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Contents

Establishing Backup Fish Stock Kerapu (Blue-lined seabass) Suspended Situbondo 1
Samsul huda, Siti Naviah, Yola Berta Calvinanda, Samrotul fikriyah

Making Better Indonesia's Thin Capitalization Rules (Lesson Learn from China) 8
Neni Susilawati

Fantasy Themes in Peasants Movement 24
A. Pratiwi, S. Sarwoprasodjo, E. Soetarto, N. K. Pandjaitan

The Fullfillment of The Social Rights for Child Client With Parole Status at Correctional Center in South Jakarta-Indonesia 35
Sarinah Sarinah, Fentiny Nugroho, Desi Setiana

Analysis Of Credit Risk Measurement Using CreditRisk+ Method (Study of PT XYZ (Persero) Tbk SME Loans For 2016-2018) 40
Andrey Carver, Ferdinand D Saragih, Bernardus Yuliarto Nugroho

Implementation of The JKN Programs on The Community Health Center at Level 1 (Descriptive study of the implementation of the JKN program at the Pucang Sewu Health Center, Gubeng District, Surabaya City) 46
Sri Roekminiati, Sapto Pramono, Nihayatus Sholichah, Ika Devy Pramudiana

The Implementation of Deep Learning for White Blood Cell Subtype Classification from Microscopic Images 53
Yustisia Amalia, Miftahul Khairoh, Arkha Rosyaria B, Budi Santoso

The Application of Omotenashi in Japanese-Conceptualized Company in East Java 60
Cicilia Tantri Suryawati, Isnin Ainie, Ni Nyoman Sarmi

The Challenges of Government Public Relations and Abuse of Power over Indonesia 66
Suwandi Sumartias, Nurtyasih Wibawanti Ratna Amina

The Impact Of Double Role Conflict and Job Satisfaction to Work Performance of The Woman Employees in PT Bio Farma (PERSERO) 79
Sedarmayanti Sedarmayanti, Nitta Aprilianti Ashari, Fedianty Augustinah, Meithiana Indrasari

Difable Literacy: Analysis of Difable Representation in Indonesian Media 87
Hanna Nurhaqiqi

Information Technology Strategy in Applying and Developing Knowledge Management Systems (R & D Study to Improve the Quality of Lecturers' Performance in Higher Education) 96
A T R Rosa

Financial Technology Readiness: Strategic Innovation Management in the Service Industry 4.0 108
J T Purba, H Hery, V N S Lestari

Bahan dengan hak cipta

15 Pillars of Islamic Good Corporate Governance for The Corporate Level 121
Maulidah Narastri

The Relationship between Ethical Work Climate and Organizational Innovation 128
Adibah Abdul Kadir, Fadillah Ismail, Asad Khan, Adnan Ali Hassan Humaid AlHosani, Nor Syafiqah Izzati Zaidi

The Modified Conceptual Understanding Layer "PKS" Model As An Alternative Assessment Tool On Hots Type Problems 150
Viktor Sagala, Ahmad Hatip, Sucipto Sucipto, Kusmiyati Kusmiyati

The Role of Teachers in Utilizing Learning Media as A Learning Source for Millenial Students 158
Talizaro Tafonao, Setinawati Setinawati, Ezra Tari

Education Literacy Expectations on Technology Industry Development of Humanities Revolution society 5.0 Era 166
Ade Tutty Rokhayati Rosa

The Effect of Compensation and Benefits Towards Employee Performance 171
Adibah Abdul Kadir, Adnan Ali Hassan Humaid AlHosani, Fadillah Ismail, Norseha Sehan

Forecasting of Vivo and Advan Handphone Sales Using Cheng Fuzzy Time Series Method 187
Anisah Anisah, Mas'amatuz Zahrah, Qurrotul Aini, Tony Yulianto

Determining The Types Of Tiles Based On Building Location And Building Elevation Using Fuzzy Weighted Product (WP) Methods 205
Sayyidah Sayyidah, Nurul Huda Maksum, Sarmiatul Hasanah, Tony Yulianto

Forecasting the Number of Tuberculosis (TBC) Using Fuzzy Prey Predator 213
Subaidah Subaidah, Putri Ukhrowi, Achmad Alam, Tony Yulianto

Key Determinants of Online Product Purchase Decisions for Students in Surabaya City (Case Study at FEB Students, Dr. Soetomo University) 229
Firdaus Firdaus, Sukesi Sukesi, Windyra Fitriani, Meithiana Indrasari, Sugiyanto Sugiyanto

Blusukan and Personal Branding of Regional Head Election Candidates in Solo City 238
Betty Gama, Bani Sudardi, Wakit Abdullah, Mahendra Wijaya

The Wage Gap for Women Homeworkers and Their Role in Family Resilience 250
Intan Fatma Dewi, Fentiny Nugroho

Implementation of The Democracy Culture for Fulfillment of The Social Economic Rights for The Correctional Clients at Correctional Center in Central Jakarta-Indonesia 247
Dina Setyani, Fentiny Nugroho

The Implication of "Ewuh Pakewuh" Cultural in OCB Implementation of Service Employee at Pesantren Sub District of Kediri City 252
Restin Meilina, Dodi Kusuma Hadi

Design of Health Telemonitoring System on Vital Sign Patient's Web-Based 258
Mery Subito, Alamsyah Alamsyah, Ardi Amir

Bahan dengan hak cipta

Rating of Bottled Drinking Water (AMDK) Sellers in Local and National in Madura Using Fuzzy TOPSIS 267
Tony Yulianto, M. Rofiqi Mudassir, Faisol Faisol

Can Regional Free-Trade Bring Positive Impact on Local Farmers? (A Study on the Ornamental Fish Farmers in Depok City, West Java, Indonesia) 277
Fentiny Nugroho, Marsudi Marsudi

Implementation of the Government Credit Card Policy in the Ministry of Foreign Affairs of the Republic of Indonesia 281
Paramita Nur Kurniati, Bernardus Yuliarto Nugroho, Ferdinand D. Saragih

Dimension of Management Control in Entrepreneurial University 287
Wirawan ED Radianto, Oscarius Yudhi Ari Wijaya

The Influence of Education on The Depressing of Unemployment and The Increasing of The Society Economy in East Java 292
Suyanto Suyanto, Bambang Purnomo, Rahmawati Erma Standsyah

The Effectiveness of The Use of The "Kartubarpel" Media in Learning Calistung Mentally Disabled Children Based on Learning to Play in "Tunas Kasih" SLB Lidah Kulon Surabaya 299
Wahyu Widayati, Viktor Sagala, Sri Utami, Ardianik Ardianik

Communicating Environmental Issue: Movie as Medium on Earth Conservation 304
Redi Panuju, Daniel Susilo

Effect of Organizational Culture on Individual Work Performance and Organizational Performance (Study at PT. Kramayudha Tiga Berlian Motors) 309
Pebri Tutur Srihadi, Ferdinand Dehoutman Saragih, Bernardus Yuliarto Nugroho

