DYNAMICAL SYSTEM STUDIES IN MODEL ECOSYSTEMS

by

Ranjit Kumar Upadhyay

DEPARTMENT OF MATHEMATICS

Submitted

in fulfilment of the requirements of the degree of
Doctor of Philosophy

to the

INDIAN INSTITUTE OF TECHNOLOGY, DELHI
INDIA
OCTOBER, 1999

DEDICATED

TO MY (Late) MOTHER . . .

CERTIFICATE

This is to certify that the thesis entitled

"DYNAMICAL SYSTEM STUDIES IN MODEL ECOSYSTEMS"

which is being submitted by **RANJIT KUMAR UPADHYAY** *for the award of the degree of* **DOCTOR OF PHILOSOPHY in MATHEMATICS** *to the* **INDIAN INSTITUTE OF TECHNOLOGY, NEW DELHI,** *is a bonafide record of research work done under my guidance and supervision.*

The thesis has reached the standard fulfilling the requirements of the regulations relating to the degree. The results obtained in this thesis have not been submitted to any other University or Institute for the award of any degree or diploma.

S. R.K. Iyengar

(S. R. K. Iyengar)

Professor

Department of mathematics

Indian Institute of Technology

Hauz Khas, New Delhi-110 016, INDIA

ACKNOWLEDGEMENTS

At the zenith of ecstasy, I am filled with a great sense of gratitude to all those who helped in making this endeavour of mine a reality and a dream come true. This thesis is the beginning of a new era in my life.

It gives me great pleasure to express my deep sense of gratitude to my supervisor Professor S. R. K. Iyengar, Department of Mathematics, IIT, Delhi for his valuable guidance and encouragement and his presence as a beacon of knowledge, towards the successful completion of my doctoral thesis.

I take this opportunity to express my profound sense of respect and sincere gratitude to Dr. Vikas Rai, Delhi College of Engineering, Delhi, under whom I had the priviledge to enhance my learning.

I extend my regards to my earlier guide Professor (late) Rama Shankar, Prof. O. P. Bhutani, Prof. K. N. Mehta, Prof. R. K. Jain, Prof. J. B. Srivastava, Prof. Suresh Chandra, A. Nagabhushanam, Dr. S. Chandra Shekhar Rao, Dr. Niladri Chatterjee and other faculty members of the Mathematics Department, IIT, Delhi for their tremendous support and help through out the period of my research work. I also extend my regard to Prof. P. C. Sinha, Prof. Maithili Sharan, Prof. S. K. Dubey, Prof. Girija Jayaraman from CAS, IIT Delhi.

I am thankful to the Prof. (Dr.) R. C. Bahl, Principal, S. B. S. College of Engg. and Technology, Ferozepur, for providing me the research facility to undertake this research work.

To my father I owe more than I can possibly express. My sister-in-law, Nanda deserves all praise and sincere appreciation for putting up cheerfully with all the inconveniences and hardships during my absence from home. Finally, I sincerely thank all my friends and colleagues, especially D. K. Tiwari, Karanjeet singh, Shalini Arora, Anamika, Samanta, Indivar, Ravi seth, Mr. Davinder, Dr. I. Bhattacharya, Dr. A. K. Tyagi, Mr. Kulbhushan and Mr. Rakesh Kumar for their encouragement and help throghout my studies.

I am grateful to the American Institute of Physics for providing a copy of the ODE workbench for conducting the numerical experiments.

(Ranjit Kumar Upadhyay)

ABSTRACT

This thesis, entitled **"Dynamical System Studies in Model Ecosystems"**, is a study of Chaos, Stability, Complexity and effect of perturbations in model ecosystems. The subject matter has been divided into seven chapters. We have studied the following aspects of the dynamical behaviour in model systems.

(i) An attempt is made to understand why chaotic dynamics has received poor evidential support from field studies. The reasons for the failures of the attempts to observe chaos in natural populations are studied. A new technique (Pseudo-prey method) is used to study the dynamical behaviour of the 3D nonlinear systems.

(ii) Four model systems which describe some of the common ecological situations in terrestrial ecology are studied to answer the question whether an ecosystem evolution is chaotic in certain situations.

(iii) Using some model systems, we tried to answer the following question: Is complexity necessary for the stability of an ecosystem ? In this context, we also need to consider the following : (a) Does the structural complexity guarantee structural stability?

(b) What is the relationship between structural stability and dynamical complexity ?

(iv) Some issues regarding the effects of genetic and ecological factors on the extinction of species in ecological systems are studied.

(v) The influence of environmental perturbations (seasonal and sudden) on the evolutionary modes of the model ecosystems are studied.

(vi) Eight 2D and 3D model systems and their perturbed versions are studied to determine (a) whether stable regions or part of the stable regions are converted into chaos due to seasonal perturbations, and (b) whether part of the chaotic regions are dragged (converted) into stable regions.

Numerical simulation studies using the bifurcation diagrams, calculation of basin boundaries, two dimensional parameter scans etc., are made and the following conclusions are drawn from these studies:

(i) Crisis limited chaotic dynamics was found to be the primary cause for the existence

of chaos in very narrow ranges of the parametric values.

(ii) The study suggests that the possible cause for the failure of the attempts to observe chaos in natural populations, might not be the poor quality of data but may be an ecological reality.

(iii) It is found that chaos exists in narrow ranges of parameter values. It was concluded that the existence of chaos in narrow parameter ranges might have been caused by the crisis induced sudden death of the chaotic attractors.

(iv) The model systems with interference among individuals of predators do not support chaotic dynamics at all. Even stable limit cycle solutions are not observed. At best, some model systems admit chaotic solutions in very narrow parameter regimes as well as in regions of natural measure zero. We conclude that for the corresponding real systems, chaos may not be a suitable representation of the system dynamics.

(v) Basin boundary structures provide a qualitative idea of the dynamical complexity of a system. The results obtained for the model systems indicate that structural complexity is not essential for dynamical complexity to exist. For systems which possess smooth basin boundaries with one of the attractors existing in a narrow parameter range, it is difficult to discuss its stability. In certain cases, when riddled basins are found, even qualitative predictability is denied.

(vi) In the case of the species extinction problem the simulation experiments suggest that both the factors, genetic and ecological, are important and that they should be given suitable weightage in working out strategies for any conservation efforts. A general conclusion which emerges from this study is that the species belonging to the higher life form, especially, generalist predators are less prone to extinction in comparision to those which are placed in the interior of the food-chain. The sexually reproducing predators bring stability, diversity and thus prosperity to the terrestrial ecosystems.

(vii) Sudden perturbations are found to influence the dynamical modes significantly. The co-existence of two or more distinct attractors for the same set of parametric values suggest that sudden environmental disturbances may alter the dynamical regimes of these systems. Two dimensional parameter scans suggest that even a smooth (seasonal) perturbation which bring changes in system parameters and thus decide different dynamics, are able to induce variations in these modes frequently. The analysis suggests that the influence of sudden and unforeseen perturbations on the ecosystem dynamics can be controlled provided the dynamical complexity is under control.

(viii) Seasonally induced perturbations of weaker strength are found to transform stable limit cycle attractors into chaotic ones in the case of the two-dimensional systems. Strong perturbations are required to effect the same in the case of the three dimensional ecosystems. In both the 2D and 3D systems, chaotic attractors were not destroyed by the influence of seasonality. These results may be helpful in working out strategies for the management of man made and natural ecosystems involving economically important species.

Contents