Modeling and Simulation Analysis of Multi-modal and Multi-dimensional Insect Ecological Network Intelligence System

Guilan Luo¹, Xuan Liu²*, Lianbiao Fang², Hongjun Hao², Zhongmu Li² and Mei Zhang¹

¹School of Mathematics and Computer Science, Dali University, Dali 671003, China
²Institute for Astronomy and History of Technology, Dali University, Dali 671003, China

*Corresponding author email: lx18229695934@163.com

Abstract. The purpose of this study is to understand the current situation of insect ecological development in the Erhai wetland and explore the key factors to maintaining the stability of the insect ecological network. The research method is based on complex network, through a variety of angles to realize the insect ecological network modeling and simulation analysis, to study the correlation between wetland habitat and insect community. Then, the parameters and definitions of the multi-mode and multi-dimensional insect ecological network models were given. The components of the insect ecological network structure of different regions were analyzed. The results showed that the changes of ecological environment caused by human activities directly affected the changes of dominant insect groups. At last, through the analysis of structural characteristic parameters and correlation of insect ecological network, the conclusion is that species richness and diversity index are important indicators to maintain the stability of insect ecological network structure.

Keywords: Insect ecological network; Correlation; Structural characteristic; Stability.

1. Introduction

According to related research, insects are the most numerous animals, accounting for 73% of all animals[1]. Moreover, insects play an important role in the ecosystem[2]. Insects can be used as indicator species for monitoring wetland ecological environment and biodiversity[3]. Han Zhengwei[4] studied the insect community structure and diversity of Taihu Wetland and found that the important factors affecting the insect community in Taihu wetland were wetland vegetation type and artificial disturbance. He Yunchuan[5] studied the diversity and stability of terrestrial insect communities in four wetlands in Yinchuan. He made a cluster analysis of the characteristic indices of insect communities. He found that insect community diversity varied from seasons. Insects are very sensitive to environmental changes, and environmental changes will lead to changes in insect population and community structure.

Erhai Lake is the second largest freshwater lake in Yunnan Province. This paper selected three typical wetlands in Erhai Lake as the research objects. The seasonal dynamics and adaptability of insect diversity were investigated by investigating and analyzing the diversity, evenness, and dominant concentration index of insect communities in different habitats from November 2018 to October 2019. The innovation of this paper is the cross-disciplinary research of complex network science, ecology, and entomology.
2. Sample Data of Modeling
The data samples were provided by the National Natural Science Foundation of China "Study on the universal characteristics of insect population ecological network in Erhai Wetland". The sample data were collected from three Erhai wetlands, namely, Eryuan Donghu, Erhaiyue, and Luoshijiang. It includes Insect species data, habitat data, and vegetation data. Habitat data are obtained by periodically collecting temperature, humidity, rainfall, light, etc. The vegetation data were identified by wetland investigation and sampling, and more than 60 species of vegetation were identified. Insect samples were collected by the sweeping and catching method, and the collected insects were placed in the identification plate for preliminary classification.

3. Model Parameters and Definitions
Parameter 1 Relative abundance $P_i$ refers to the number of individuals of species $i$ account for the ratio of the total number of individuals of the species. $M_i$ refers to the number of individuals of species $i$, and $M$ represents the total number of individuals of the species collected. The formula is as follows.

$$P_i = \frac{M_i}{M}$$

Parameter 2 Species diversity index $H'$ refers to the adaptability of insects to the environment, the degree of evolution of species in a specific space, and the degree of diversity of species.

$$H' = -\sum (P_i \cdot \ln P_i)$$

Parameter 3 Species richness index $\ln S$, $S$ is the number of species collected. The greater the richness index value, the richer the species, and conversely, the more single the species.

Parameter 4 Species evenness index $J$ refers to the distribution of all insects in the community.

$$J = \frac{H'}{\ln S}$$

The higher value of $J$ indicates, the stronger stability of the insect community.