Atmospheric Impact Analysis of Work on Employee Performance Through Aspects of Employee Welfare 316
Agustiawan Djoko Baruno, Meithiana Indrasari, Dandy Patrija Wirawan, Jovi Iristian

Effect of Organizational Commitment and Work Motivation on Job Satisfaction and Individual Performance 327
Sarwani Sarwani, Andry Herawati, Liling Listyawati, Damajanti Sri Lestari

Da'wah Ethics in Candra Malik's Sufistic Literature 336
Imron Amrullah, Hetty Purnamasari, Ni Nyoman Sarmi, Imayah Imayah

Determinants of Stock Returns on the Indonesian Stock Exchange 343
Aminullah Assagaf, Meithiana Indrasari, Eddy Yunus

Improvement of Human Resources Performance Through Online Presence Applications Based on Android Using UML - Iconix process 356
Amirul Mustofa, Achmad Muzakki, Slamet Kacung, Eny Haryati

Orientalism on Malay People in Kipling's Limitation of Pambe Serang 368
Hariyono Hariyono, Putut Handoko, Sanhari Prawiradiredja, Meithiana Indrasari

Bahan dengan hak cipta

Do Technological Innovation Capabilities Contribute to New Product Development Performance? A Conceptual Framework 374
Gogor Arif Handiwibowo

Islamic Higher Education and Human Capital Development (The Study of Ma'had Aly As Education Training for 'Ulama') 381
Fatah Syukur, Abdul Wahib, Mahfud Junaedi

Weighted sum model for Spatial Analysis in Classification of Areas Prone to Diphtheria Tetanus 387
Anik Vega Vitianingsih, Achmad Choiron, Dwi Cahyono, Suyanto Suyanto

The disparity of Economic Development and Social in Coastal Area of East Java 397
Totok Hendarto

The Importance of Thinking Skills for Islamic Education 406
Meithiana Indrasari, Bambang Raditya, Bambang Purnomo, Iwan Sugianto, Lusiana Prastiwi

The Effect of Quality of Products and Services on Trust and Decision of Customers to Choose Banks (Study at Sampang Bank Rakyat Indonesia Branch) 414
Bambang Raditya, Meithiana Indrasari, Sri Handini, Susanto Soekiman

Right of Workers are Guaranteed in the Constitution 425
Siti Marwiyah, M. Syahrul Borman, Bachrul Amiq, Vieta Imelda Cornelis

Government policy in giving land procurement replacement for development 429
Wahyu Prawesthi, Meithiana Indrasari, Basoeki Nugroho, Nur Syamsudin

Addition of Foam Agent Using Polyester and Polystyrene Waste for Lightweight Mixed 432
Safrin Z. Bambang S. Budi H. Wisnu A. Riky Sim

The Implementation of the Street Vendor Arrangement Policy on Jalan Diponegoro, Bandung 445
Rezky Afiahtul Barokah, Sedarmayanti Sedarmayanti, Kurhayadi Kurhayadi, Amirul Mustofa

Identification of Nutrition, Phytochemicals and Antioxidants Taro (Colocasia sp) 459
Arlin, B. D., Fadjar, K. H., Nunuk, H.

Implementation of the Authority of Financial Services Supervision in Legal Protection of Customers Storing Funds in Sharia Banks 464
Sri Astutik, Irawan Soerodjo, Ach. Rubaie, Bachrul Amiq

Patterns of Use of Social Media in the Culinary Community "Langsungenak" 472
Zulaikha Zulaikha, Achmad Muzzaki, Jovi Iristian, Meithiana Indrasari

Opinion Polarisation in Indonesia Politics 478
Senja Yustitia, Muhammad Edy Susilo, Subhan Afifi

Effect of Corporate Social Responsibility Disclosure, Capital Structure, and Ownership Structure on Value of The Firm with Intervening Variables of Financial Performance and Dividend Policy in Manufacturing Companies Listed in Indonesia Stock Exchange 488
S Rahayuningsih, D R Prihastuty, Hwihanus Hwihanus

Bahan dengan hak cipta

Estimation Cost Method Using Cost Significant Model On Channel Work in The Public Work In Sidoarjo 497
W Oetomo, J Rochyantine, K Koespiadi, H T Tjendani

Conceptual Review of Rethinking Marine Tourism Visit Intention from Word of Mouth, Destination Image dan Destination Branding 510
A Y A Fianto, C Candraningrat

Radical Detection on Student Knowledge Using Classification Supervised Learning Method 519
Asantoso Asantoso, F Rodli, R N Sari, S Hadayatullah, A Prasnowo, S Sehman

Natural Vs. Synthetic Food: Which Is Better? 527
A Wangsa, H. Hery, J T Purba

The Influence of Quality of Services, Innovation of Products, Prices and Trust on Customer Satisfaction Telkomsel In Surabaya 532
F A B K Panjaitan, T Andjarwati, S Sumiati, H Panjaitan

The Use of The Semanding Tuban Limestone as A Partial Replacement of Coarse Aggregate in Concrete Mixes 542
N Rochmah, G Sarya, F Setiawan

Reflection: Using Photovoice to Encourage Mastering Vocabularies for Computer Science Students 548
F Nurhidayati, A Cipto, H Hafid, S Mahmudah, M. A. Gunawan

Language Ideology of Tengger Community in Tutur District 553
H Hariyono, P Handoko, C T Suryawati, C Pujimahanani

The paradigm of Character Building Between Hope and Challenge 557
H Hendri, R Handoko, A Darmawan, L Y Prakoso, GSAchmad Daengs

Corruption of Regional Heads in Indonesia; Anatomy, Causative Factors, And Solutions 564
H Agustina, A Sutarih

Investment Analysis for Replacement Premium Economy Trains into Executive Trains of Argo Parahyangan A Case Study of PT Kereta Api Indonesia (Persero) 573
R Irwanto, A H Anggono

The Effect of Human Capital, Social CapitaLand Competency on Women Entrepreneur Success in Surabaya Indonesia 585
S Mujanah, A Kusmaningtyas, Candraningrat Candraningrat

Risk Level Analysis Using The Job Safety Analysis Method In Manufacturing System Laboratory 593
S Sastrodiharjo, Q Sholihah, E L Zedniawan

Design and Control Self Balancing Robot 600
S Santoso, S Yuliananda

Developing Spatial Intelligence by Utilizing City Park Green Open Space for Educational Functions 606
S Fadjarajani, R As'ari

Bahan dengan hak cipta

Influence of Length Variation in Bamboo Fiber on Tensile Strength and Compressive Strength of Concrete 613
R Trimurtiningrum, Faziz Faziz, Lendah Lendah

The Spirit of Islam in the Development of Good Governance and Anti-Corruption Concepts 620
Ulul Albab

An Analysis of The Level of Information Technology (TI) Service Satisfaction (A Case Study of Gojeck Application) 628
Lin Yan Syah, Siti Nurhayati Nafsiah

Effect of Compensation and Work Environment on Employee Performance (Study at PT Segar Murni Utama, Mojokerto Regency) 636
Bambang Raditya, Meithiana Indrasari, Agus Surya, Maulida Hardianti Bandi

Bahan dengan hak cipta

Forecasting the Number of Tuberculosis (TBC) Using Fuzzy Prey Predator

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Abstract. Tuberculosis (TB or TB) is an infectious disease caused by the bacterium Mycobacterium tuberculosis. Tuberculosis (TB) is still a major health problem in the world, so from this it is necessary to forecast to determine the increase in the number of TB diseases, and later can be taken in prevention. This study uses the Fuzzy prey predator method. The data source used is data on TB patients at Baturnarmar Health Center. From the results of this study, it was found that the population of Prey and Predator was sought for stability, so that after applying the fuzzy prey predator model, convergent results were obtained. Prey population and Predator population decreased for one month, afterwards covergen.

