BAB V
PENUTUP

A. Kesimpulan

Berdasarkan uraian pembahasan sebelumnya, maka dapat ditarik kesimpulan sebagai berikut:

a. Diperoleh model *predator-prey* antara populasi burung hantu, padi, dan tikus dengan kontrol berupa perangkap tikus

$$\frac{dP}{dt} = \alpha P\left(1 - \frac{P}{K}\right) - \beta PT$$

$$\frac{dT}{dt} = \delta PT - \gamma BT - \mu T - uT$$

$$\frac{dB}{dt} = \sigma BT\left(\frac{B}{A} - 1\right) - \theta B$$

b. Terdapat lima titik ekuilibrium yang diperoleh dari model *predator-prey* antara populasi padi, tikus, dan burung hantu tanpa kontrol ($u = 0$)

- Titik Ekuilibrium Pertama (tidak stabil)

$$E_1 = (0,0,0)$$

- Titik Ekuilibrium Kedua (stabil bersyarat)

$$E_2 = (K, 0,0)$$

- Titik Ekuilibrium Ketiga (stabil bersyarat)

$$E_3 = \left(\frac{\mu}{\delta}, \frac{\alpha(K\delta - \mu)}{K\beta\delta}, 0\right)$$

- Titik Ekuilibrium Keempat (tidak stabil)

$$E_4 = \left(\frac{\left(\frac{1}{2}\frac{-\alpha\mu\sigma + c_1 + \sqrt{c_2 - c_3}}{\gamma\alpha\sigma}\right)\gamma + \mu}{\delta}, -\frac{\mu A}{\sigma\left(-\frac{1}{2}\frac{-\alpha\mu\sigma + c_1 + \sqrt{c_2 - c_3}}{\gamma\alpha\sigma} + A\right)}, \frac{1}{2}\frac{-\alpha\mu\sigma + c_1 + \sqrt{c_2 - c_3}}{\gamma\alpha\sigma}\right)$$

- Titik Ekuilibrium Kelima (tidak stabil)

$$E_5 = \left(\frac{\left(\frac{1}{2}\frac{-\alpha\mu\sigma + c_1 - \sqrt{c_2 - c_3}}{\gamma\alpha\sigma}\right)\gamma + \mu}{\delta}, -\frac{\mu A}{\sigma\left(-\frac{1}{2}\frac{-\alpha\mu\sigma + c_1 - \sqrt{c_2 - c_3}}{\gamma\alpha\sigma} + A\right)}, \frac{1}{2}\frac{-\alpha\mu\sigma + c_1 - \sqrt{c_2 - c_3}}{\gamma\alpha\sigma}\right)$$

c. Diperoleh $u^* = \min\left\{\max\left\{0, \frac{\lambda_2 T}{C_2}\right\}, 1\right\}$ yang meminimumkan jumlah populasi tikus yang memangsa padi dan biaya pemasangan perangkap yang keluarkan untuk mengendalikan tikus serta yang memenuhi model *predator-prey* antara populasi padi, tikus, dan burung hantu. Simulasi numerik menggambarkan bahwa penerapan kontrol perangkap tikus dapat meningkatkan populasi padi.

B. Saran

Penelitian ini fokus pada pengkajian model *predator-prey* antara populasi padi, tikus, dan burung hantu dengan diberikan kontrol yang berupa perangkap tikus. Penelitian selanjutnya disarankan agar mempertimbangkan penambahan respon Holling tipe II agar menghasilkan model yang rasional.