Parameter 5 Dominance concentration index $C$ refers to the composition of the insect community.

$$C = \sum \left( \frac{M_i}{M} \right)^2$$

The larger the value of $C$, the smaller the value of $H'$, indicating that the number of individuals in the community is concentrated on a few groups.

Parameter 6 $S_r$ is the number of species in the community and $S_i$ is the number of individuals in the community. The ratio of $S_r$ to $S_i$ reflects the quantitative restriction on species. The greater the ratio, the stronger the relative stability. $S_n$ is the number of natural enemy species and $S_p$ is the number of herbivorous species. The ratio of $S_n$ to $S_p$ reflects the complexity and mutual constraints of the food web. The greater the ratio, the stronger community stability.

Parameter 7 Correlation coefficient $S(X, Y)$. $x_i$ and $y_i$ denote quantity or value. $\bar{x}$ and $\bar{y}$ represent averages within 12 months, respectively. The formula is as follows.

$$S(X, Y) = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^{n} (y_i - \bar{y})^2}}$$

Definition 1 Dominant species are more adapted to the environment in the insect community, with more than 10% of total individuals.

Definition 2 Common species are that individual number accounts for more than or equal to 1% of the total number of collected individuals.

Definition 3 Rare species, with less than 1% of total individuals.
4. Modeling and Simulation of Multi-modal and Multi-dimensional Insect Ecological Network

To reduce the errors caused by different collectors, this paper improved the insect ecological network model in Reference [3]. The time series was constructed according to the number proportion of insect individuals collected each month, and the correlation between the number proportion of each species was calculated as the connection edge.

The multi-mode refers to network models with different node types. The multi-dimensional refers to the same node type but different dimensions of node information factor. The multi-mode and multi-dimensional insect ecological network is divided into four layers. The first layer is the vegetation layer, and the nodes are the vegetation communities identified in the wetland. The second layer is the vegetation type layer, and the nodes are the classification of vegetation communities. The nodes are divided into grasses and shrubs. The third layer is the insect network layer, and the nodes are insect populations. The fourth layer is multi-dimensional information layer, nodes are multi-dimensional environments, including temperature, rainfall, etc.

The vegetation layer is classified according to the vegetation type, and then the vegetation types are directly connected. The connection rule between vegetation type layer and insect network layer is that only insects collected in specific vegetation types are connected to the node of vegetation type layer. The insect network layer and the multi-dimensional information layer construct the connection relationship based on the correlation between insect population and multi-dimensional environmental factors. If the multi-dimensional environmental factors have a positive impact on the insect population, the connection relationship is directed from the multi-dimensional environmental factor node to the insect population node. Conversely, the connection relationship is directed from the insect population node to the multi-dimensional environmental factor node.

The node area of the insect population in the topological graph of the constructed multi-mode and multi-dimensional insect ecological network models represents the size of the insect population in a

Figure 1. Donghu wetland.

Figure 2. Erhaiyue wetland.

Figure 3. Luoshijiang wetland.

The node area of the insect population in the topological graph of the constructed multi-mode and multi-dimensional insect ecological network models represents the size of the insect population in a
certain region. Node color depth represents the size of node degree. Edges represent the correlation between insect number ratios. The topological graph of the multi-dimensional and multi-mode insect ecological network in Donghu Wetland, Erhaiyue Wetland, and Luoshijiang Wetland is shown in figure 1-3. The connection between the multi-dimensional information layer and insect network layer shows that the environment has a significant impact on the insect population. Because of the strong correlation between the environment, an insect population node will connect with multiple environmental nodes. For example, temperature, humidity, and other environments on insect nodes are mostly positive correlation, instantaneous wind speed, ultraviolet cumulative value is negatively correlated.

5. Insect Ecological Network Structure and Characteristics Analysis

5.1. Network Structure Composition Analysis
A total of 2578 insects belonging to 11 orders were collected in the three wetlands in one year. About 30 species of insects were collected, but the proportion of the individual number of insects in the three wetlands was greatly different. Figure 4 shows the structural components of insect communities.