Keywords: Tuberculosis (TBC), forecasting, fuzzy prey predator.

1. Introduction

Tuberculosis (TB or TB) is an infectious disease caused by the bacterium Mycobacterium tuberculosis. Tuberculosis (TB) is still a major health problem in the world. This causes health problems in millions of people each year and becomes ranked second as the main cause of death from disease infections worldwide after the Human Immunodeficiency Virus (HIV). In 2012, there were 8.6 million people worldwide affected by TB and 1.3 million people died from this disease (including 320,000 deaths of people with HIV). Most of the tuberculosis (TB) germs attack adults in productive age. However, in the group of children one million children (0-14 years old) were sick because TB and 170,000 children died of TB in 2015 [1]. According to WHO data in 2011 states that Indonesia is ranked fourth in the world with the most TB sufferers after India, China and southern Africa.

The World Health Organization (WHO) states that, in 1999 in Indonesia every year 583 new cases occurred with the death of 130 patients with positive tuberculosis in their phlegm. Whereas according to the results of the Kusnindar research in 1990, the number of deaths caused by tuberculosis was estimated at 105,952 per year. The most increase in tuberculosis cases occurs in groups of people with weak socio-economic conditions, influenced by endurance, nutritional status, individual personal hygiene and density of housing [2]

TB is one of the most infectious diseases found in East Java, in 2015 East Java occupied the second highest case of pulmonary TB patients after West Java, which amounted to 23,183 patients [3]. TB sufferers in the pamekasan city are ranked fifth, under Sumenep Regency, Lumajang, Malang City and Jember [4]. Based on data from the Pameksan District Health Office, there were 1,110 in 2014 [5].

Many methods can predict the number of TB disease, one method that can be used is fuzzy prey predator. In this method, fuzzy set theory is used to create a model that studies the

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interaction between prey (prey) and predator (predator) characters in the form of ordinary differential equations that characterize classical deterministic models [6].The prey in this study was humans, while the predators were tuberculosis. Then the decomposition of predator-prey models that represent the interaction between prey (prey) and predator (predator) using a fuzzy rule-based system. Next, it is proposed the deterministic classical model given by the system of ordinary differential equations, for example there is a predator-prey system whose solution coincides with the fuzzy model. By adjusting the parameters of the differential equation from the fuzzy model obtained, so that system stability analysis can be carried out [6].

Based on previous research entitled "Predator Prey Model with Early Fuzzy Populations" the results of his research propose a new way to study prey-prey population models, which take into account the uncertainties that arise when determining predator and prey initial populations. By using the concept of fuzzy interval interactivity, the Runge-Kutta Method, to estimate the number of predators and prey over time. In research entitled "PredatorPrey Fuzzy Delay System. Theory of the Existence of the Theorem and Oscillation Solution "succeeded in proving the existence and uniqueness of FDPP solutions at intervals [0, interval].

Based on the research, no one has examined the problem of forecasting the number of tuberculosis. For this reason, in this study the authors are interested in using Fuzzy Prey Predator in a study entitled "Forecasting the number of TB diseases using the Fuzzy Prey Predator method" So that this title is expected to be able to determine the amount of TB disease increase.

2. Definition of fuzzy logic

Fuzzy logic was first introduced by Prof. Lotfi A. Zadeh in 1965. Classic and Fuzzy Sets Basically, fuzzy set theory is an extension of classical set theory. In crisp, the value of membership of the item is written with μ_A [x], has 2 possibilities, namely [7]. One, which means that an item becomes a member in a set, or Zero, which means that the item is not a member of a set.

3. Prey predator

The prey predator system with two predators can be seen in the following differential equation:

$$\begin{aligned} \frac{dN}{dt} &= rN\left(1-\frac{N}{K}\right) - \alpha PN - \varphi QN \\ \frac{dP}{dt} &= -cP + \beta NP \\ \frac{dQ}{dt} &= -eQ + \gamma NQ \end{aligned} \tag{1}$$

K = the carrying capacity of the prey environment
r = prey growth rate
c = first predator growth rate
e = the growth rate of the second predator
β = first predator rate of prey
γ = second predator contraction rate to prey
α = prey contraction rate of the first predator
φ = prey contraction rate of the second predator

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4. Equilibrium point

Definition 2.1 [6]

A point x_e is said to be the equilibrium point of equation

$$\dot{x}_1(t) = x_1(t)(\mu_1 - r_{12}x_2(t))$$
$$\dot{x}_2(t) = x_2(t)(\mu_2 - r_{21}x_1(t))$$

at time t_0, if for each $t \geq t_0$, then the result $f(x_e) = 0$.

From this definition it gives the meaning that the equilibrium point x_e is a constant solution of equation

$$\dot{x}_1(t) = x_1(t)(\mu_1 - r_{12}x_2(t))$$
$$\dot{x}_2(t) = x_2(t)(\mu_2 - r_{21}x_1(t))$$

when $f(x_e) = 0$ so that $\boldsymbol{x}'(t) = 0$ at that point.

Proposition 2.1 [6]

If an x_e equilibrium point is stable, the fuzzy is also stable.

5. System linearization

Linearizasion system of a system of nonlinear differential equations using a Taylor series.

Given a dynamic system as follows:

$$\dot{x}_1 = f_1(x_1, x_2)$$
$$\dot{x}_2 = f_2(x_1, x_2) \quad (2)$$

Suppose the function component $f_i(x_1, x_2), i = 1,2,$ has a continuous derivative around the equilibrium point (c_1, c_2). So that from equation (2.) can be written in the form of a matrix as follows:

$$\begin{bmatrix} x_1' \\ x_2' \end{bmatrix} = \begin{bmatrix} \frac{\partial f_1}{\partial x_1}\Big|_{(c_1,c_2)} & \frac{\partial f_1}{\partial x_2}\Big|_{(c_1,c_2)} \\ \frac{\partial f_2}{\partial x_1}\Big|_{(c_1,c_2)} & \frac{\partial f_2}{\partial x_2}\Big|_{(c_1,c_2)} \end{bmatrix} \begin{bmatrix} y_1 \\ y_2 \end{bmatrix}$$

6. Stability

Definition 2.1 [8]

Suppose matrix $(n \times n)$. A nonzero vector v in R^n is called the eigenvector of A, if for a scalar λ is called the eigenvalue of matrix A, then it applies:

$$Av = \lambda v \quad (3)$$

The vector is called the eigenvector of A when it corresponds to the eigenvalue λ.

