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A Model for the Effectiveness of Hibernate on Complex Ecology System

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Abstract: There are significant differences between plant activities and animal activities in ecological networks. On this basis, this article aims to evaluate the effectiveness of the hibernate (forgetting and remembering mechanism). For this purpose, the hibernation interaction is derived model (linear UAH model) of continuous-time individual-level activity. This model is an effective approach to understand the effectiveness of the construction of the communication network on the complex ecology system. These standards cover the influence of the fundamental parameters and network structure on network effectiveness of hibernate. Theoretical analysis shows that the supreme eigenvalue of the related model matrix is determined whether hibernators tend to become extinct or continue. Moreover, the simulation experiments demonstrate that dynamics of the linear UAH model is very consistent with the actual situation activity-hibernate interacting process. and so, the linear UAH model provide appropriate basis for evaluating effectiveness of hibernate.

Keywords: Effectiveness, Qualitative Analysis of Dynamical System, Network Structure, Forgetting and Remembering Mechanism

Introduction

As a means of communication, activities have individual life plants. The dynamics of plant activities is aimed at modeling and research the activity process of plants, to understand the effect of different factors on plant prevalence of plants, so as to formulate cost-effective restriction strategy activities. Van Mieghem *et al.* (2009) suggested an individual-level mode in 2009, (the accurate SIS model), which an accurate description of the average dynamics of the SIS epidemic. The continuous-time individual-level models are particularly useful in investigating the effective of the network topology and suitable for the study of ecological network. Thus this article aims to evaluate the effectiveness of hibernate (forgetting and remembering mechanism). For this purpose, the individual-level activity-hibernate interacting model (the linear UAH model) is derived. Then put forward a set of standards for extinction activities. These standards capture the combined effects of main parameters and network structure on the effectiveness of hibernation. The simulation experiments demonstrate that the dynamics of the linear UAH model is very suitable for the actual activity-hibernate interacting process. Therefore, the linear UAH model provides an appropriate basis for evaluating the effectiveness of hibernate.

The traditional modeling approach is to classify all agents and then to inspect the evolution of the size of every compartment over time. Čokl *et al*. (2019) show the stink bugs investigated so far communicate with species and sex-specific narrow-band calling and courtship song signals produced by abdomen vibration. Delgado *et al*. (2021) present the creative online lab alternatives can provide students valuable scientific learning experiences when in-person learning is not possible. Garvin *et al*. (2020) identify mutations that are likely compensatory adaptive changes that allowed for rapid expansion of the virus. Narendra and Shorten (2010) show the method is based on the well-known fact that a Hurwitz Metzler matrix is also diagonally stable. Stewart (2009) introduce the "Probability, Markov Chains, Queues and Simulation" provides a modern and authoritative treatment of the mathematical processes that underlie performance modeling. Sun *et al.* (2020b) show the fresh weight and relative water content of EPS. Swierczynski (2019) present the ASDs frequently manifest in the form of behavioral inhibition-aversion to novelty and preference for familiar. Zare (2019) introduce the vivo evaluation on breast cancerhas not been conducted. Sun *et al.* (2020a) determines fish provide an important supply of Long-Chain Polyunsaturated FATTY acids (LC-PUFAs) for human consumption.

The materials are arranged in this way. Section 2 derives the exact UAH model and the linear UAH model respectively. Section 3 discusses the dynamics of the linear UAH model. At last, Section 4 generalizes this study.

Formation of the Linear UAH Model

This section is dedicated to establish a individual-level model, which is capturing the effectiveness of hibernate for plant activity.

Notions, Notations and Fundamental Hypotheses

Consider an ecological network consisting of N plants labelled $1,2,\cdots,N$ and let $V(G) = \{1,2,\ldots,N\}$ an ecological activity through a ecological network $G = (V(G),E(G))$, $(i,j) \in E(G)$ only if $j \in V(G)$ can effect $i \in V(G)$. Let $A = [a_{ij}]_{N \times N}$ indicate adjacency matrix of G. Hereafter, the network is always assumed to be a strong connection.

