INTRAGUILD PREDATION MODEL (IGP) WITH DISEASE

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ABSTRACT

Intraguild Predation (IGP) classified as killing and eating among potential competitors. Intraguild Predation is ubiquitous interaction, differing from competition or predation. The purpose of this study is to investigate the effects of disease on the susceptible prey. Here we analyze the LotkaVolterra competition model and Intraguild Predation model. In order to keep the model simple, an assumption has been made that is no any migration or immigration for the intraguild predator and intraguild prey. We also analyze using the SI model, the simplest epidemiological model. We analyzed the entire model by finding the stability of the equilibrium points by using Routh – Hurwitz criteria. Numerical example is used to show the stability of the equilibrium point by using the MAPLE software.

ABSTRAK

Pemangsaan Intaguild (IGP) didefinasikan sebagai pembunuhan dan pemakanan antara potensi masing – masing. Pemangsaan Intraguild (IGP) merupakan interaksi yang sentiasa ada tetapi berbeza daripada persaingan atau pemangsaan. Kajian ini bertujuan untuk menganalisis kesan penyakit terhadap sistem sekiranya mangsa dijangkiti penyakit. Dalam kajian ini kami menganalisis model persaingan Lotka – Volterra dan model Pemangsaan Intraguild (IGP). Bagi memudahkan model, satu andaian kukuh telah dibuat, iaitu tiada sebarang penghijrahan dan imigresen untuk intraguild pemangsa dan intraguild mangsa. Selain itu, kami juga menganalisis menggunakan model SI iaitu model epidemiologi ringkas. Titik keseimbangan perlu berada dalam kuadran pertama dan kestabilan titik keseimbangan akan diuji menggunakan kriteria Routh – Hurwitz. Contoh berangka juga digunakan untuk menguji kestabilan titik keseimbangan dan pengiraan berangka dijelaskan dengan menggunakan perisian MAPLE.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF SYMBOLS

P	-	IG Predator
N	-	IG Prey
k_1	-	Carrying capacity IG predator
k_2	-	Carrying capacity IG prey
r_1	-	Intrinsic growth IG predator
r_2	-	Intrinsic growth IG prey
β_1	-	Competition coefficients (effect of IG prey on the population of IG predator)
β_2	-	Competition coefficients (effect of IG predator on the population of IG prey)
a_1	-	Benefit provided the IG predator by IGP
a_2	-	Extra mortality suffered by the IG prey due to IGP
S	-	Susceptible population
I	-	Infected population
β	-	Infection rate of susceptible prey
μ	-	Average death due to infection
N_s	-	Susceptible IG prey
N_I	-	Infected IG prey
a_3	-	Decrease rate of susceptible IG prey due to interaction with IG predator
a_4	-	Decrease rate of susceptible IG prey due to interaction with infected IG prey
σ	-	Mortality rate for infected preys
p	-	Nondimensionalize IG predator
n	-	Nondimensionalize susceptible IG prey

i	-	Nondimensionalize infected IG predator
θ_1	-	Nondimensionalize competition coefficients effects (IG prey on the population of IG predator)
θ_2	-	Nondimensionalize benefit provided the IG predator by IGP
θ_3	-	Nondimensionalize competition coefficients effects (effect of IG predator on the population of IG prey)
θ_4	-	Nondimensionalize negative rate of susceptible IG prey due to interaction with IG predator
θ_5	-	Nondimensionalize negative rate of susceptible IG prey due to interaction with susceptible IG prey
θ_6	-	Nondimensionalize positive rate infected IG prey due to interaction with susceptible IG prey
θ_7	-	Nondimensionalize negative rate of infected IG prey due to interaction with IG predator
θ_8	-	Nondimensionalize intrinsic growth rate
θ_9	-	Nondimensionalize mortality rate of infected IG prey
τ	-	Time
E_m	-	Equilibrium point for solution *m*
J	-	Jacobian matrix
λ_m	-	Eigenvalue *m*

LIST OF APPENDICES

LIST OF ABBREVIATION

IGP	Intraguild Predation
IG	Intraguild
SIR	Susceptible, Infected, Removed
SIS	Susceptible, Infected, Susceptible
SI	Susceptible, Infected

CHAPTER 1

INTRODUCTION

1.1 Introduction

Ecology is a relationship between organism and the environment. The word of ecology is from Greek, *oikos* (habitat) and *logos* (knowledge). It means with the knowledge, the relationship will easily interact to the living creature and the environment. The term has been introduced by Ernst Haeckel around 1834 to 1914. In the other meaning, ecology is the interaction between living creature and their union and the environment.

