heritage sites situated in Bharatpur, Rajasthan, India. This man made park was declared as national park in 1981 and spread in about 28.73 km^2; 11 km^2 is covered by marshes and the rest is covered by scrubland and grassland (Upadhyay et al., 2014). This famous avifauna sanctuary hosts almost thousands of birds especially in winter season. Wetlands provide critical habitat for waterfowl including ducks, egrets, geese and migratory birds. The fauna includes more than 350 species of birds which include 42 species of raptors and 9 species of owls, 27 species of mammals, 13 species of reptiles, 7 species of amphibians, 58 species of fishes and 71 species of butterflies, more than 30 species of dragonflies and more than 30 species of spiders inhabit the park. KNP is often referred as Birds Paradise due to the abundance of the birds (Sharma, 2015). The deepest zones of the wetland park was characterized by floating marsh during the 1980 and involved submersed species like *Hydrilla verticillata*, floating-leaved species such as *Nymphoides cristatum* and grasses such as *Paspalum distichum*, all species with very low root biomasses (Van der Valk et al., 1993; Middleton et al., 2015). From last decade, the number and variety of migratory birds used to come in KNP has been decreasing continuously due to deprived ecology which is very serious concern. It has been observed that population of Siberian crane reduced sharply which were 100 in 1970, was two in 2002 and completely absent after 2004 (Rosewarne and Envis, 1997). Migratory birds are main attraction of ecotourism. Diversity as well as the tourism are affecting due to this serious concern of decreasing number of migratory birds. Biological invasions are currently regarded as a major threat to biodiversity and agriculture all over the world, often resulting in huge economic losses (Petrovskii and McKay, 2010). Due to uncontrolled expansion of the *Eleocharis plantagenia*, *Paspalum distichum*, *Typha angustata* and *Vetiveria zizanoides* communities, KNP experienced considerable change in whole character (Reddy et al., 2011).

Several theoretical works and field studies on this park has been done by Beth A. Middleton and her co-workers. Middleton and Van der Valk (1987) studied the food habitats of *Greylag* and *Barheaded* geese and suggested that geese choose more nutritious food prior to migration or to breeding. Later on in 1992, Middleton (1992) constructed goose management plans for *Greylag* and *Barheaded* geese over wintering in the Keoladeo National Park and other parts of Northern India. Middleton (2009) also prepared a brief survey report on the vegetation status of the Keoladeo National Park and suggested that the hydrologic fluctuation drives vegetation change in monsoonal wetlands. Modeling aspects on this park by constructing several predator–prey type models has been studied by many scientists from Indian sub-continent including our group. Shukla and Dubey (1996) proposed a model to study the effect of ecological changes due to excessive growth of wild grasses, *Paspalum distichum* in KNP, Rajasthan, India. Shukla (1998) re-investigated this model to study the effect of *Paspalum distichum* on the growth of other macrophytes. Rai (2008) proposed and analyzed a model for wetland part of KNP from ecological as well as economical point of view with Holling type II functional response. Rai et al. (2011) try to understand the relevant dynamical processes in the physical systems in natural as well constructed wetlands with the help of the proposed model. Upadhyay and Tiwari (2013) studied the emergence of spatial patterns in a model proposed by Rai (2008). Upadhyay et al. (2014) have extended the model proposed by Rai (2008) by including Beddington–DeAngelis (BD) type functional response in place of Holling type II functional response in situations where predator interference is minimal. They have shown that per capita rate of predation to be a function of intensity of interference among individuals of predator populations which decides the dynamics of the wetland park. Recently, Patra et al. (2017) studied and analyzed the degradation and conservation of Keoladeo National Park through a temporal model with Crowley–Martin functional type response among the species interaction. Most of the above cited works deal with the temporal dynamics on the temporal model systems. In the present work, we have modified the model proposed by Patra et al. (2017) by including the spatial heterogeneity which affects the growth of logistically growing good biomass population and the diffusion to assume that the good biomass and bird population movement are random and uniformly distributed in all directions. We also assume that there is no movement of bad biomass from one place to another in the wetland. Therefore, we only consider the reaction term for the rate equation of bad biomass. We have tried to establish the reaction-diffusion model with Crowley–Martin type functional response for revealing the degradation of biotic part of wetland ecosystem in KNP, India and its possible restoration.

In this paper, we have proposed a reaction-diffusion model by considering the entire species which are grouped into three categories (i) good biomass, (ii) bad biomass and (iii) avian predators (resident as well as migratory birds). The good biomass, which consists of fishes and a few plant species eaten by small fishes, serves as food for birds. *Paspalum distichum* and its family that affects the growth of good biomass are termed as bad biomass. Our objective is to study the degradation and conservation of biotic part of wetland park. We will also study the role of space (i.e. diffusion coefficients) as well as per capita availability of water to the bad biomass on the ecological dynamics of the park in the presence as well as absence of spatial heterogeneity. The paper is organized as follows. In Section 2, we discuss the model system. Under the Section 3, the stability analysis along with Hopf bifurcation and Turing instability has been carried out. Section 4 depicts the numerical results. Finally, discussions and conclusions are presented in the last Section.

2. Development of the proposed spatiotemporal model

A reaction-diffusion model was proposed by Rai et al. (2011) among good biomasses, bad biomasses and bird population and suggested that two primary ecological factors are responsible for degradation of natural wetland. Upadhyay et al. (2014) have proposed a reaction-diffusion model of biotic interaction of KNP with mutual interference and figured out that the interference