After the appearance of the activity, at any time, assume that each plant in the ecological network is in one of the following three possible states: *Uncertain*, *acting* and *hibernating*. Depending on the individual difference, every plant may choose to be uncertain, or to be activity, or to be hibernator. At time t, let $P_i(t) = 0$, 1 and 2 mean that, plant I is uncertain, activity and hibernator, separately. At time t, the state of ecological network is indicated by the vector:

$$p(t) = \left(p_1(t), p_2(t), \ldots, p_N(t)\right)^T.$$

As below, introduce a group of hypotheses:

(H_1) Due to the effectiveness of an active plant j, an uncertain plant i, at any time becomes activity at rate $\beta_{ij} \geq 0$. Here, $\beta_{ij} > 0$ only if $(i,j) \in E(G)$.
(H_2) Due to the forgetfulness, an active plant i turn to be a hibernator, at any time at rate $\delta_i > 0$.
(H_3) Due to the forgetfulness, an hibernator i turn to be an uncertain, at any time at rate $\alpha_i > 0$.
(H_4) Due to the rememberance, an hibernator i turn to be a activity, at any time at rate $\gamma_i > 0$.
(H_5) $\Pr\{P_i(t) = 0, P_j(t) = 1\} = U_i(t)A_j(t), 1 \leq I, j \leq N, i \neq j$.
(H_6) Due to the effectiveness of an actor j, every uncertain plant becomes actor at rate $\beta_j \geq 0$ at any time

The Linear UAH Model

Based on equivalent models and these independent assumptions, the following model can be derived:

$$\begin{cases} \dfrac{dU_i(t)}{dt} = -U_i(t)\sum_{j=1}^{N} a_{ij}\beta_j A_j(t) + \alpha_i H_i(t), \\ \dfrac{dA_i(t)}{dt} = U_i(t)\sum_{j=1}^{N} a_{ij}\beta_j A_j(t) + \gamma_i H_i(t) - \delta_i A_i(t) \\ \dfrac{dH_i(t)}{dt} = \delta_i A_i(t) - \gamma_i H_i(t) - \alpha_i H_i(t) \\ t \geq 0. \end{cases} \quad (2.1)$$

As $U_i(t) + A_i(t) + H_i(t) = 1$, the following model is derived:

$$\begin{cases} \dfrac{dA_i(t)}{dt} = \left(1 - A_i(t) - H_i(t)\right) \\ \sum_{j=1}^{N} a_{ij}\beta_j A_j(t) + \gamma_i H_i(t) - \delta_i A_i(t) \\ \dfrac{dH_i(t)}{dt} = \delta_i A_i(t) - \gamma_i H_i(t) - \alpha_i H_i(t) \\ t \geq 0. \end{cases} \quad (2.2)$$

We name this model as *linear UAH* because of the acting rate are linear in the arguments.

Figure 1 shows these state transition rates of plant under the linear UAH model.

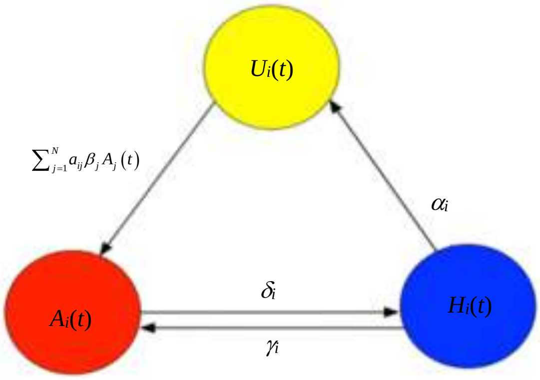

Fig.1: The state transition rates plant i under the linear UAH model

Dynamics of the Linear UAH Model

The generic UAH model is considered. Let $A(t)$ mean the fraction of plant-activity at time t. So:

$$At(t) = \frac{1}{N}\sum_{i=1}^{N} A_i(t).$$

The main purpose of this study is to define the tendency of $A(t)$. For fundamental knowledge on matrix, from. In the following, only real square matrices are considered. Given the matrix M, let $s(M)$ denote the maximum eigen value of M. If the off-diagonal entries of **A** are all non-negative, it is *Metzler*.

The linear UAH model might have two different equilibria, which are defined as below.

