The risk of dandelion invasion

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Abstract. Dandelion originated in the Mediterranean coastal region, under suitable conditions, its seeds can spread and spread with the wind, and there are a large number of seeds. This article uses the WINDISPER-L model to analyze the propagation distance of seeds under different settling rates, settling heights, and wind speeds. And it was considered that the number of seeds and inflorescences may vary due to random factors such as climate during different growth cycles. After four growth cycles, most of the dandelion falls about 30 meters away from its mother body and grows and reproduces normally. Subsequently, when establishing a risk assessment system for invasive species, three aspects were considered: the characteristics of the species themselves, the natural environment, and human activities. The Analytic Hierarchy Process (AHP) was used to assign weights to indicators at each level, and ultimately all indicators at all levels passed the consistency test. And use a risk assessment system to calculate the potential risks that may arise from the invasion of dandelion, Canadian Solidago, and Ambrosia trifida. This can provide some inspiration and reference for corresponding managers in evaluating whether a species is an invasive species.

Keywords: Dandelion; wind dispersal; AHP; risk assessment.

1. Background

Dandelion, which is a plant that can be found almost everywhere globally. It is known for its distinctive and eye-catching flowers and unique seed appearance (see in Figure 1). It has a very strong reproductive capacity, and in suitable environments, a dandelion will produce 50~100 seed heads per year. The average number of seeds on each head is 100~200[1, 2].

Fig.1 Dandelion’s flower and seeds head

In some places, it is considered a pesky weed and an invasive species. It has adapted to the local environment and reproduces prolifically, affecting the native habitat and the growth of crops. In other regions, it is considered non-invasive. Because its rate of reproduction is within manageable limits due to climatic conditions. Additionally, dandelions possess some aesthetic, medicinal, and culinary values, and human activities to some extent restrict their uncontrolled expansion, preventing them from becoming invasive species. It is evident that whether a species becomes invasive is influenced by various factors, including the species' reproductive characteristics, climate conditions, human activities, and native biota.

Studying the population growth patterns of biological species under different conditions is of great significance in analyzing the invasiveness of introduced species.

2. Restatement

Invasive plant species can disrupt the native ecological system and pose threats to native animals, plants, and even human health within that environment. The objective of our research work is to develop a mathematical model to analyze the invasiveness of dandelion.

First, we try to design a mathematical method to describe the population of dandelion under different climatic conditions. Second, we are asked to design a evaluate model that determine a plant is a plant is an invasive species. Besides, the model should be capable to analysis the impact factor for invasive species. Third, two other plants need to be considered. The impact factor should be identified the region in where one of the selected plants are invasive.

3. Assumptions and Variables

Assumption 1: The growth process of dandelion goes through five stages, namely sowing, emergence (6 days), flowering (40 days), fruiting (30 days), and seed maturation (14 days).

Justification 1: Generally speaking, dandelion seeds take 6 days to germinate after sowing, about 30-50 days to bloom, and 30 days to bear fruit. The seeds need to continue to mature for 13-15 days. This article takes the average of the growth cycle duration events of the dandelion mentioned.

Assumption 2: The areas studied in this article all have natural conditions such as sunlight, water, and soil nutrients required by the plants to be studied, and no extreme climate phenomena occurred during the study period.

Justification 2: Plants need to have certain natural conditions in order to grow.

Assumption 3: Each "puffball" stage has 100 seeds of dandelion.

Justification 3: Generally, there are more than 100 seeds in the head of each dandelion [3]. To simplify the calculation, this article takes its minimum value.

The symbols and meanings of the variables used in the model are defined in Table1.

Table 1 Definition of Variables

Variables	Meaning
d	The propagation distance of a seed per second
v*	Friction rate
k	Karman constant, usually taken as 0.4
v	Horizontal wind speed
w	Vertical wind speed
f	Seed settling rate
h	Seed settling height
H	Plant height
D	Dynamic zero displacement
z	Aerodynamic roughness
ε	Random variables subject to standard normal distribution
n_s	The number of seeds of a dandelion in the pufferfish stage
n_f	Number of dandelions with mature seeds
n_x	The number of inflorescences in a dandelion plant

4. Dandelion diffusion model

This study first established a horizontal distance propagation model of a dandelion seed under different climate phenomena. Then, a binary normal distribution was used to describe the geographical location of the seed falling with different wind directions. Finally, the above model was used to simulate the growth of dandelion after 1, 2, 3, 6, and 12 months.

4.1 WINDISPER-L seed wind propagation model

The climate varies greatly in different regions, and the growth of dandelions also varies. According to Madeleine Seale et al.'s research, the settling speed of dandelion seeds varies under different humidity and temperature conditions [4]. In environments with high humidity and low temperature, some of the water vapor in the air will attach to the seeds of dandelion, increasing the weight of the seeds and accelerating their sedimentation rate; The drier the climate, the lower the sedimentation rate of seeds, thereby extending their propagation distance and expanding their diffusion area. Generally speaking, the higher the wind speed, the longer the seed stays in the air, and the longer the distance it travels through wind media.