![Figure 4. Composition of insect ecological network structure.](image)

5.2. Analysis of Network Characteristic Parameters
The diversity characteristic parameters of insect communities in Erhai wetland were calculated by using formulas (2)-(4). Taking the characteristic parameters of Eryuan Donghu as the benchmark “1”, the column diagram of the ratio of three wetland characteristic parameters is shown in figure 5.

![Figure 5. Column diagram of ratio of three wetland characteristic parameters.](image)

The rules of diversity index and evenness index are the same, which are Eryuan Donghu > Luoshijiang > Erhaiyue. The dominant concentration index is Erhaiyue > Eryuan Donghu > Luoshijiang. The parameters showed that the insect community in Donghu and Luoshijiang Wetland was rich in species, and the number of species was relatively balanced. There were no extreme dominant species, and the insect community was relatively stable compared with that in Erhaiyue.

5.3. Correlation Analysis of Characteristic Parameters
In order to further study the relationship between characteristic parameters and the influence of characteristic parameters on the stability and diversity of insect communities. Correlation coefficient calculated by formula 5. The value of correlation coefficient is between −1 and 1. The closer to 1, the stronger the positive correlation is, and the closer to −1, the stronger the anti-correlation is. The correlation coefficient is shown in figure 6.
The correlation coefficient between diversity index and evenness index of three wetlands is about 0.9, indicating that there is a strong positive correlation between diversity index and evenness index. The correlation coefficients between dominance concentration index and diversity index and evenness index of three wetlands were less than -0.9, indicating a strong negative correlation.

Figure 6. Correlation coefficient of characteristic parameters.

In summary, to protect the insect community in the Erhai wetland, the species richness should be protected first. Especially rare species, the number of rare groups directly determines the size of the wetland insect ecological network. The larger insect ecological network has better robustness. The dominant species largely limit the diversity of insect communities. Therefore, the protection strategy of the insect community in Erhai wetland is a priority to protect the endangered species, and focus on monitoring the development of dominant species.

5.4. Analysis of the Influence of Habitat on Characteristic Parameters

According to the habitat data collected at three wetlands, the average values of temperature, humidity, ultraviolet instantaneous value, rainfall and wind speed within three days before and after insect collection were obtained. The correlation between habitat and insect ecological network characteristic parameters within one year was investigated. The correlation is shown in table 1.

Table 1. Correlation coefficient between habitat factors and characteristic parameters.

|                      | $H'$ | lnS  | J    | C    | Species number | Quantity |
|----------------------|------|------|------|------|----------------|----------|
| Daily UV             | 0.213| 0.356| 0.206| 0.176| 0.367          | 0.273    |
| Soil temperature     | 0.428| 0.489| 0.486| 0.479| 0.478          | 0.325    |
| Environment temperature | 0.397| 0.431| 0.502| 0.488| 0.417          | 0.299    |
| Ambient humidity     | 0.294| 0.680| 0.164| 0.182| 0.681          | 0.379    |
| Dew-point temperature | 0.355| 0.654| 0.373| 0.349| 0.648          | 0.389    |
| Instantaneous wind speed | 0.276| 0.667| 0.246| 0.230| 0.674          | 0.442    |
| Soil humidity        | 0.389| 0.398| 0.250| 0.326| 0.416          | 0.253    |
| Rainfall             | 0.065| 0.190| 0.165| 0.112| 0.186          | 0.182    |

Table 1 shows that the correlation of ambient humidity, dew point temperature, instantaneous wind speed, richness index and species number reached more than 0.6, which may be related to the geographical factors of Dali. Dali is located in the subtropical plateau monsoon climate zone, with sufficient sunshine, large water evaporation and dry climate. The temperature difference between day and night is large, and there is often gale weather. The richness index of insect community increases with the increase of ambient humidity and dew point temperature but increases with the decrease of instantaneous wind speed. The number of insect species increases with the increase of ambient humidity and dew point temperature but increases with the decrease of instantaneous wind speed. The greater the ambient humidity and the higher the dew point temperature is, the richer the species of insect population are, and the excessive wind speed will reduce the number of species of flying insects.