Definition 1

Let $\mathbf{E} = (U_1,\ldots,U_N,A_1,\ldots,A_N,H_1,\ldots,H_N)^T$ be an equilibrium of the linear UAH model (3):

(a) **E** is activity-free *if* **A** = **0**.A activity-free equilibrium represents for a steady ecological network there is certainly no active plant
(b) **E** *is* uncertain-free *if* ***U***= **0**. A uncertain-free equilibrium represents for a steady ecological network there is certainly no uncertain plant

Obviously, the linear UAH model always has a unique activity-free equilibrium $\boldsymbol{E}_1 = (1,\ldots,1,0,\ldots,0,0,\ldots,0)^T$ and a unique uncertain-free equilibrium $E_2 = \left(0,\cdots,0,\bar{A}_1,\cdots,\bar{A}_N \bar{H}_1,\cdots\right)$ where $\bar{A}_I = \frac{\gamma_i}{\delta_i + \gamma_i}$, $\bar{H}_I = \frac{\delta_i}{\delta_i + \gamma_i}$. For the aim of checking hibernate equilibria of the model, we define a matrix:

$$Q_1 = diag\alpha_i \cdot A \cdot diag\beta_i - diag\frac{\delta_i}{\gamma_i + \delta_i}$$

Since G is strongly connected and $\boldsymbol{Q}_1$ is irreducible. On this basis, define an auxiliary matrix as:

$$Q_2 = diag\beta_i \cdot A \cdot diag\beta_i - diag\frac{\beta_i \delta_i}{\alpha_i\left(\gamma_i + \delta_i\right)}$$

Obviously, $Q_1 = diag\frac{\alpha_i}{\beta_i}$.$\mathbf{Q}_2$, then $s(\mathbf{Q}_1) < 0$ if and only if $s(\mathbf{Q}_2) < 0$.

Theorem 3.1

If $S\left(Q_1\right) < 0, \alpha_i \neq \sum_{j=1}^{N} a_{ij}\beta_j$ then the activity-free equilibrium $\boldsymbol{E}_1$ is globally asymptotically stable.

Proof

Let $(A_1,\ldots,A_N,H_1,\ldots,H_N)^T$ become a model(2) solution. It comes from the model that:

$$\frac{dU_i(t)}{dt} \le \alpha_i\left(1 - A_i(t) - U_i(t)\right) \le \alpha_i - \alpha_i U_i(t), i = 1,2,\cdots,N.$$

We have the comparison system:

$$\frac{dz_i(t)}{dt} = \alpha_i - \alpha_i z_i(t)$$

has stable $\bar{A}_i$, there holds:

$$U_i(t) \le 1 + \varepsilon$$

and hence, $\overline{\lim}_{t\to\infty} U_i(t) \le 1$.

Let $T = \max\{T_1,\ldots,T_N\}$.For all $t \ge T$, from the model(2), it follows that:

$$\begin{cases} \frac{dA_i(t)}{dt} = U_i(t)\sum_{j=1}^{N} a_{ij}\beta_j A_j(t) + \gamma_i H_i(t) - \delta_i A_i(t) \\ = U_i(t)\sum_{j=1}^{N} a_{ij}\beta_j A_j(t) + \gamma_i\left(1 - U_i(t) - A_i(t)\right) - \delta_i A_i(t) \\ \le U_i(t)\sum_{j=1}^{N} a_{ij}\beta_j A_j(t) - \delta_i A_i(t) \\ \le (1+\varepsilon)\sum_{j=1}^{N} a_{ij}\beta_j A_j(t) - \delta_i A_i(t) \end{cases}$$

So:

$$\frac{dw_i(t)}{dt} = (1+\varepsilon)\sum_{j=1}^{N} a_{ij}\beta_j w_j(t) - \delta_i w_i(t)$$

with $w_i(T) = A_i(T), i = 1,\ldots,N$. Let $w(t) = (w_1(t),\ldots,w_n(t))^T$ and define a positive definite function as:

$$V(w) = \frac{1}{2} w(t)^T .diag\left(\frac{\beta_i}{1+\varepsilon}\right).w(t). \qquad (3.1)$$

Through calculation, we have:

$$\begin{aligned} \frac{dV(w(t))}{dt}\Big|_{(6)} &= w(t)^T \cdot diag\frac{\beta_i}{1+\varepsilon}.\frac{dw(t)}{dt} \\ &= w(t)^T \cdot diag\frac{\beta_i}{1+\varepsilon}.\left[(1+\varepsilon)\cdot A \cdot diag\beta_i - diag\delta_i\right].w(t) \\ &= w^T(t).\left[diag\beta_i \cdot A \cdot diag\beta_i - diag\frac{\beta_i\delta_i}{1+\varepsilon}\right].w(t) \end{aligned}$$

