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Prediction of species invasion based on GIS

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Abstract. Along with the deepening of economic globalization, the expansion of human activities, and the development of transportation networks, the phenomenon of species invasion has become increasingly common in human life, which not only affects the balance and stability of the original ecological environment but also has an impact on human normal life. Therefore, it is necessary to timely prevent and control species invasion, in which the timely prediction and analysis of species invasion is particularly important in species invasion prevention and control management. Based on GIS has strong integration and presentation capabilities for geographic information, this article selects GIS as a medium to explain the general methods of species invasion prediction and analysis, specifically divided into two parts: prediction of colonization possibility of invasive species and prediction of the potential geographical distribution. Through the organization and explanation in this article, the importance of GIS in geographic data presentation is clarified, as well as how to use the method of ecological niche modeling to process and analyze geographic information data, and the specific steps of using GIS technology and data to analyze species invasion. Through these steps, timely prevention and control of invasive species can be achieved, thereby protecting the environment, and maintaining a normal human life, which is necessary for people today and in the future.

Keywords: GIS, Species Invasion, Ecological Niche Models, Prediction.

1. Introduction

Species invasion refers to the migration of a biological species from its original ecosystem to other non-native areas due to human activities or other factors. Due to their strong adaptability and other reasons, they form breeding populations in new distribution areas, causing potential or actual negative impacts on local species and ecosystems. Invasive species that enter non-native habitats are called alien invasive species.

According to the definition of alien species by the International Union for Conservation of Nature (IUCN), alien species are non-native species that are brought to a certain place through natural forces or human activities. Alien species invasion, in simple terms, refers to the invasion of alien species into introduced areas' ecosystems, where they survive, reproduce, and suppress the ecological activities of native organisms, posing threats or damages to local biodiversity and ecosystems. It can be seen that to form a situation of alien species invasion, two conditions need to be met. Not every alien species entering the introduced area can be called an "invasion". Firstly, the species must be alien rather than native, and it can maintain ecological balance and mutual restriction with other organisms in its original ecological environment. However, once it enters an ecosystem where there are no natural predators to restrict its growth, it will grow rapidly and disrupt the original ecological balance of the introduced area. Secondly, it poses a threat or damage to the local biodiversity and ecosystems. The term "invasion" refers to the phenomenon of the introduced alien species entering the introduced area, which means that the introduced alien species cannot be accepted by the original ecosystem. Therefore, if an alien species wants to cause invasive results, it needs to meet the above two conditions to be called an alien invasive species [1]. Alien species may cause harm to native species through competition, predation, parasitism, infectious diseases, and other means, leading to various issues in agriculture, ecology, society, etc. It is estimated that there are over 400,000 unregistered invasive species globally, many of which have successfully established populations and adapted to new territories. Currently, invasive species pose a growing threat to local ecosystems worldwide. According to the International Union for Conservation of Nature (IUCN), approximately 23% of birds, 25% of mammals, 7% of reptiles, 3% of fish, and 20% of plants are threatened by invasive species globally.

In recent decades, China's population growth, economic development, and globalization have contributed to an increasing number of invasive species. Some invasive species have established populations in China and are beginning to negatively affect local ecosystems. According to relevant surveys and statistics, there are currently over 600 invasive species in China. Some of these invasive species have already established local populations and caused varying degrees of impact on the local ecosystem, such as invasive plants like Japanese knotweed, Acer negundo, and purple loosestrife, as well as imported aquatic animals and plants like red swamp crayfish and foreign green algae, which have been proven to be harmful. These invasive species have had negative impacts on the original local ecosystems, as well as human economic activities and social welfare.

With the increasing globalization of the economy, expansion of human activities, and development of transportation networks, invasive species events have occurred worldwide. For example, the apple snail, which reproduces rapidly and is highly adaptable, has caused extensive damage since its introduction to Asia from the Amazon River. It not only harms the environment but also poses a threat to human and animal health by carrying and transmitting certain diseases and parasites. Another example is the gypsy moth, which was introduced to China from the United States and caused serious economic losses to Chinese agriculture and forestry. Its larvae are herbivorous and mainly feed on tree leaves, such as oak, poplar, maple, and pine. Large-scale infestations of gypsy moth can cause serious damage to forests and vegetation, resulting in tree death and forest destruction.

Invasive species not only seriously affect the stability of local ecosystems, but also cause huge economic losses. Therefore, timely prediction and analysis of invasive species is an important aspect of invasive species prevention and control management. Invasive species prediction is a complex and diversified field that involves multiple technologies and methods and often requires the integration of multiple factors and methods for analysis. For example, Chinese scholars predicted the suitable habitat of cherry laurel in China based on the MaxEnt model and GIS. The study showed that cherry laurel is mainly distributed in Southeast China, and its highly suitable habitat is mainly distributed in the coastal areas of Southeast China, eastern Sichuan, and central Guangxi, consistent with the actual distribution range of cherry laurel [2].