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LAMPIRAN

Lampiran 1. Simulasi Numerik Titik Ekuilibrium Kedua

```
> restart :
>
with(linalg) : with(LinearAlgebra) : with(plots) : with(Student[VectorCalculus]) : with(DEtools) : with(plots,
    implicitplot) : with(Student[Calculus1]) :
```

$> dP := \alpha \cdot P \cdot \left(1 - \frac{P}{K}\right) - \beta \cdot P \cdot T;\ dT := \delta \cdot P \cdot T - \gamma \cdot B \cdot T - \mu \cdot T;\ dB := \sigma \cdot B \cdot T \cdot \left(\frac{B}{A} - 1\right) - \theta \cdot B;$

$$dP := \alpha P \left(1 - \frac{P}{K}\right) - \beta P T$$

$$dT := -B T \gamma + P T \delta - T \mu$$

$$dB := \sigma B T \left(\frac{B}{A} - 1\right) - \theta B$$

$> TK := solve(\{dP, dT, dB\}, \{P, T, B\});$

$$TK := \{B = 0, P = 0, T = 0\}, \{B = 0, P = K, T = 0\}, \left\{B = -\frac{\mu}{\gamma}, P = 0, T = -\frac{\theta A \gamma}{\sigma (A \gamma + \mu)}\right\}, \left\{B = 0, P = \frac{\mu}{\delta}, T = \frac{\alpha (K \delta - \mu)}{K \beta \delta}\right\}, \left\{B = -\frac{K\, RootOf\left(K \beta \delta \sigma \_Z^2 + (A \alpha \gamma \sigma - K \alpha \delta \sigma + \alpha \mu \sigma)\_Z + A \alpha \gamma \theta\right) \beta \delta - K \alpha \delta + \mu \alpha}{\gamma \alpha}, P = -\frac{K \left(RootOf\left(K \beta \delta \sigma \_Z^2 + (A \alpha \gamma \sigma - K \alpha \delta \sigma + \alpha \mu \sigma)\_Z + A \alpha \gamma \theta\right) \beta - \alpha\right)}{\alpha}, T = RootOf\left(K \beta \delta \sigma \_Z^2 + (A \alpha \gamma \sigma - K \alpha \delta \sigma + \alpha \mu \sigma)\_Z + A \alpha \gamma \theta\right)\right\}$$

$> TK2 := TK[2];$

$$TK2 := \{B = 0, P = K, T = 0\}$$

$> jac := Matrix(Jacobian([dP, dT, dB], [P, T, B]));$

$$jac := \begin{bmatrix} \alpha \left(1 - \frac{P}{K}\right) - \frac{\alpha P}{K} - T \beta & -\beta P & 0 \\ T \delta & -B \gamma + P \delta - \mu & -T \gamma \\ 0 & \sigma B \left(\frac{B}{A} - 1\right) & \sigma T \left(\frac{B}{A} - 1\right) + \frac{\sigma B T}{A} - \theta \end{bmatrix}$$

$> jacTK2 := subs(TK2, jac);$

$$jacTK2 := \begin{bmatrix} -\alpha & -K \beta & 0 \\ 0 & K \delta - \mu & 0 \\ 0 & 0 & -\theta \end{bmatrix}$$

$>$

$parameter := \{\alpha = 0.6, K = 100, \beta = 0.01, \delta = 0.003, \gamma = 0.004, \mu = 0.4, \sigma = 0.003, A = 10, \theta = 0.05, P = P(t), T = T(t), B = B(t)\};$

$TitikStasioner := subs(parameter, TK2);$

$parameter := \{A = 10, B = B(t), K = 100, P = P(t), T = T(t), \alpha = 0.6, \beta = 0.01, \delta = 0.003, \gamma = 0.004, \mu = 0.4, \sigma = 0.003, \theta = 0.05\}$

$$TitikStasioner := \{B(t) = 0, P(t) = 100, T(t) = 0\}$$

> $MatrixTK2 := subs(parameter, jacTK2);$

$$MatrixTK2 := \begin{bmatrix} -0.6 & -1.00 & 0 \\ 0 & -0.100 & 0 \\ 0 & 0 & -0.05 \end{bmatrix}$$