Since $\mathbf{Q}_2$ has the negative spectrum, then choose a ε, so that matrix:

$$Q_2' = diag\beta_i \cdot A \cdot diag\beta_i - diag\frac{\beta_i \delta}{1+\varepsilon}$$

has the negative spectrum. Let $u_1, u_2, \ldots, u_N$ mean the eigen values of Q'_2 and assume u_1 is the maximum eigen value. As Q'_2 is symmetric, we have the orthogonal matrix T so that:

$$Q_2' = T^T \cdot diag(u_i).T.$$

So, we get:

$$\frac{dV(w(t))}{dt}\bigg|_{(6)} = (T.w(t))^T \cdot diag(u_i) \cdot (T \cdot w(t)) \le u_1 w(t)^T w(t).$$

It follows from the Lemma (Theorem 31.4 in) and Lemma (Corollary 3.3 in (Strauss and Yorke, 1967)) that $\lim_{t\to\infty} w(t) = 0$, which implies that, $1 \le i \le N$. Then, for any $\varepsilon > 0$, have $T > 0$ so that $t \ge T$, there is $U_i(t) < \varepsilon$, $1 \le i \le N$:

$$\frac{dU_i(t)}{dt} = -U_i(t)\sum_{j=1}^{N} a_{ij}\beta_j A_j(t) + \alpha_i\left(1 - U_i(t) - A_i(t)\right)$$
$$\le (1-\varepsilon)\alpha_i - \left(\varepsilon\sum_{j=1}^{N} a_{ij}\beta_j + \alpha_i\right)U_i(t)$$

Since the comparison system:

$$\frac{dy_i(t)}{dt} = (1-\varepsilon)\alpha_i - \left(\varepsilon\sum_{j=1}^{N} a_{ij}\beta_j + \alpha_i\right)y_i(t)$$

has a globally asymptotically stable equilibrium $\frac{(1-\varepsilon)\alpha_i}{\varepsilon\sum_{j=1}^{N} a_{ij}\beta_j + a_i}$, for any $\epsilon > 0$, there exists $T_2 > 0$ such that for all $t \ge T_2$:

$$A_i(t) \ge \frac{(1-\varepsilon)\alpha_i}{\varepsilon\sum_{j=1}^{N} a_{ij}\beta_j + a_i} - \in.$$

This implies that

$$\underline{\lim}_{t\to\infty} U_i(t) \ge 1$$

Then, we get $\lim_{t\to\infty} U_i(t) = 1$.

Theorem 3.2

If $S(Q_1) < 0, \alpha_i = \sum_{j=1}^{N} \alpha_{ij}\beta_j$ and then the uncertain-free equilibrium $\boldsymbol{E}_2$ is globally asymptotically stable. Define an auxiliary matrix $\boldsymbol{Q}_3$ as:

$$Q_3 = diag\frac{\alpha_i(\gamma_i + \delta_i)}{\delta_i} \cdot A \cdot diag\beta_i$$

Obviously, $Q_1 = diag\frac{\delta_i}{\gamma_i + \delta_i}.\left[Q_3 - I\right]$, then $s(\boldsymbol{Q}_1) > 0$ if and only if $s(\boldsymbol{Q}_3) > 1$.

Theorem 3.3

If $s(\boldsymbol{Q}_1) > 0$,thus the hibernate equilibrium $\boldsymbol{E}^*$is a unique.

Proof

Suppose the model has a hibernate equilibrium $E^* = (U_1^*, \cdots, U_N^*, A_1^*, \cdots A_N)$.

From the equation of model (2), we can get:

$$U_i^* = -\frac{\alpha_i + \gamma_i + \delta_i}{\alpha_i + \gamma_i}A_i^* + 1, 1 \le i \le N.$$
$$A_i^* = \frac{(\alpha_i + \gamma_i)\sum_{j=1}^{N} a_{ij}\beta_j A_j^*}{\alpha_i\delta_i + (\alpha_i + \gamma_i + \delta_i)\sum_{j=1}^{N} a_{ij}\beta_j A_j^*}, 1 \le i \le N.$$

This observation inspired, a continuous mapping $H = (h_1, \ldots, h_N) : (0,\infty)^N \to (0,1)^N$ is defined in this way:

$$h_i(y) = \frac{(\alpha_i + \gamma_i)\sum_{j=1}^{N} a_{ij}\beta_j y_j^*}{\alpha_i\delta_i + (\alpha_i + \gamma_i + \delta_i)\sum_{j=1}^{N} a_{ij}\beta_j y_j^*}.$$

It suffices to enough to prove that H recognizes a unique fixed point and we must to prove two affirmers.