2. Species distribution analysis method: GIS

Geographic Information System (GIS) is software used for integrating species distribution data, environmental variable data, and other geographic information data, as well as performing spatial interpolation and pattern recognition. These techniques can help predict which regions are more likely to be affected by species invasions. Ecological geographic GIS prediction modeling involves five steps, including conceptual model expression, statistical model description, model computation, model prediction, and model evaluation [3].

GIS consists of two main components. The first component is geographic information, which refers to location information and spatial features on Earth, including maps, satellite images, climate data, etc. The second component is the information system, which includes software and hardware tools used for collecting, storing, processing, and displaying geographic information.

Assessing the potential economic losses caused by a certain invasive species is also a crucial part of preventing and mitigating the impacts of alien invasions. Currently, the commonly used method for assessing potential economic losses of harmful organisms is the estimation model constructed by combining ecological niche modeling with GIS. For example, based on the ArcGIS raster data map generated by the GARP ecological niche model, the potential distribution area of stem canker disease in Chinese rapeseed was extracted using the masking tool Extract by Mask. On this basis, models for estimating potential losses were constructed from three aspects: potential direct economic losses, potential indirect economic losses, and potential non-economic losses [4]. Ecological niche modeling is an analytical approach based on the interaction between species and their environment. This method uses species distribution data and environmental factors to infer a species' adaptability and range of distribution. Commonly used ecological niche modeling methods include MaxEnt (maximum entropy) and ENM (ecological niche models). MaxEnt is a statistical model based on the principle of maximum entropy, used for predicting the potential distribution range of species. The model predicts the probability distribution of a species in new areas based on known species occurrence points and environmental variables. ENM, on the other hand, is a model based on environmental factors and species' ecological niche requirements, used for predicting the potential distribution range of species. This model integrates species distribution data, environmental factor data, and species' ecological niche characteristics to predict suitable habitats and potential distribution ranges. GIS can combine species occurrence data and environmental factors to construct species distribution models and predict their range and suitable habitats. Through spatial analysis and simulation, it is possible to understand the distribution patterns, habitat preferences, and potential ecological niches of species. GIS can help study the population dynamics of species. By integrating species survey data, remote sensing data, and environmental data, it is possible to track the abundance, distribution, and migration of species, and research spatial distribution patterns, ecological processes, and population dynamics.

GIS plays an important role in species invasion and ecological risk assessment. By integrating species distribution data, climate data, and geographic information, it is possible to assess the potential invasion risk of alien species, analyze their spatial spreading patterns and impact ranges, and provide decision support for preventing and controlling invasive species.

3. Application aspects of GIS-oriented predictions

3.1. Prediction of colonization possibility of invasive species

Biological invasion is an orderly process in ecology, which involves a series of events including the alien species introduction, colonization, incubation, expansion, eruption, etc. Colonization, among the series of events, is the process in which the initial population of the alien species undergoes filtrations of biotic and abiotic factors, adapts to the new environment and begins self-reproducing and establishment of the new population. This link determines whether an alien species is able to successfully invade a new area, which lies the foundations of future research [5]. All effects that alien species impact on the colonies are based on the success of colonization, and if an alien species successfully adapted to the new environment and began mass reproductions, then it would be viewed as a “successful colonizer” and be classified into “invasive species”; and if the situation were on the opposite, it would not fit into the invasive category [5], thus rendering it harmless. Prediction of colonization has the significance of the highly purposefulness and economic value, an alien species cannot be defined as an invasive species until it has completed its colonization process, and colonization prediction is the most important means of examining whether a species will be classified as invasive, which is the “definition” process. Therefore, colonization prediction is a very important aspect of the prediction applications of alien species [6]. In terms of the prediction of alien species colonization, its necessary to consider information like life cycles, host ranges, reproducing manners etc, and also the environmental suitability, techniques of plant cultivation, and control measures in the risky areas under study [7]. The general process involved in the current research mainly focuses on the steps including the reading of literature and data collection, construction of databases in the species occurring spots, simple preprocessing of collected data, optimization of parameters with Maxent etc, obtaining latent suitable areas, overlaying and reclassification of raster pictures with ArcGIS, and obtaining the future areas of colonization, wherein the data collection and followed treatment process can be exemplified by a 2022 prediction assessment of Yunnan University on the colonization risks of important alien invasive species in the Lancang-Mekong subregion, based on the changes of climate environment [5]. The dissertation is directed toward the impacts of climate changes on the colonization of alien species in the Lancang-Mekong subregion, which includes Yunnan Province in China and Thailand, Vietnam, Cambodia, Myanmar, and Laos on the Indochina Peninsula. It respectively adopted the data lists of 5 major categories and 95 important invasive species in the International Union for Conservation of Nature (IUCN) except marine organisms, animal viruses and microorganisms, the climate data information on the WorldClim, and the corresponding invasive sites of the 95 invasive species on the official website of Global Biodiversity Information Facility (GBIF) indicated with coordinates of latitude and longitude. All of the sources have shown typical manners of data collection on the prediction of colonization [5].

