Chaos in Ecology

Emily Taft, Katherine Wilsey, and Dr. Amina Eladdadi, Department of Mathematics

{tafte566, wilseyk593, eladdada} @strose.edu

ABSTRACT

Dynamical systems include mathematical models that are of great use and importance in ecology. Chaos theory studies the behavior of dynamical systems that are highly sensitive to initial conditions. Chaotic behavior can be observed in many natural systems. The predator-prey mathematical population model can be used to analyze the effects one species has on another in a certain ecosystem, and also to determine any chaotic behavior in the species population. In this study, we examine actual data of Nile perch being introduced into Lake Victoria, their effects on the population of cichlids, and any chaotic behavior that occurs.

INTRODUCTION

The Nile perch is an enormous fish native to the Ethiopian region. This fish was introduced to East Africa's Lake Victoria in an effort to boost the fisheries production of the lake. A dramatic increase in population size of the Nile perch coincided with a drastic decline or disappearance of many indigenous species.

Fisheries based on non-native or introduced fish species in many aquatic environments have been of great interest to scientists. They study aspects from species' establishment and performance in their new habitats, to environmental impact, and socioeconomic benefits.

The introduction of the Nile perch resulted in a fivefold increase in the amount of fish protein available to local communities. This consequently increased income and employment opportunities. Fish catches from Lake Victoria made up more than 90% of the regions total fisheries production.

The tremendous increase in the Nile perch resulted in drastic changes in the ecology of the lake. Prior to the introduction of this non-native species the Lake had a very diverse fish fauna with over 28 species. One of the most popular was the cichlid fish family. The cichlids have the ability to adapt to a wide range of conditions. With a high level of adaptability and ecological versatility one would consider them to have a level of protection against extinction. However, upon introduction of the Nile perch this cichlid fish population began to decline drastically. This is clear indication of the magnitude of change that has taken place within Lake Victoria.

MATERIALS AND METHODS

The predator-prey system model describes the population growth of two species. One species known as the prey provides sustenance for the other, the predator. This model allows one to analyze how a population will either grow or decay exponentially. The linear prey-predator model a relationship between two interacting species is as follows.

$P_{n+1}=r_1P_n-s_1Q_n$

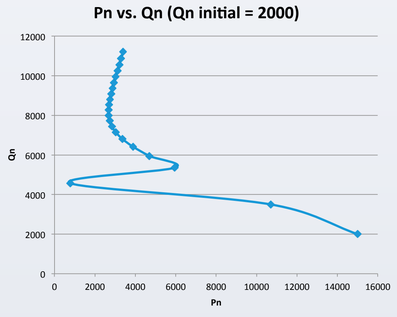
$Q_{n+1}=s_2P_n+r_2Q_n$

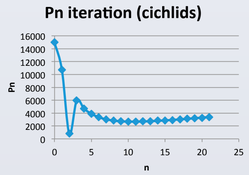
P_n is representative of the prey and Q_n of the predator. The r value is defined as the intrinsic growth rate and all of the parameters are non-negative. This prey-predator system is classified as linear, for each of its two equations is a linear function of its two variables. If the system were to undergo immigration a constant, k, would be added to the equation. Similarly, if the population were to experience migration or harvesting, a constant would be subtracted from the equation. This system indicates the iteration of two equations for two interacting quantities P_n and Q_n that evolve over time. It is important to note that the number of equations usually matches the number of variables. In an effort to iterate the system the pair of initial conditions must be known.

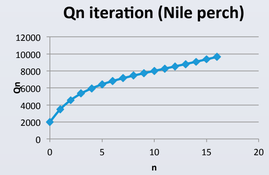
We further implored the concept of initial condition sensitivity in relation to chaos. Solutions that begin close to one another may lead to very different dynamics. The behavior is unique and unpredictable. When dealing with a stable fixed point or periodic cycle the long term or asymptotic behavior of the set of solutions can be predicted. However, with a scrambled set there exist an infinite number of different asymptotic behaviors. Thus to determine the dynamics for any particular X_0 one must use direct numerical iteration. The true initial X_0 can never really be known, implying long-term predictions in modeling are virtually impossible. With each step of the iteration any specific predictions become increasingly inaccurate. Thus the model is too sensitive to make practical long term predictions. This sensitive dependence is commonly referred to as the butterfly effect. For in theory the motion of the butterfly's wings could have an effect on weather conditions, which we consider chaotic behavior.

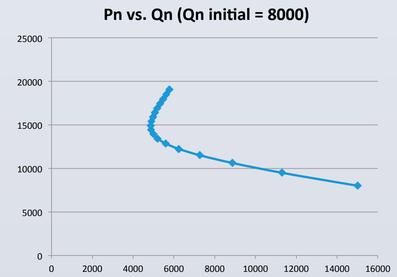
RESULTS

To see what results the system would yield an Excel file was created. In the first graph two species populations, the Nile perch and the cichlids were plotted against each other. This visual allows one to see clearly how the Nile perch population grew, while the cichlid population declined. Another graph was created in an effort to show the importance of initial condition sensitivity. Various initial conditions were plotted and tried to see how altering their values would change the outcome.









CONCLUSIONS

Studying this mathematical model we gained a deeper understanding for the sensitivity of the initial population. Relating the model to a real-life ecological concern, we learned of the affects of adding just one non-native species to a Lake. The chaotic behavior and unpredictability found within ecology is truly fascinating! We encountered difficulties in finding real Nile perch data and realized thus how hard it is for scientist to predict the future of the lake.

The situation in Lake Victoria appears to be a double edged sword. "Some have decried the loss of Lake Victoria's native species, while others praise the introduction of the Nile perch (Kaufman)." Clearly the importance of biodiversity comes into question when a commodity of value appears in its place. There are many factors all of which are altered by the addition of this one species. Lake Victoria experienced the appearance of high algae blooms associated with lower oxygen levels. However, it is important to realize that human intervention is not the only cause of a changing ecosystem. Shifting continents have the ability to shift the earth's flora and fauna. There are collisions with extraterrestrial debris and obviously naturally occurring events such as hurricanes, volcanoes, predator outbreaks, and disease.

The collapse of the species-rich ecosystem of Lake Victoria replaced by a simplified community raises numerous questions and concerns. The answers must address the dynamics of speciation extinction, the knowledge of non-native introductions and the practices of fisheries.

The predator-prey model can be advantageous to scientists analyzing species populations; however there are numerous variables to consider. One such being mother nature, whose chaotic behavior one can never truly predict!

REFERENCES

Hastings, Alan. Chaos in Ecology: Is Mother Nature a Strange Attractor? *Annual Review of Ecology and Systematics* © 1993 pg.1-33

Kaufman, Les. Catastrophic Change in Species-Rich Freshwater Ecosystems. The Lessons of Lake Victoria; BioScience; Dec-1992 Research Library Core pg.846

http://www.annualreviews.org/doi/abs/10.1146/annurev.es.24.110193.000245?journalCode=ecolsys.1

Marotto. Introduction to Mathematical Modeling Using Discrete Dynamical Systems. 1st Edition

Taabu, Anthony Munyaho. ASSESSMENT OF THE STATUS OF THE STOCK AND FISHERY OF NILE PERCH IN LAKE VICTORIA, UGANDA United Nations University 2004 pg.1-53 http://www.unuftp.is/static/fellows/document/taabuprf04.pdf