Affirmer 1. H is monotonic. Let $p, q \in (0,\infty)^N$, $p \le q$ (i.e., $p_i \le q_i$, $1 \le i \le N$). Then for $1 \le i \le N$:

$$h_i(p) = \frac{(\alpha_i + \gamma_i)\sum_{j=1}^{N} a_{ij}\beta_j p_j}{\alpha_i\delta_i + (\alpha_i + \gamma_i + \delta_i)\sum_{j=1}^{N} a_{ij}\beta_j p_j}$$
$$\le \frac{(\alpha_i + \gamma_i)\sum_{j=1}^{N} a_{ij}\beta_j q_j}{\alpha_i\delta_i + (\alpha_i + \gamma_i + \delta_i)\sum_{j=1}^{N} a_{ij}\beta_j q_j},$$

which implies $H(p) \le H(q)$.

Affirmer 2

H recognizes a only fixed point in $(0,1)^N$. According to the Lemma (Lemma 2.3 in), $\boldsymbol{Q}_3$ has a simple positive eigenvalue $s(\boldsymbol{Q}_3) > 1$ and there is a positive eigenvector $w = (w_1, \cdots, w_N)^T$ belonging to $s(\boldsymbol{Q}_3)$. Let:

$$\varepsilon_1 = \min_i \frac{\alpha_i + \gamma_i}{\alpha_i^2(\gamma_i + \delta_i)}\left[1 - \frac{1}{S(Q_3)}\right]\min_i \frac{\alpha_i + \gamma_i}{\alpha_i + \gamma_i + \delta_i}\frac{1}{\max_i w_i}$$
$$\varepsilon_2 = \min_i \frac{\alpha_i + \gamma_i}{\alpha_i^2(\gamma_i + \delta_i)}\left[1 - \frac{1}{S(Q_3)}\right]\max_i \frac{\alpha_i + \gamma_i}{\alpha_i + \gamma_i + \delta_i}\frac{1}{\min_i w_i}$$

Then, $0 < \varepsilon_1 \leq \varepsilon_2$. Thus

$$h_i(\varepsilon_1 w) = \frac{(\alpha_i + \gamma_i)\varepsilon_1 \sum_{j=1}^{N} a_{ij}\beta_j w_j}{\alpha_i \delta_i + (\alpha_i + \gamma_i + \delta_i)\varepsilon_1 \sum_{j=1}^{N} a_{ij}\beta_j w_j}$$

$$= \frac{(\alpha_i + \gamma_i)\varepsilon_1 w_i s(Q_3)}{\alpha_i^2(\gamma_i + \delta_i) + (\alpha_i + \gamma_i + \delta_i)\varepsilon_1 w_1 s(Q_3)} \geq \varepsilon_1 w_i, 1 \leq i \leq N.$$

Then$H(\varepsilon_1 w) \geq \varepsilon_1 w$:

$$h_i(\varepsilon_2 w) = \frac{(\alpha_i + \gamma_i)\varepsilon_2 \sum_{j=1}^{N} a_{ij}\beta_j w_j}{\alpha_i \delta_i + (\alpha_i + \gamma_i + \delta_i)\varepsilon_2 \sum_{j=1}^{N} a_{ij}\beta_j w_j}$$

$$= \frac{(\alpha_i + \gamma_i)\varepsilon_2 w_i s(Q_3)}{\alpha_i^2(\gamma_i + \delta_i) + (\alpha_i + \gamma_i + \delta_i)\varepsilon_2 w_1 s(Q_3)} \geq \varepsilon_2 w_i, 1 \leq i \leq N.$$