To find the eigenvalue of the matrix A equation (3) can be written as follows:

$$(A - I\lambda)v = 0 \quad (4)$$

With I is an identity matrix. Equation (2.8) has a nonzero solution which if only if, det $(A - I\lambda)v = 0$ is called the characteristic equation of A.

equilibrium point stability (x_0, y_0) is divided into three, namely as follows [9]:

a. the equilibrium point $(x_0, y_0)$is said to be asymptotically stable if $\lambda_i < 0$
b. equilibrium point $(x_0, y_0)$is said to be stable if $\lambda_i = 0$.
c. the equilibrium point (x_0, y_0)) is said to be unstable if $\lambda_i > 0$.

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7. Non homogeneous system solutions

Given a non homogeneous system

$$\dot{x} = Ax + b(t) \tag{5}$$

With A the matrix n × n and b (t) are vectors whose elements are continuous functions.

Definition: [10]
The fundamental solution matrix for the system

$$\dot{X} = Ax \tag{6}$$

Is the matrix ϕ (t) measuring n × n that satisfies

$$\dot{\phi}(t) = A\phi(t) \tag{7}$$

For each $t\epsilon R$
With the matrix $\phi(t) = e^{At}$ satisfies equation (7) with the initial value $\phi(0) = I$, so that $\phi(t) = e^{At}$ is called the fundamental matrix.

Theme: [10]
If $\phi(t)$ and ψ are two fundamental solution matrices for the system (6) then there is a constant matrix C so that $\phi(t) = \psi(t)C$

Theorem: [10]
If $\phi(t)$ is the fundamental solution matrix of the system (6) then

$$e^{At} = \psi(t)\psi^{-1}(0)$$

Theorem: [10]
If $\phi(t)$is the fundamental matrix for the system (6) then the solution of the non homogeneous system (5) with the initial value is $X(0)$

$$X(t) = \phi(t)\phi^{-1}(0)X(0) + \phi(t)\int_0^t \phi^{-1}(s)B\,ds \tag{8}$$

8. Fuzzy prey predator model

Predator prey models with fuzzy initial conditions in linear form are given [6]

$$\dot{X} = CX + B \tag{9}$$

The solution to equation (8) is

$$\bar{X}(t) = \psi(t)\psi^{-1}(0)\bar{X}(0) + \psi(t)\int_0^t \psi^{-1}(s)B$$

Or it can be written

$$\left[\bar{X}, \underline{X}\right] = \psi(t)\psi^{-1}(0)\left[\bar{X}_0, \underline{X}_0\right] + \psi(t)\int_0^t \psi^{-1}(s)B \tag{10}$$

With $X(0) = \bar{X}_0$ and $Y(0) = \bar{Y}_0$

9. Model Fixed Point Analysis

To analyze the fixed point on the equation (1) that is by way of making $\frac{dN}{dt} = 0, \frac{dP}{dt} = 0$ and $\frac{dQ}{dt} = 0$ so that equation (1) can be written as

$$0 = rN\left(1 - \frac{N}{K}\right) - \alpha PN - \varphi QN \tag{11}$$

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$$0 = -cP + \beta NP \tag{12}$$

$$0 = -eQ + \gamma NQ \tag{13}$$

When $\frac{dN}{dt} = 0$, then in equation (12) is obtained

$$-cP + \beta NP = 0$$

$$P \neq 0 \text{ or } -cP + \beta N = 0$$

$$N = \frac{c}{\beta} \tag{14}$$

When $\frac{dN}{dt} = 0$, then in equation (13) is obtained

$$-eQ + \gamma NQ = 0$$

$$Q \neq 0 \text{ or } -e + \gamma N = 0$$

$$N = \frac{e}{\gamma} \tag{15}$$

Whereas in equation (11) when $\frac{dQ}{dt} = 0$, it is obtained

$$rN\left(1 - \frac{N}{K}\right) - \alpha PN - \varphi QN = 0$$

$$N \neq 0 \, atau \, r\left(1 - \frac{N}{K}\right) - \alpha P - \varphi Q = 0$$

If N = 0, P = 0 is substituted in equation (16) then obtained

$$r - \varphi Q = 0$$

$$Q = \frac{r}{\varphi} \tag{17}$$

If N = 0, Q = 0 is substituted in equation (16) then obtained

$$r - \alpha P = 0$$

$$P = \frac{r}{\alpha} \tag{18}$$

In equation (17) and (18) do not fulfill because in equation (16) the condition is $N \neq 0$.
The first fixed point is $TE_1 = (0,0,0)$
Whereas if P = 0 and Q = 0 are substituted in equation (16) then obtained

$$r\left(1 - \frac{N}{K}\right) = 0$$

$$r \neq 0 \, atau \, 1 - \frac{N}{K} = 0$$

$$N = K$$

So that the second fixed point is obtained $TE_2 = (K, 0,0)$

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If $N = \frac{c}{\beta}, Q = 0$ is substituted in equation (16) then obtained

$$r\left(1 - \frac{N}{K}\right) - \alpha P - \varphi Q = 0$$
$$\frac{1}{\alpha}\left(r - \frac{rc}{\beta K}\right) = P$$

So $TE_3 = (\frac{c}{\beta}, \frac{1}{\alpha}\left(r - \frac{rc}{\beta K}\right), 0)$

For the fourth fixed point, substitute $N = \frac{e}{\gamma}$ and P = 0 in equation (16) so that it is obtained

$$r\left(1 - \frac{N}{K}\right) - \alpha P - \varphi Q = 0$$
$$\frac{1}{\varphi}\left(r - \frac{re}{\gamma K}\right) = Q$$

So $TE_4 = \left(\frac{e}{\gamma}, 0, \frac{1}{\varphi}\left(r - \frac{re}{\gamma K}\right)\right)$

For the fifth fixed point of substitution $N = \frac{C}{\beta}, Q = Q^*$ in equation (16) is obtained

$$r\left(1 - \frac{N}{K}\right) - \alpha P - \varphi Q = 0$$
$$\frac{1}{\alpha}\left(r - \frac{rc}{\beta K} - \varphi Q^*\right) = P$$

So $TE_5 = \left(\frac{C}{\beta}, \frac{1}{\alpha}\left(r - \frac{rc}{\beta K} - \varphi Q^*\right), Q^*\right)$