Ecology is related to ecosystem with the other component that is abiotic and biotic. For the abiotic factor for example temperature, water, moisture, light and topography meanwhile for the biotic factor is live creature which included human, animal, plants and microorganism.

Prey and predator is one of the interactions in the ecosystem. Predator is an organism that eats and hunts another organism (prey). Predation occurs because the predator is utilizing the energy and nutrients from the body of prey to growth, maintenance or reproduction. Predation is habitually well known from herbivory by

requiring that the prey is an animal rather that other living creature such as plant or other type of organism (bacteria). To discriminate predation from decomposition, the prey (animal) must be killed by the predator. So, the condition that both energy and nutrients be adapted by the predator excludes carnivorous plants from being predators, since the predator assimilate only nutrients from the prey that they consume.

1.2 Background of Problem

Application of mathematical modelling has been used widely nowadays. The most popular modelling have been introduced by Alfred Lotkain 1925 where he began with theoretical papers on chemical oscillation during the early decade of this century and authored a monograph on theoretical biology. Then, he produced his research on oscillatory behaviour arising from mass action kinetics, which has provided considerable inspiration to ecologists. Later then, Vito Volterra used the similar ideas to Lotka's to investigate a wide range of ecological problems, including the effects of migration and of several species simultaneously interaction. This model has been used broadly in ecology and called as Lotka – Volterra model and used to characterize the interaction between prey and predator.

Interactions between species are usually categorized by competition, predation, mutualism, commensalism or amenssalism. Intraguild predation known as IGP is from interaction predation and prey interaction where there is more than one interaction of predator towards prey. Specifically, interaction of IGP is the killing and eating of species that use similar resources and hence potential competitors (Polis et al, 1989). Intraguild predation is distinguished from traditional concepts of competition by the immediate energetic gains for one participant which is the predator (Polis et al. 1989).

Interaction between prey and predator play an important role in explaining the population dynamics, which it refers to changes in the sizes of populations of organism through time. Some of the interaction is an antagonistic interaction type, which population of one species of predators has a negative effect on the population of prey meanwhile the other interaction has a positive effect on the first. For the population dynamics, prey and predator interactions are similar to other types of antagonistic interactions for example pathogen-host and herbivore plant interactions.

It happens when there are two predators (combination of predator) compete with only one prey to survive. This interaction is called Intraguild predation, which predation within the guild of predators. Generally, species within an ecological community interact by a simplest conception, where plants or other photosynthetic organism at the bottom, followed by herbivores, then the predators eat herbivores and lastly the other predators eat other predator. Moreover, many species are omnivores, feeding at different times as either predators or herbivores. So, the role of particular predator species in a community is often complex.

1.3 Problem statement

Intraguild Predation (IGP) is a combination of competition and predation, which IGP is a common within communities which can occur at different trophiclevels (level of food chain) and has the potential to affect the distribution, abundance and evolution of the species involved (Arim&Marquet, 2004). In IGP interactionIntraguild Predator (IG Predator) preys on Intraguild Prey (IG Prey). At the same time, IG Predator and IG Prey compete for the same resource.

This study is focused on formulating and analysing an IGP model with disease using differential equations (DEs).

1.4 Objectives of research

The objectives of this research are:

1. to formulate a mathematical model of Intraguild Predation with infectious disease
2. to find the equilibrium points of Intraguild models with diseasein prey to describe the system's behaviour.
3. to analyse the stability of the equilibrium points of Intraguild Predation models with disease using Routh Hurwitz criteria.

1.5 Scope of the research

The main scope of this research is to analyse the Intraguild Predation models. These models are formulated by using first order differential equation. In this research, we shall only focus on two species population where only one species will be infected at one time. We will only consider the *SI* (susceptible and infective) model where the ways in which individuals deal with the disease are mass action incidence.

1.6 Significant of the research

This research is useful for the mathematicians who have interest in the field of ecology and especially to the ecologists, because from the findings, this research will contribute more understanding in IntraguildPredation model with the presenceof disease and the effect of disease on the stability of the population. Besides, this research is useful to widen applications of ordinary differential equations in the population field.

1.7 Organization of the research

The organization of the research can be divided into six chapters. The research will begin with research framework, continue with literature review and end with conclusion and recommendation.