Then$H(\varepsilon_2 w) \leq \varepsilon_2 w$. It follows from affirmer 1 that $H|(k)$, where:

$$k = \prod_{i=1}^{N} [\varepsilon_1 w_i, \varepsilon_2 w_i].$$

It follows from Lemma (Theorem 4.10 in, we have H has a fixed point in k. Denote this fixed point by $A^* = (A_1^{**}, \cdots, A_N^{**})^T$. Suppose H has a fixed point $A^{**} = (A_1^{**}, \cdots, A_N^{**})^T$ other than A^*. Let:

$$\theta = \max_{1 \leq i \leq N} \frac{A_i^*}{A_i^{**}}, i_0 = org \max_{1 \leq i \leq N} \frac{A_i^*}{A_i^{**}}$$

Without limiting the generality, assume $\theta > 1$:

$$A_0^* = H_{i_0}(A^*) \leq H_{i_0}(\theta A^{**}) = \frac{(\alpha_i + \gamma_i)\sum_{j=1}^{N} a_{i_0 j}\beta_j A_j^{**}}{\alpha_i \delta_i + \theta(\alpha_i + \gamma_i + \delta_i)\sum_{j=1}^{N} a_{i_0 j}\beta_j A_j^{**}}$$

$$< \theta \frac{(\alpha_i + \gamma_i)\sum_{j=1}^{N} a_{i_0 j}\beta_j A_j^{**}}{\alpha_i \delta_i + (\alpha_i + \gamma_i + \delta_i)\sum_{j=1}^{N} a_{i_0 j}\beta_j A_j^{**}} = \theta H_{i_0}(A^{**}) = \theta A_{i_0}^{**}.$$

This violates the assumption of $A_{i_0}^* = \theta A_{i_0}^{**}$. Therefore, A^* is the only fixed point of H.

Experiments and Concluding Remarks

Experiment

Scale-free and Small-world networks are a type of networks with a wide range of applications (Albert and Barabási, 2002). Take a stochastic generated scale-free network and Small-world networks with 100 nodes and the experiments on the networks are shown in Figs. 2 and 3 separately.

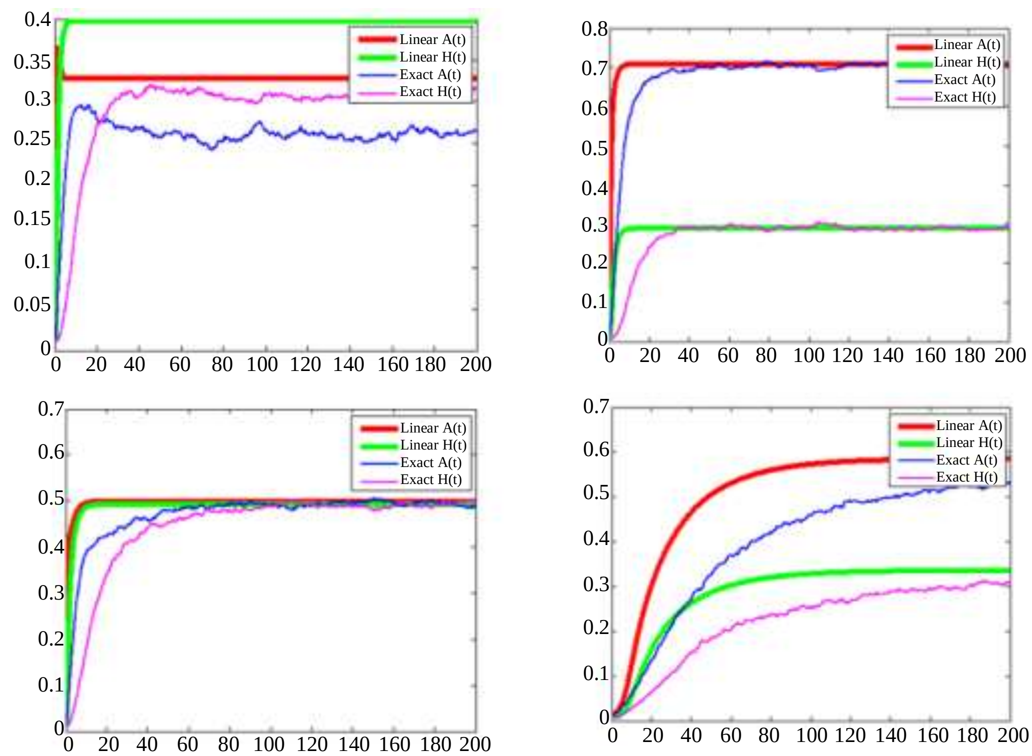

Fig. 2: The time plots of Linear A(t), Linear H(t),Exact A(t), Exact H(t)