> $CharaTK2 := simplify(factor(CharacteristicPolynomial(MatrixTK2, \lambda)));$

$$CharaTK2 := (0.6 + \lambda)\ (\lambda + 0.1)\ (0.05 + \lambda)$$

> $eigenTK2 := fsolve(CharaTK2, \lambda, complex);$

$$eigenTK2 := -0.6000000000, -0.1000000000, -0.05000000000$$

>

$sis := diff(P(t), t) = subs(parameter, dP), diff(T(t), t) = subs(parameter, dT), diff(B(t), t) = subs(parameter, dB);$

$$sis := \frac{d}{dt} P(t) = 0.6\, P(t) \left(1 - \frac{1}{100} P(t)\right) - 0.01\, P(t)\, T(t), \frac{d}{dt} T(t) = -0.004\, B(t)\, T(t) + 0.003\, P(t)\, T(t) - 0.4\, T(t), \frac{d}{dt} B(t) = 0.003\, B(t)\, T(t) \left(\frac{1}{10} B(t) - 1\right) - 0.05\, B(t)$$

> $inicial := P(0) = 80, T(0) = 10, B(0) = 6;$

$$inicial := P(0) = 80, T(0) = 10, B(0) = 6$$

> $sol := dsolve(\{sis, inicial\}, numeric);$

$sol :=$ **proc**(x_rkf45) ... **end proc**

> $plotP := odeplot(sol, [t, P(t)], 0..150, color = green);$

> $plotT := odeplot(sol, [t, T(t)], 0..150, color = red);$

> $plotB := odeplot(sol, [t, 7 \cdot B(t)], 0..150, color = blue);$

> $display(plotP, plotT, plotB);$

Lampiran 2. Simulasi Numerik Titik Ekuilibrium Ketiga

> $restart:$

>

$with(linalg) : with(LinearAlgebra) : with(plots) : with(Student[VectorCalculus]) : with(DEtools) : with(plots, implicitplot) : with(Student[Calculus1]) :$

> $dP := \alpha \cdot P \cdot \left(1 - \frac{P}{K}\right) - \beta \cdot P \cdot T;\ dT := \delta \cdot P \cdot T - \gamma \cdot B \cdot T - \mu \cdot T;\ dB := \sigma \cdot B \cdot T \cdot \left(\frac{B}{A} - 1\right) - \theta \cdot B;$

$$dP := \alpha\, P \left(1 - \frac{P}{K}\right) - \beta\, P\, T$$

$$dT := -B\, T\, \gamma + P\, T\, \delta - T\, \mu$$

$$dB := \sigma\, B\, T \left(\frac{B}{A} - 1\right) - \theta\, B$$

> $TK := solve(\{dP, dT, dB\}, \{P, T, B\});$

$$TK := \{B=0, P=0, T=0\}, \{B=0, P=K, T=0\}, \left\{B=-\frac{\mu}{\gamma}, P=0, T=-\frac{\theta A \gamma}{\sigma (A\gamma+\mu)}\right\}, \left\{B=0, P=\frac{\mu}{\delta}, T=\frac{\alpha (K\delta-\mu)}{K\beta\delta}\right\}, \left\{B=-\frac{K\, RootOf\left(K\beta\delta\sigma\_Z^2+(A\alpha\gamma\sigma-K\alpha\delta\sigma+\alpha\mu\sigma)\_Z+A\alpha\gamma\theta\right)\beta\delta-K\alpha\delta+\mu\alpha}{\gamma\alpha}, P=-\frac{K\left(RootOf\left(K\beta\delta\sigma\_Z^2+(A\alpha\gamma\sigma-K\alpha\delta\sigma+\alpha\mu\sigma)\_Z+A\alpha\gamma\theta\right)\beta-\alpha\right)}{\alpha}, T=RootOf\left(K\beta\delta\sigma\_Z^2+(A\alpha\gamma\sigma-K\alpha\delta\sigma+\alpha\mu\sigma)\_Z+A\alpha\gamma\theta\right)\right\}$$