Chapter 1 is about overview of this research. In this chapter the background and problem statement would be discussed. Besides, objectives, scope and significant of the research also included in this chapter.

Chapter 2, literature review, discussed the related issues for this chapter. It contains all important information gathered throughout the entire course of the research. Ecology, prey and predator, Intraguild Predation (IGP), population in competition and modelling of epidemics are all compiled in this chapter.

In Chapter 3, explains basic concept of the theory needed to analyse the intraguild predation model such as nullclines, close to steady state, determinant of Jacobian matrix and the Routh Hurwitz criteria.

Chapter 4 would analyse LotkaVolterra competition model by finding the stability using methods in Chapter 3. Example of selected parameters been used to satisfied the conditions.

Chapter 5 would analyse the Intraguild predation model with disease. Firstly the nullclines and the steady state for this model will be found. Then, each of the equilibrium points will be tested by using selected parameters to satisfy the condition of the stability.

The final chapter of this research is Chapter 6 which is the conclusion for the whole research and some recommendations for the further studies.

REFERENCES

Alan A. B (1992). The Origins and Evolution of Predator – Prey Theory.*Ecology*, 73(5), 1530 – 1535. Ecological Society of America.

Arim M.,Marquet P.A. (2004).Intraguild Predation: A Widespread Interaction Related to Species Biology. *Ecology Letters*, 7, 557 – 564.

BrauerF.,Chavez C. C (2012).Mathematical Models in Population Biology and Epidemiology Text. 40, 345 – 409.

Chong TzeChiann (2009). Mathematical Modeling in Intraguild Predation. Undergraduate Report ,UniversitiTeknologi Malaysia.

Edelstein-Keshet, L.(1988). Mathematical Models in Biology. New York: Random House Publishers.

Hethcote H. W., Wang, Han and Ma (2004).A Predator Prey Model with Infected Prey.*Theoretical Population Biology*, 66, 259 – 268.

Hilker, F. M, Schmitz K. (2008). Disease – induced Stabilization of Predator – Prey Oscillations. *Journal of Theoretical Biology*, 255, 290 – 306.

Holt, R.D, Huxel G.R. (2007). Alternative Prey and The Dynamics of IntraguildPredation : Theoretical Perspectives. *Ecology* ,88(11), 2706 – 2712. Ecological Society of America.

Holt, R.D, Polis G.A, Myers C.A (1989). The Ecology and Evolution of Intraguild Predation: Potential Competitors That Eat Each Other. Journal of Ecology, 20, 297 – 330.

Holt, R. D, Polis G.A (1997).A Theoretical Framework for Intraguild Predation. 149(4), 745 – 761.

Janssen A. et al (2006). Intraguild Predation Usually Does Not Disrupt Biological Control. *Trophic and Guild Interactions in Biological Control*, 21 -44.

Jose D. Flores (2011). Routh – Hurwitz Criteria.*Math-735: Mathematical Modeling*. Department of Mathematical Sciences of South Dakota.

Kermack W.O and Mc Kendrick A.G (1927). Contributions to the Mathematical theory of epidemics,part 1: Proceedings of the Royal Society Series, 115, 700 – 721.

NurAziraBinti Abdullah (2012). LotkaVolterra Predator – Prey Models with Disease. Undergraduate Report, UniversitiTeknologi Malaysia.

Roy S. and Chattopadhyay (2005). Disease-selectivepredation may lead to prey extinction. *Mathematical Methods in the Applied Sciences,*28,1257-1267

Ruggieri. E., Schreiber S. J (2005). The Dynamics of TheSchoener-Polis-Holt Model of Intra-Guild Predation.*Mathematical Biosciences and Engineering*, 2, 279 – 288.

SieberM.,Hilker F. M (2011). Prey, Predator, Parasites: Intraguild Predation or Simpler Community Modules in Disguise? *Journal of Animal Ecology*, 80, 414 – 421. British Ecological Society.

Spencer, R. Hall et. al (2002). Chapter Ten: Is Infectious Disease Just Another Type of Predator – Prey Interaction. 224 – 236.

Sze-Bi Hsu (1981). On a Resource Based Ecological Competition Model with Inteference. *Journal of Mathematical Biology*, 12, 45 – 52.

Venturino,Ezio. (1994). The Influence of Disease on Lotka – Volterra Systems. *Journal of Mathematics*, 24, 381- 402.

Wiklund, K. et. al (2012). Computational Science and Engineering.Department of Physics.