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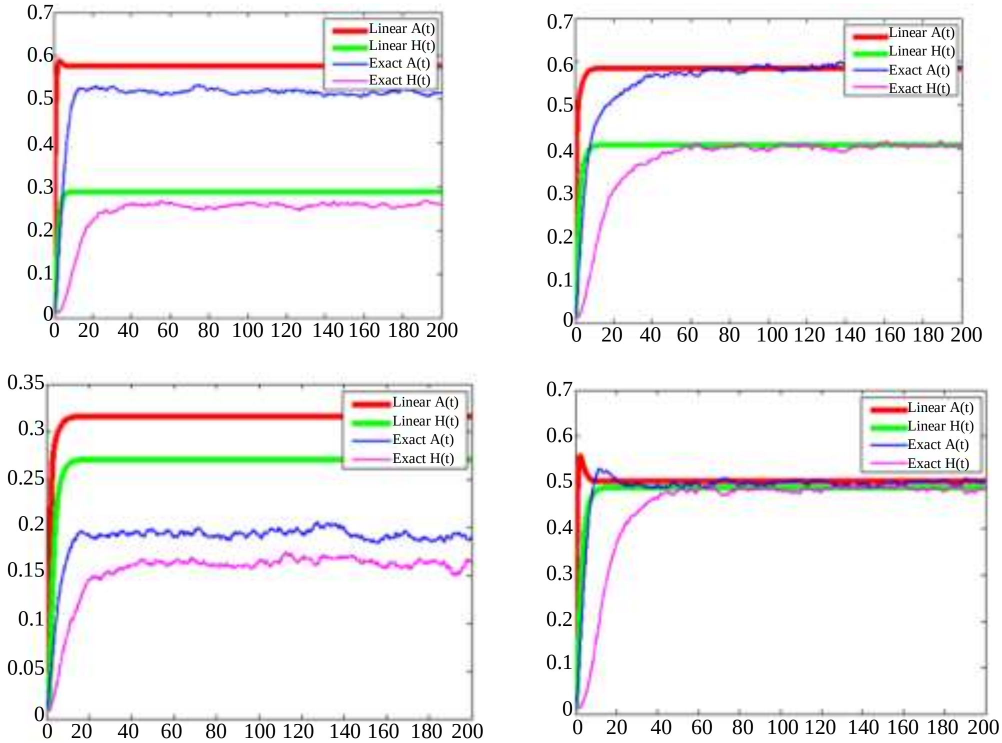

Fig. 3: The time plots of Linear A(t), Linear H(t),Exact A(t), Exact H(t)

The following outcomes are from the previous above experiments:

(a) If $A(t)$ approaches a nonzero value, then the linear UAH model can truly capture the average evolutionary process of the plant
(b) If $H(t)$ becomes a nonzero value, after that the linear UAH model can truly capture the average evolutionary process of the plant

Concluding Remarks

This article has discusses the effects that of hibernate on plant activity and the linear UAH model has been exported. Under this model, a group of criteria for extinction of a activities is given. The extensive simulations result that, the dynamics of the linear UAH model fits well with the actual of the hibernate for activity process of hibernate. The following completions are drawn from the above demonstrates. In this case, the linear UAH model works fine; it can be utilized to quickly predict this average dynamics of activity in the ecological network. For this purpose, one individual-level activity-hibernate interacting model (the linear UAH model) is derived. Simulation experiments show that dynamics of the linear UAH model are very consistent with the actual activity-hibernate interacting process. So, the linear UAH models provide an appropriate basis for evaluating the effectiveness of hibernate.

Moving in the direction, there are many works under study. With the generic UAH model criteria, the existence/activity of coexistence balance should be found. Thus, it is valuable exploit a new UAH model that brings the restraining efficacy into account. Because of individual-level model, it is practical importance to know the influence of many factors on the complex ecology system.

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Author's Contributions

Lingli Pei: Contributed to the conception of the study; performed the experiment; performed the data analyses and wrote the manuscript.

Jiangdong Liao: Contributed significantly to analysis and manuscript preparation.

Hongjun Wang: Helped perform the analysis with constructive discussions.

Ethics

Authors should be able to submit, upon request, a statement from the research ethics committee or institutional review board indicating approval of the research.

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