If $N = \frac{e}{\gamma}$ and $Q = Q^*$ are substituted in equation (15) obtained

$$r\left(1 - \frac{N}{K}\right) - \alpha P - \varphi Q = 0$$
$$\frac{1}{\alpha}\left(r - \frac{re}{\gamma K} - \varphi Q^*\right) = P$$

So $TE_6 = \left(\frac{e}{\gamma}, \frac{1}{\alpha}\left(r - \frac{re}{\gamma K} - \varphi Q^*\right), Q^*\right)$

Substitute $N = \frac{C}{\beta}, P = P^*$ in equation (16) then obtained

$$r\left(1 - \frac{N}{K}\right) - \alpha P - \varphi Q = 0$$
$$\frac{1}{\varphi}\left(r - \frac{rc}{\beta K} - \alpha P^*\right) = Q$$

So $TE_7 = \left(\frac{C}{\beta}, P^*, \frac{1}{\varphi}\left(r - \frac{rc}{\beta K} - \alpha P^*\right)\right)$

If $N = \frac{e}{\gamma}$ and $P = P^*$ are substituted in equation (16) obtained

$$r\left(1 - \frac{N}{K}\right) - \alpha P - \varphi Q = 0$$
$$\frac{1}{\varphi}\left(r - \frac{re}{\gamma K} - \alpha P^*\right) = Q$$

So $TE_8 = \left(\frac{e}{\gamma}, P^*, \frac{1}{\varphi}\left(r - \frac{re}{\gamma K} - \alpha P^*\right)\right)$

10. Linearization

Linearization is the process of linearizing nonlinear functions. from equation (1) suppose a function can be written as follows:

For example:

$$\dot{N} = f_1(N, P, Q) \qquad (19)$$

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$$\dot{P} = f_2(N, P, Q,) \tag{20}$$

$$\dot{Q} = f_3(N, P, Q,) \tag{21}$$

So that from equations (19), (20) and (21) by using a Taylor series, the blue matrix is obtained as follows:

$$\begin{bmatrix} \dot{N} \\ \dot{P} \\ \dot{Q} \end{bmatrix} = \begin{bmatrix} \frac{\partial f_1}{\partial N} & \frac{\partial f_1}{\partial P} & \frac{\partial f_1}{\partial Q} \\ \frac{\partial f_2}{\partial N} & \frac{\partial f_2}{\partial P} & \frac{\partial f_2}{\partial Q} \\ \frac{\partial f_3}{\partial N} & \frac{\partial f_3}{\partial P} & \frac{\partial f_1}{\partial Q} \end{bmatrix} \begin{bmatrix} N \\ P \\ Q \end{bmatrix} \tag{22}$$

From the equation (22) the Jacobic matrix is obtained as follows:

$$\begin{bmatrix} \dot{N} \\ \dot{P} \\ \dot{Q} \end{bmatrix} = \begin{bmatrix} r - \frac{2rN}{K} - \alpha P - \varphi Q & -\alpha N & -\varphi N \\ \beta P & -c + \beta N & 0 \\ \gamma Q & 0 & -e + \gamma N \end{bmatrix} \begin{bmatrix} N \\ P \\ Q \end{bmatrix} \tag{23}$$

So that based on equation (23) is obtained:

$$A = \begin{bmatrix} r - \frac{2rN}{K} - \alpha P - \varphi Q & -\alpha N & -\varphi N \\ \beta P & -c + \beta N & 0 \\ \gamma Q & 0 & -e + \gamma N \end{bmatrix} \tag{24}$$

11. Stability

At this stage the eigenvalue of equation (23) will be searched as follows

$$|\lambda I - A|$$

Then obtained

$$\left| \begin{bmatrix} \lambda - r + \frac{2rN}{K} + \alpha P + \varphi Q & \alpha N & \varphi N \\ -\beta P & \lambda + c - \beta N & 0 \\ -\gamma Q & 0 & \lambda + e - \gamma N \end{bmatrix} \right| = 0 \tag{25}$$

Furthermore, from equation (25), the determinant will be obtained as follows

$$\lambda^3 + \lambda^2 \left(e - \gamma N + c - \beta N - r + \frac{2rN}{K} + \alpha P + \varphi Q \right) + \lambda \left(ce - c\gamma N - \beta eN + \beta \gamma N^2 - er + \gamma rN - cr + \beta rN + \frac{2reN}{K} - \frac{2\gamma rN^2}{K} + \frac{2crN}{K} - \frac{2\beta rN^2}{K} + e\alpha P - \gamma \alpha NP + c\alpha P + e\varphi Q + c\varphi Q - \beta \varphi NQ \right) + \left(-cer + c\gamma rN + \beta erN - \beta \gamma rN^2 + \frac{2cerN}{K} - \frac{2c\gamma rN^2}{K} - \frac{2\beta erN^2}{K} + \frac{2\beta r\gamma N^3}{K} + ce\alpha P - c\gamma \alpha NP + ce\varphi Q - \beta eNQ \right) = 0 \tag{26}$$

The parameter calculation of equation (1) is as follows

$$r = \frac{\sum terkonfirmasi}{total}$$
$$= \frac{150}{295}$$
$$= 0{,}373$$
$$K = \frac{\sum for\ terak\ tidak\ dilakukan}{total}$$
$$= \frac{245}{295}$$
$$= 0{,}831$$

Bahan dengan hak cipta

$$c = \frac{\sum fot\ torak\ tidak\ dilakukan\ bakteriologis}{total}$$
$$= \frac{113}{295}$$
$$= 0{,}383$$

$$e = \frac{\sum fot\ torak\ tidak\ dilakukan\ terdiagnosis\ klinis}{total}$$
$$= \frac{35}{295}$$
$$= 0{,}119$$
$$\alpha = \left(\frac{\sum M\ positif\ bakteriologis}{total}\right)\left(\frac{bakteriologis}{total}\right)$$
$$= \left(\frac{117}{295}\right)\left(\frac{126}{total}\right)$$
$$= 0{,}170$$
$$\beta = \left(\frac{\sum M.positif\ bakteriologis}{total}\right)\left(\frac{terkonfirmasi}{total}\right)$$
$$= \left(\frac{117}{295}\right)\left(\frac{150}{total}\right)$$
$$= 0{,}148$$
$$\varphi = \left(\frac{\sum M.positif\ terdiagnosis\ klinis}{total}\right)\left(\frac{terdiagnosis\ klinis}{total}\right)$$
$$= \left(\frac{21}{295}\right)\left(\frac{60}{total}\right)$$
$$= 0{,}014$$
$$\gamma = \left(\frac{\sum M.positif\ terdiagnosis\ klinis}{total}\right)\left(\frac{terkonfirmasi}{total}\right)$$
$$= \left(\frac{21}{295}\right)\left(\frac{150}{total}\right)$$
$$= 0{,}026$$

Based on these parameter values, a prey predator model with two predators is obtained

$$\frac{dN}{dt} = 0{,}373N\left(1 - \frac{N}{0{,}831}\right) - 0{,}170PN - 0{,}014QN \quad (27)$$
$$\frac{dP}{dt} = -0{,}383P + 0{,}148NP \quad (28)$$
$$\frac{dQ}{dt} = -0{,}119Q + 0{,}026NQ \quad (29)$$