> TK4 := TK[4];

$$TK4 := \left\{B=0, P=\frac{\mu}{\delta}, T=\frac{\alpha(K\delta-\mu)}{K\beta\delta}\right\}$$

> jac := Matrix(Jacobian([dP, dT, dB], [P, T, B]));

$$jac := \begin{bmatrix} \alpha\left(1-\frac{P}{K}\right)-\frac{\alpha P}{K}-T\beta & -\beta P & 0 \\ T\delta & -B\gamma+P\delta-\mu & -T\gamma \\ 0 & \sigma B\left(\frac{B}{A}-1\right) & \sigma T\left(\frac{B}{A}-1\right)+\frac{\sigma B T}{A}-\theta \end{bmatrix}$$

> jacTK4 := subs(TK4, jac);

$$jacTK4 := \begin{bmatrix} \alpha\left(1-\frac{\mu}{\delta K}\right)-\frac{\mu\alpha}{\delta K}-\frac{\alpha(K\delta-\mu)}{K\delta} & -\frac{\beta\mu}{\delta} & 0 \\ \frac{\alpha(K\delta-\mu)}{K\beta} & 0 & -\frac{\alpha(K\delta-\mu)\gamma}{K\beta\delta} \\ 0 & 0 & -\frac{\sigma\alpha(K\delta-\mu)}{K\beta\delta}-\theta \end{bmatrix}$$

>

parameter := {α = 0.5, K = 100, β = 0.01, δ = 0.005, γ = 0.001, μ = 0.1, σ = 0.002, A = 5, θ = 0.05, P = P(t), T = T(t), B = B(t)};
TitikStasioner := subs(parameter, TK4);

$$parameter := \{A=5, B=B(t), K=100, P=P(t), T=T(t), \alpha=0.5, \beta=0.01, \delta=0.005, \gamma=0.001, \mu=0.1, \sigma=0.002, \theta=0.05\}$$

$$TitikStasioner := \{B(t)=0, P(t)=20.00000000, T(t)=40.00000000\}$$

> MatrixTK4 := subs(parameter, jacTK4);

$$MatrixTK4 := \begin{bmatrix} -0.1000000000 & -0.2000000000 & 0 \\ 0.2000000000 & 0 & -0.04000000000 \\ 0 & 0 & -0.1300000000 \end{bmatrix}$$

> CharaTK4 := simplify(factor(CharacteristicPolynomial(MatrixTK4, λ)));

$$CharaTK4 := (\lambda+0.1300000000000000004)\left(\lambda^2+0.1000000000000000006\,\lambda+0.0400000000000000\right)$$

> eigenTK4 := fsolve(CharaTK4, λ, complex);

$$eigenTK4 := -0.1300000000, -0.05000000000-0.1936491673\,I, -0.05000000000+0.1936491673\,I$$

>

sis := diff(P(t), t) = subs(parameter, dP), diff(T(t), t) = subs(parameter, dT), diff(B(t), t) = subs(parameter, dB);

$$sis := \frac{d}{dt} P(t) = 0.5\, P(t) \left(1 - \frac{1}{100} P(t)\right) - 0.01\, P(t)\, T(t),\ \frac{d}{dt} T(t) = -0.001\, B(t)\, T(t) + 0.005\, P(t)\, T(t) - 0.1\, T(t),\ \frac{d}{dt} B(t) = 0.002\, B(t)\, T(t) \left(\frac{1}{5} B(t) - 1\right) - 0.05\, B(t)$$

```
> inicial := P(0) = 80, T(0) = 10, B(0) = 6;
                              inicial := P(0) = 80, T(0) = 10, B(0) = 6
> sol := dsolve({sis, inicial}, numeric);
                              sol := proc(x_rkf45) ... end proc
> sol := dsolve({sis, inicial}, numeric);
                              sol := proc(x_rkf45) ... end proc
> plotP := odeplot(sol, [t, P(t)], 0..150, color = green);
> plotT := odeplot(sol, [t, T(t)], 0..150, color = red);
> plotB := odeplot(sol, [t, 7· B(t)], 0..150, color = blue);
> display(plotP, plotT, plotB);
```