5.5. Stability Analysis of Network Structure

Parameter 6 is used to study the stability of insect ecological network structure. The stability indexes of the three wetlands are calculated monthly and the average value is obtained. Taking the characteristic parameters of Eryuan Donghu as the benchmark “1”, the relative stability of insect communities in the three wetlands is shown in figure 7.
Figure 7. Comparison of relative stability of insect communities.

The relative stability index values of Donghu are in the second place and close to the first. The other two wetland stability index values are too small. The internal relationship of insect community network in Donghu wetland is complex, and the stability is the highest. The insect community stability of the other two constructed wetlands is lower than that of Donghu but is close to that of Donghu.

6. Conclusion

Through the modeling and simulation analysis of insect ecological networks, the results showed that except for the natural habitat changes caused by seasonal changes, human activities have a great influence on wetland insect ecological networks. The structure of the insect ecological network in the three wetlands of Erhai Lake is similar and the species are relatively abundant. The insect ecological network structure of Donghu wetland is the most stable, and the other two wetland insect ecological networks also have strong self-regulation and repair ability. The greater the diversity index, richness index and evenness index of insect ecological network in Erhai wetland, the smaller the dominant concentration index, which reflects that the insect ecological network is rich in species, stable in structure and better in habitat ecological environment.

Acknowledgments

Thanks, National Natural Science Foundation of China (No.61661001, No.11863002), Project of Basic Applied Research Program in Yunnan Province (No.C0120180115), Scientific Research Fund Project of Yunnan Education Department(2021Y396), and Yunnan Academician Workstation of Wang Jingxiu (No. 202005AF150025), for their support.

References

[1] Camila Leandro, Pierre Jay-Robert, Perceptions and representations of animal diversity: Where did the insects go[J]. Biological Conservation, 2019, 237:400-408.
[2] Pe A, Psb B, Kb C, et al. Scientists' warning to humanity on insect extinctions - Science Direct[J]. Biological Conservation, 2020, 242.
[3] Luo Guilan, Hao Hongjun, Wang Xiao, Zhang Mei. Study on the universal characteristics of insect population ecological network [J/OL]. Journal of Systems Simulation, 2020,1-11.
[4] Han Zhengwei, Ma ling, Cao Chuanwang, Zhang Jing, WangBuyoung. The structure and diversity of insect community in Taihu wetland [J]. Acta Ecologica Sinica, 2013,33(14):4387-4397.
[5] He Yunchuan,Yang Guijun, Wang Xinpu. Diversity and stability of terrestrial insect community in different wetlands in Yinchuan [J]. Acta Entomologica Sinica,2018,61 (12): 1439-1452.
[6] Li Xinyun, Yang Yichun, He Zeshuai, Yang Guijun. Diversity of butterflies community and its environmental factors in Helan Mountain Nature Reserve, Ningxia[J]. Journal of Environmental Entomology, 2020,42 (03): 660-673.
[7] Ren Zhentao, Shen Wenjing, Liu Biao. Effects of Transgenic Maize on Biodiversity of Arthropod Communities in the Fields[J]. Scientia Agricultura Sinica, 2017, 50 (12): 2315 -2325.
[8] Zhaohongmei, Chen Fushou, Wang Yan, Xu Xingcai, Yuan Qiongfen, Yang Yanxian, Chen Zongqi. The temporal dynamics and structure of insect community in the vegetable garden in Jinning county, Kunming [J]. Chinese Journal of Biological Control, 2017, 33 (01): 56 – 62.
[9] Li Guofeng, Hou Yunping, Wang Chunmei, Yang Chenghua. Research on the structure and function of insect communities in aquilaria crassna forest of Xishuangbanna[J]. Sichuan Journal of Zoology, 2016,35 (02): 190-200 + 209.