Furthermore, the values of these parameters are substituted at the known fixed points as follows

For the first fixed point obtained:

$$TE_1 = (0{,}0{,}0) \quad (30)$$

For the second fixed point:

$$TE_2 = (K, 0{,}0)$$
$$= (0{,}831; 0) \quad (31)$$

For the third fixed point obtained

$$TE_3 = \left(\frac{c}{\beta}; \frac{1}{\alpha}\left(r - \frac{rc}{\beta K}\right); 0\right)$$
$$= (2{,}588; -7{,}93; 0) \quad (32)$$

For the fourth fixed point obtained:

Bahan dengan hak cipta

$$TE_4 = \left(\frac{e}{\gamma}; 0; \frac{1}{\varphi}\left(r - \frac{re}{\gamma K}\right)\right)$$
$$= (4{,}577; 0; -110)$$

(33)

For the fifth fixed point obtained:

$$TE_5 = \left(\frac{c}{\beta}; \frac{1}{\alpha}\left(r - \frac{rc}{\beta K} - \varphi Q^*\right); Q^*\right)$$
$$= (2{,}588;\ -4{,}647 - 0{,}082Q^*;\ Q^*) \quad (34)$$

For the sixth fixed point obtained:

$$TE_6 = \left(\frac{e}{\gamma}; \frac{1}{\alpha}\left(r - \frac{re}{\gamma K} - \varphi Q^*\right); Q^*\right)$$
$$= (4{,}577;\ -9{,}571 - 0{,}082Q^*;\ Q^*) \quad (35)$$

For the seventh fixed point obtained:

$$TE_7 = \left(\frac{c}{\beta}; P^*; \frac{1}{\varphi}\left(r - \frac{rc}{\beta K} - \alpha P^*\right)\right)$$
$$= (2{,}588; P^*;\ -56{,}429 - 12{,}143P^*) \quad (36)$$

For the eighth fixed point obtained:

$$TE_8 = \left(\frac{e}{\gamma}; P^*; \frac{1}{\varphi}\left(r - \frac{re}{\gamma K} - \alpha P^*\right)\right)$$
$$= (4{,}577; P^*;\ -116{,}214 - 12{,}143P^*) \quad (37)$$

Furthermore, to find out the stability of the fixed point, the fixed point value of equation (30) and the parameters are substituted in equation (26) so that it is obtained

$$\lambda^3 + 0{,}129\lambda^2 - 0{,}141\lambda - 0{,}017 = 0 \quad (38)$$

So the lamda value of equation (38) is $\lambda_1 = 0{,}3723$; $\lambda_2 = -0{,}3817$ dan $\lambda_3 = -0{,}1196$
Furthermore, to determine the stability of the fixed point, the fixed point value of equation (31) and the parameters are substituted in equation (26) so that it is obtained

$$\lambda^3 + 0{,}729\lambda^2 - 0{,}16\lambda - 0{,}013 = 0 \quad (39)$$

So the lamda value of equation (39) is $\lambda_1 = -0{,}4239$; $\lambda_2 = -0{,}1526$ dan $\lambda_3 = -0{,}1526$
To find out the stability of the fixed point, the fixed point value of equation (32) and the parameters are substituted in equation (26) so that it is obtained

$$\lambda^3 + 0{,}654\lambda^2 - 0{,}484\lambda - 0{,}015 = 0 \quad (40)$$

So the lamda value of equation (40) is $\lambda_1 = -1{,}1045$; $\lambda_2 = 0{,}4180$ dan $\lambda_3 = 0{,}0325$
Furthermore, to determine the stability of the fixed point, the fixed point value of equation (33) and the parameters are substituted in equation (26) so that it is obtained

$$\lambda^3 + 1{,}902\lambda^2 - 0{,}829\lambda + 8{,}926 = 0 \quad (41)$$

So the lamda value of equation (41) is $\lambda_1 = -3{,}0990$; $\lambda_2 = 0{,}5985$ dan $\lambda_3 = 0{,}5985$
Furthermore, to determine the stability of the fixed point, the fixed point value of equation (34) and the parameters are substituted in equation (26) so that it is obtained

$$\lambda^3 + 1{,}212\lambda^2 + (-0{,}147 - 0{,}004Q^*)\lambda + (0{,}12 - 0{,}044Q^*) = 0 \quad (42)$$

If $Q^* = 2$, the lamda value of equation (42) is $\lambda_1 = -1{,}3449\lambda_2 = 0{,}0665$; and $\lambda_3 = 0{,}0665$, and if $Q^* = 3$, the lamda value of equation (42) is $\lambda_1 = -1{,}3252$; $\lambda_2 = 0{,}1673$ dan $\lambda_3 = -0{,}054$

Bahan dengan hak cipta

Furthermore, to determine the stability of the fixed point, the fixed point value of equation (35) and the parameters are substituted in equation (26) so that it is obtained

$$1{,}815\lambda^2 + (-1{,}721 - 0{,}007Q^*)\lambda + (0{,}129 - 0{,}08Q^*) = 0 \qquad (43)$$

If $Q^* = 2$, the lamda value of equation (43) is $\lambda_1 = -2{,}5032$; $\lambda_2 = 0{,}7057$; and $\lambda_3 = -0{,}0175$ and if $Q^* = 5$ then the lamda value of equation (43) is $\lambda_1 = -2{,}4792$; $\lambda_2 = 0{,}8007$ dan $\lambda_3 = -0{,}0601$.

Furthermore, to determine the stability of the fixed point, the fixed point value of equation (36) and the parameters are substituted in equation (26) so that it is obtained

$$\lambda^3 + 1{,}212\lambda^2 + (0{,}084 + 0{,}05P^*)\lambda + (2{,}581 + 0{,}551P^*) = 0 \qquad (44)$$

If $P^* = 2$, the lamda value of equation (44) is $\lambda_1 = -2{,}0219$; $\lambda_2 = 0{,}4050$ dan $\lambda_3 = 0{,}4050$

Furthermore, to determine the stability of the fixed point, the fixed point value of equation (37) and the parameters are substituted in equation (26) so that it is obtained

$$\lambda^3 + 1{,}212\lambda^2 + (0{,}084 + 0{,}05P^*)\lambda + (2{,}581 + 0{,}551P^*) = 0 \qquad (45)$$

If $P^* = 2$, the lamda value of equation (45) is $\lambda_1 = -3{,}1664$; $\lambda_2 = 0{,}6757$ dan $\lambda_3 = 0{,}6757$

12. Application of Fuzzy Based Prey Predator Model

Substitute fixed points N = 4,577 in equation (27) so that they are obtain

$$\dot{N} = 0{,}373(4{,}577)\left(1 - \frac{4{,}577}{0{,}831}\right) - 0{,}170(4{,}577)P - 0{,}014(4{,}577)Q$$