Lampiran 3. *Syntax* Model tanpa diterapkan Kontrol

```
function yt = PTB_TK(t,y)
%Nilai Parameter
alpha = 0.5; %Laju pertumbuhan padi
beta = 0.01; %Laju interaksi padi dan tikus
delta = 0.005; %Laju interaksi tikus dan padi
gamma = 0.001; %laju interaksi tikus dan burung hantu
mu = 0.1; %Laju kematian alami tikus
sigma = 0.002; %laju burung hantu dan tikus
theta = 0.05; % laju kematian alami burung hantu
K = 100; %carring capacity
A = 5;% allee effect

%Model Matematika
yt = zeros(3,1);
yt(1) = alpha*y(1)*(1-(y(1)/K)) - (beta*y(1)*y(2));
%P
yt(2) = (delta*y(1)*y(2)) - gamma*y(3)*y(2) -
mu*y(2); %T
yt(3) = sigma*y(3)*y(2)*((y(3)/A)-1) - theta*y(3); %B
```

Lampiran 4. *Syntax* Simulasi Numerik Model dengan diterapkan Kontrol

```
clear all;
close all;
clc;
%Nilai parameter
alpha = 0.5; %Laju pertumbuhan padi
beta = 0.01; %Laju interaksi padi dan tikus
delta = 0.005; %Laju interaksi tikus dan padi
```

```
gamma = 0.001; %laju interaksi tikus dan burung hantu
mu = 0.1; %Laju kematian alami tikus
sigma = 0.002; %laju burung hantu dan tikus
theta = 0.05;%Laju kematian alami burung hantu
K = 100; %carring capacity
A= 5;% allee effect

%Nilai awal
P0 = 80;
T0 = 10;
B0 = 6;

tfinal = 100; %waktu akhir pengamatan
C1 = 1;
C2 = 5;

y1 =
PTB_u(alpha,beta,delta,gamma,mu,sigma,theta,K,A,C1,C2
,P0,T0,B0,tfinal);

options = odeset ('RelTol',1e-4,'AbsTol',[1e-4 1e-4
1e-4]);
t0 = 0;
y0 = [P0, T0, B0];

disp('         ')
T1 = linspace(t0,tfinal,1001);
[t,y]=ode45('PTB_TK',T1,y0,options);

%Plot populasi tikus
figure(1)
plot(t,y(:,2),'r', y1(1,:),y1(3,:),'-
b','LineWidth',2)
xlabel('t(hari)')
ylabel('Populasi Tikus')
legend('tanpa diterapkan kontrol', 'diterapkan
kontrol u')

%plot profil kontrol
figure(2)
plot(y1(1,:),y1(5,:),'-b','LineWidth',2)
xlabel('t(hari)')
ylabel('profil kontrol')
legend('u')
axis([0 tfinal 0 1])

%Plot populasi padi
```

```
figure(3)
plot(t,y(:,1),'r', y1(1,:),y1(2,:),'-
b','LineWidth',2)
xlabel('t(hari)')
ylabel('Populasi Padi')
legend('tanpa diterapkan kontrol', 'diterapkan
kontrol u')

%Plot populasi burung hantu
figure(4)
plot(t,y(:,3),'r', y1(1,:),y1(4,:),'-
b','LineWidth',2)
xlabel('t(hari)')
ylabel('Populasi Burung Hantu')
legend('tanpa diterapkan kontrol', 'diterapkan
kontrol u')

%perhitungan indeks performansi
H = C1*y1(3,:) + 0.5*C2*y1(5,:).^2;
T = y1(1,:);
J1 = trapz(T,H);
```