Among all the methods of data processing in the predictions of biological distributions, Maximum Entropy Model, shortly named Maxent, is universally recognized as a relatively scientific and efficient model due to its advantages of swift construction, simple operation, a small number of samples, and high accuracy and stability of simulation, therefore it is considered as having better predictions on the latent distributions of species than any other software [8]. Information including coordinates of the latitude and longitude of the species and the climate data can both be processed using the Maxent. However, the data that programs output during this process are usually in ASC form, which requires a necessary transformation of the data into the raster form before their input into the GIS.

The data layout of GIS has two types, the vector, and the raster, and the raster is the data form that uses pixels to present information based on the division of grids [9,10]. To convert the data form into a raster, the most frequently used way is to find Conversion Tools under the menu bar of Arc Toolbox in Geoprocessing, in which the To Raster indicates the path of converting ASC format to the raster. In the data input, the Reclassify in the Spatial Analyst Tools under the same menu bar is used to input and output raster, and also make classifications so that the data will stratify. Meanwhile, the Symbology in the Property menu can also be used to adjust the color so that the map can be made. The use of ArcGIS is relatively convenient in this colonization prediction because it does not require specific biological properties of the species in study, but rather include properties in the corresponding databases like WorldClim and GBIF, therefore can achieve fast and numerous data predictions and image productions.

3.2. Prediction of the potential geographical distribution

Prediction of the potential geographical distribution is an essential component of species invasion prediction. It involves using a range of information, including the distribution and biological data of the target species, as well as climate and geographical data, to predict the suitable range and degree of suitability of the target invasive species in the study area. Only by predicting the potential geographical distribution can further predictions be made regarding the impact on human life, such as potential economic losses. To predict the potential geographical distribution, the first step is to collect and organize relevant information about the invasive species. Data can be sourced from field surveys or databases. If domestic data is needed, databases such as the Database of Invasive Alien Species in China and the Invasive Alien Species of China (IASC) can be used. If global data is needed, databases such as the Global Invasive Species Database, CABI-ISC (CABI-Invasive Species Compendium), and EPPO Global Database can be used [11].

However, detailed geographic and species information necessary for experiments or research is often difficult to obtain from databases. Field surveys are challenging, and data accuracy can be influenced by subjective factors such as recording errors and route selection. Therefore, when obtaining species geographic distribution information, ecological niche models are often relied upon. Ecological niche models use known species distribution data and related environmental variables to build models using certain algorithms to determine the species' ecological requirements and project the results to different times and spaces to predict the actual and potential distribution of the species [12]. However, even with the same data basis, different ecological niche models may yield different results due to differences in the adaptability of each model, depending on the selected species and the requirements of the experiment or research. Therefore, when predicting the potential geographical distribution of species, appropriate ecological niche models should be chosen based on the actual situation. Commonly used models include CLIMEX, GIS, GARP, MaxEnt, etc.

The obtained models are overlaid and calculated in GIS to produce the final predictions. Taking into account multiple influencing factors, the specific steps are as follows: under certain conditions, select multiple influencing factor data such as climate factors, use methods such as multiple regression to establish regression models for each influencing factor, and calculate the residuals for each factor. Then, compare the interpolation methods in the GIS spatial analysis module, such as Kriging, and choose the interpolation method with the smallest RMSE value that simultaneously considers relevant factors to perform blended spatial interpolation for the factors, resulting in raster data [13]. Next, combine the ecological niche model used and the obtained data results to determine the standard level and load the calculation results in ArcGIS software for suitability level classification and visualization.

4. Conclusion

The predictions of invasive species with GIS are essentially computer science applications with various subtopics applied in practical fields. Therefore, conducting experiments related to predictions of invasive species requires not only a certain degree of understanding of invasive species in biology but also skillful knowledge and high proficiency in computer science. Current studies related to invasive species predictions focus more on geographical distributions and economic losses due to the damage caused by the invasive species. The topics are suitable to the developed geographical information software system, but the problem with GIS-oriented software study will also bring a problem, which is that researchers cannot predict the dynamic changes of human societies and their impacts on the natural environment being studied as precisely and timely as the same geographical predictions. The spread of invasive species is also influenced by human activities like a migration of people and local economics, and although various economic predictions have already been tested, the models are still static in large numbers due to the highly volatile property and unpredictability of human activity and its impact on the natural environment, which makes the dynamic predictions of human societies still pending. With the development of computer science, the expected efficiency and precision of invasive species predictions will be higher, and the complexity and difficulty, however, will be deducted to fit in more various needs, which might provide a possible solution to improve the static defects, like predictions of economic losses and human population migrations existing in the current study.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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