Can be simplified to be

$$\dot{N} = -7{,}6958482142 - 0{,}77809P - 0{,}064078Q \qquad (46)$$

Subsequently the substitution of fixed points P = -9,981 in equation (28) follows

$$\dot{P} = -0{,}383(-9{,}981) + 0{,}148(-9{,}981)N$$

Can be simplified to be

$$\dot{P} = 3{,}822723 - 1{,}477188N \qquad (47)$$

Furthermore, substitution of fixed points Q = 5 in equation (29) follows

$$\dot{Q} = -0{,}119(5) + 0{,}026(5)N$$

Can be simplified to be

$$\dot{Q} = -0{,}595 + 0{,}13N \qquad (48)$$

From equations (46), (47) and (48) can be made a C matrix measuring 3 × 3 and vector B measuring 3 × 1 as follows:

$$C = \begin{bmatrix} 0 & -0{,}77809 & -0{,}064078 \\ -1{,}477188 & 0 & 0 \\ 0{,}13 & 0 & 0 \end{bmatrix} \text{ and } B = \begin{bmatrix} -7{,}6958482142 \\ 3{,}822723 \\ -0{,}595 \end{bmatrix}$$

By using menggunakan $\lambda_1 = -2{,}4792$ the eigenvectors will be searched from the C matrix as follows: $(\lambda_1 - A)x = 0$

$$\left[-2{,}4792\begin{bmatrix}1 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & 1\end{bmatrix} - \begin{bmatrix} 0 & -0{,}77809 & -0{,}064078 \\ -1{,}477188 & 0 & 0 \\ 0{,}13 & 0 & 0 \end{bmatrix}\right]\begin{bmatrix}N\\P\\Q\end{bmatrix} = \begin{bmatrix}0\\0\\0\end{bmatrix}$$

Bahan dengan hak cipta

$$\begin{bmatrix} -2,4792 & 0 & 0 \\ 0 & -2,4792 & 0 \\ 0 & 0 & -2,4792 \end{bmatrix} - \begin{bmatrix} 0 & -0,77809 & -0,064078 \\ -1,477188 & 0 & 0 \\ 0,13 & 0 & 0 \end{bmatrix} \begin{bmatrix} N \\ P \\ Q \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} -2,4792 & 0,77809 & 0,064078 \\ 1,477188 & -2,4792 & 0 \\ -0,13 & 0 & -2,4792 \end{bmatrix} \begin{bmatrix} N \\ P \\ Q \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

Can be written to be

$$-2,4792N + 0,77809P + 0,064078Q = 0 \quad (49)$$
$$1,477188N - 2,4792P = 0 \quad (50)$$
$$-0,13N - 2,4792\,Q = 0 \quad (51)$$

So the eigenvector of equation (49) is

$$-2,4792N + 0,77809P + 0,064078Q = 0$$
$$0,064078Q = 2,4792N - 0,77809P$$
$$Q = \frac{2,4792N - 0,77809P}{0,064078}$$

$$\begin{bmatrix} 1 \\ 1 \\ 26,5474889978 \end{bmatrix}$$

For the eigenvector of equation (50) it is obtained

$$1,477188N - 2,4792P = 0$$
$$-2,4792P = -1,477188N$$
$$P = \frac{-1,477188N}{-2,4792}$$

$$\begin{bmatrix} 1 \\ 0,5958325266 \\ 0 \end{bmatrix}$$

For the eigenvector of equation (51) it is obtained

$$-0,13N - 2,4792\,Q = 0$$
$$-2,4792\,Q = 0,13N$$
$$Q = \frac{0,13N}{-2,4792}$$

$$\begin{bmatrix} 1 \\ 0 \\ -0,0524362698 \end{bmatrix}$$

From the known eigenvectors, the fundamental matrix is obtained as follows:

$$\psi(t) = \begin{bmatrix} e^{-2,4792t} & e^{-2,4792t} & e^{-2,4792t} \\ e^{-2,4792t} & 0,5958325266e^{-2,4792t} & 0 \\ 26,5474889978e^{-2,4792t} & 0 & -0,0524362698e^{-2,4792t} \end{bmatrix} \quad s(52)$$

Substitute equation (52) in equation (9) as follows

$$X(t) = \psi(t)\psi^{-1}(0)X(0) + \psi(t)\int_0^t \psi^{-1}(s)B\,ds$$

Then obtained

Bahan dengan hak cipta

$$N(t) = 150e^{-2,4792t} + e^{-2,4792t}(2,621925048e^{2,4792t} - 2,621925048) - e^{-2,4792t}(0,020310269e^{2,4792t} - 0,020310269) - e^{-2,4792t}(5,705780726e^{2,4792t} - 5,705780726) \quad (53)$$

And

$$P(t) = 125e^{-2,4792t} + 0,595832527e^{-2,4792t}(2,621925048e^{2,4792t} - 2,621925048) - e^{-2,4792t}(0,020310269e^{2,4792t} - 0,020310269) \quad (54)$$

And

$$Q(t) = 60e^{-2,4792t} - 26,547489e^{-2,4792t}(0,020310269e^{2,4792t} - 0,020310269) + 0,05243627e^{-2,4792t}(5,705780726e^{2,4792t} - 5,705780726) \quad (55)$$

From equation (53), (54) and equation (55) by using MATLAB R2015a software, Graph 1 is obtained as follows:

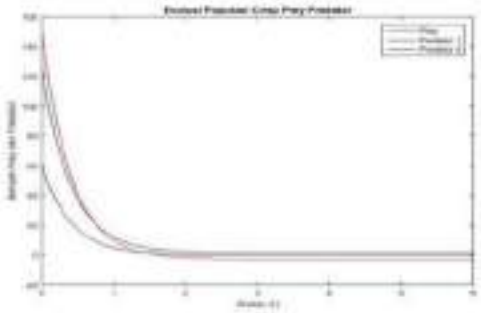

Fig. 1. Population of Crisp Prey Predator

In Figure 1 it can be explained that the population population and predator population both decreased for one month after it was convergent.

13. Application of Fuzzy Initial Value to Prey Predator Models

By substituting the initial values for triangular fuzzy numbers, it is obtained

$$\widetilde{N_0} = \begin{cases} \frac{x-110}{40}, & 110 < x \leq 150 \\ \frac{170-x}{20}, & 150 < x \leq 170 \end{cases}$$

$$\widetilde{P_0} = \begin{cases} \frac{x-85}{40}, & 85 < x \leq 125 \\ \frac{145-x}{20}, & 125 < x \leq 145 \end{cases}$$

$$\widetilde{Q_0} = \begin{cases} \frac{x-20}{40}, & 20 < x \leq 60 \\ \frac{80-x}{20}, & 60 < x \leq 80 \end{cases}$$

$$(\widetilde{N_0})^{\alpha} = [40\alpha + 110, 170 - 20\alpha]$$

$$(\widetilde{P_0})^{\alpha} = [40\alpha + 85, 145 - 20\alpha]$$

$$(\widetilde{Q_0})^{\alpha} = [40\alpha + 20, 80 - 20\alpha]$$

So $\overline{X_0} = \begin{bmatrix} 170 \\ 145 \\ 80 \end{bmatrix}$ and $\underline{X_0} = \begin{bmatrix} 110 \\ 85 \\ 20 \end{bmatrix}$

Bahan dengan hak cipta

Then by using $\overline{X_0} = \begin{bmatrix} 170 \\ 145 \\ 80 \end{bmatrix}$ in equation (10) then it is obtained

$$P(t) = 170e^{-2,4792t} + e^{-2,4792t}(2,621925048e^{2,4792t} - 2,621925048) - e^{-2,4792t}(0,020310269e^{2,4792t} - 0,020310269) - e^{-2,4792t}(5,705780726e^{2,4792t} - 5,705780726) \quad (56)$$

And

$$P(t) = 145e^{-2,4792t} + 0,595832527e^{-2,4792t}(2,621925048e^{2,4792t} - 2,621925048) - e^{-2,4792t}(0,020310269e^{2,4792t} - 0,020310269) \quad (57)$$

And

$$Q(t) = 80e^{-2,4792t} - 26,547489e^{-2,4792t}(0,020310269e^{2,4792t} - 0,020310269) + 0,05243627e^{-2,4792t}(5,705780726e^{2,4792t} - 5,705780726) \quad (58)$$

From equations (56), (57) and equations (58), using MATLAB R2015a software, Graph 2 is obtained as follows:

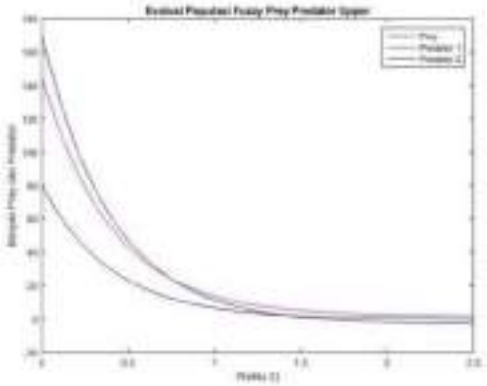

Fig. 2. Fuzzy Population Prey upper predator

Bahan dengan hak cipta

In Figure 2, it can be explained that the fuzzy population prey predator uppuer is convergent.

For $\underline{X_0} = \begin{bmatrix} 110 \\ 85 \\ 20 \end{bmatrix}$ it is referred to in equation (10) then obtained

$$N(t) = 110e^{-2,4792} + e^{-2,4792}(2,621925048e^{2,4792} - 2,621925048) - e^{-2,4792}(0,020310269e^{2,4792} - 0,020310269) - e^{-2,4792}(5,705780726e^{2,4792} - 5,705780726) \quad (59)$$

And

$$P(t) = 85e^{-2,4792} + 0,595832527e^{-2,4792}(2,621925048e^{2,4792} - 2,621925048) - e^{-2,4792}(0,020310269e^{2,4792} - 0,020310269) \quad (60)$$

And

$$Q(t) = 20e^{-2,4792} - 26,547489e^{-2,4792}(0,020310269e^{2,4792} - 0,020310269) + 0,05243627e^{-2,4792}(5,705780726e^{2,4792} - 5,705780726) \quad (61)$$

From equations (59), (60) and equations (61) then using MATLAB R2015a software is obtained in Graph 3 as follows:

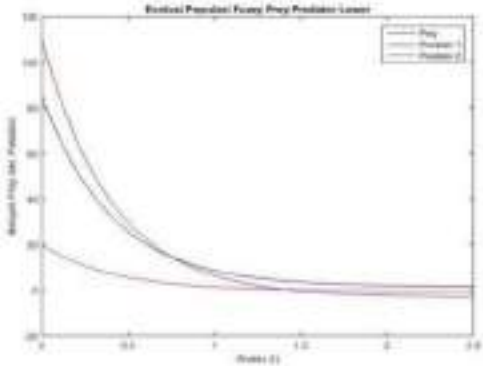

Fig. 3. Lower lower Fuzzy prey Predator population

In Figure 3, it can be explained that fuzzy prey populations are lower converging predators. Prey upper and prey lowe combined results can be seen in graph 4 as follows:

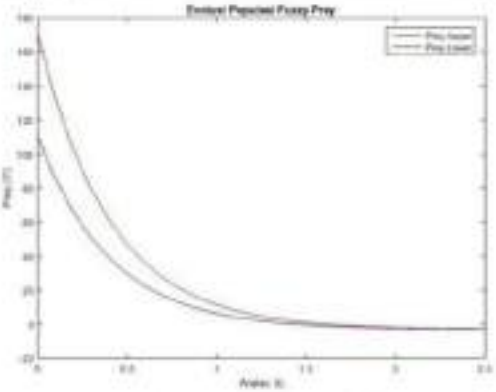

Fig. 4. The prey upper and lower prey populations proved convergent

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The combined results of the first upper predator and first predator can be seen in graph 5 as follows:

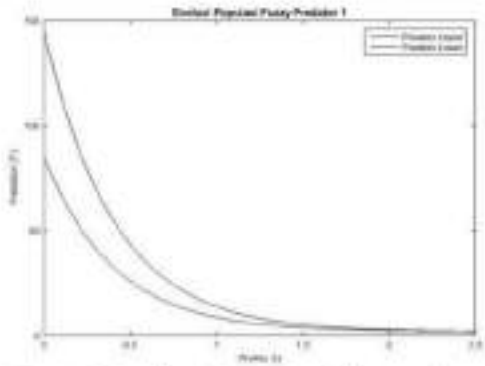

Figure 5 The first Fuzzy population predator

In figure 5 it can be explained that the upper first predator population and the first lower predator proved convergent

The combined results of the second upper and second predator lowe can be seen in graph 6 as follows:

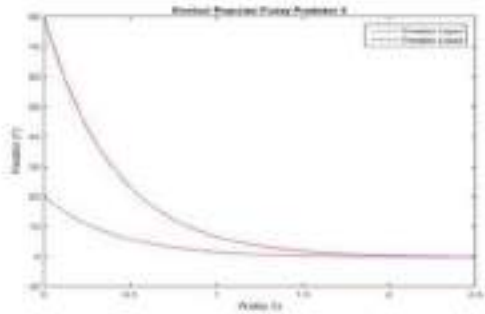

Figure 6 Second Population Fuzzy Predator

In figure 6 it can be explained that the upper first predator population and the first lower predator proved convergent.

14. Conclude

Based on the simulation results using the Fuzzy Prey Predator method, the conclusion is that the population of Prey and Predator is stable, so that after applying the Fuzzy Prey Predator model, convergent results are obtained. Prey population and Predator population have declined for one month, after that covergen ..

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