Due to the assumption that the position studied in this article is located on open land, according to Nathan et al. (2002) [4] and Soons et al. (2004) [5], the WINDISPER-L model is used to characterize the propagation distance of dandelion seeds in different climates (equation (1)).

$$d=\frac{v^*}{k(f-w)}\left((h-D)\ln\left(\frac{h-D}{e*z}\right)+z\right) \tag{1}$$

Where friction rate satisfied $v^*=k\times v\times\ln((H-D)/z)$, v is the wind speed in the horizontal direction, H is the height of plant species, h is seed settling height, e is exponential constant, instantaneous vertical wind speed $w=1.25v^*\times\varepsilon$, ε following a standard normal distribution, dynamic zero displacement $D=0.63\times h$ and aerodynamic roughness $z=0.13\times H$。

In order to describe the specific landing positions of different seeds, this article uses a two-dimensional plane as a benchmark to describe the direction in which the seeds ultimately land relative to the parent body. According to equation (1), the final landing distance of the seed with different wind speeds can be obtained. Let $X: N(d*\cos\alpha,\sigma_X)$, $Y: N(d*\sin\alpha,\sigma_Y)$ The covariance of random variables X and Y satisfies $\mathrm{COV}_{XY}=E(XY)-d^2\cos\alpha\sin\alpha$, the correlation coefficient satisfies $\rho=\mathrm{COV}_{XY}/\sigma_X\sigma_Y$, then the corresponding probability density function can be described by equation (2).

$$f(x,y)=\frac{1}{2\pi\sigma_X\sigma_Y\sqrt{1-\rho^2}}\exp\left\{-\frac{\frac{(x-d\cos\alpha)^2}{\sigma_X^2}+\frac{(y-d\sin\alpha)^2}{\sigma_Y^2}-\frac{2\rho(x-d\cos\alpha)(y-d\sin\alpha)}{\sigma_X\sigma_Y}}{2(1-\rho^2)}\right\} \tag{2}$$

where, the value of α、γ_X and γ_Y can be determined based on the perennial wind direction of the specific geographical location; $\sigma_X=\gamma_X v$ and $\sigma_Y=\gamma_Y v$, σ_X and σ_Y take different values due to different climates, horizontal wind speeds, and wind directions.

4.2 Typical growth of dandelions

A dandelion seed takes a period of time from sowing to maturity. Assuming that all seeds in the inflorescence of the same dandelion plant will mature within 15 days after the first inflorescence seed matures. The number of dandelions, inflorescences, and mature seeds in the pufferfish stage that can be obtained after a successful sowing of dandelions carried by a pufferfish in the wind and a successful growth cycle can be expressed by equation (3)

$$\begin{cases} n_{f1}=\theta_1 n_s\delta_1 n_x \\ n_{x1}=\delta_1\delta_2 n_x^2\theta_1 n_s \\ n_{s1}=\delta_1\delta_2 n_x^2\theta_1\theta_2 n_s^2 \end{cases} \tag{3}$$

where, $1-\theta$ represents the proportion of seeds that cannot grow normally due to random factors such as animal predation, human factors, and poor seed quality, and θ represents the proportion of normal growth, while δ represents the proportion of inflorescences per dandelion plant in different growth cycles caused by different climate phenomena such as temperature and humidity. After a growth cycle of c , the number of dandelions and mature seeds in the pufferfish stage is expressed as equation (4).

$$\begin{cases} n_{fc}=\prod_{i=1}^{c}\theta_i\delta_i n_s^c n_x^c \\ n_{xc}=\prod_{i=1}^{c}\theta_i\delta_i n_s^{c+1} n_x^c \\ n_{sc}=\prod_{i=1}^{c}\theta_i\delta_i n_s^{c+1} n_x^{c+1} \end{cases} \tag{4}$$

where, θ_i and δ_i represents the proportion of seeds that can grow and develop normally due to climate differences in different growth cycles and geographical locations, as well as the proportion of inflorescence per dandelion plant.

4.3 Simulation

4.3.1 Parameter settings

According to hypothesis 3, a dandelion inflorescence in the puffer fish stage carries 100 seeds. Each dandelion plant can grow up to 7 inflorescence. Due to the needs of plant growth, dandelion seeds generally mature from May to October, so this study assumes the initial research date to be May 1st. Taking the temperate monsoon climate as an example, its annual average temperature is not less than 0 degrees Celsius, with high temperatures and rainy summers and cold and dry winters. The proportion of seeds that can grow and develop normally varies depending on the season, set θ_1 follows a uniform distribution of $[0.85, 0.95]$, θ_2, θ_3 and θ_4 follow a uniform distribution of $[0.75, 0.9]$、$[0.35, 0.6]$ and $[0.8, 0.9]$, respectively .The number of inflorescence on each dandelion plant also varies with climate change, set γ_1, γ_2, γ_3 and γ_4 follow a uniform distribution of $[0.85,0.9]$, $[0.8,0.9]$, $[0.4,0.6]$ and $[0.75,0.8]$. According to Zhang Jian et al.'s study on the propagation distance of dandelion seeds [6], predicting the growth of dandelion seeds after 1 month, 2 months, 3 months, 6 months, and 12 months of wind propagation can increase plant height and sedimentation height $H = h = 0.4$ m, karman constant $k = 0.4$, the seed settling rate $f = 0.584$ m/s, and the average wind speed during the initial research period was 4.89 m/second. By incorporating the above parameters into equation (1), the propagation distance of dandelion seeds in the pufferfish stage can be obtained after experiencing wind induced propagation. Due to the fact that it takes 90 days for a dandelion to complete a growth cycle, it can be assumed that it can experience four growth cycles within a year for ease of calculation. Different growth cycles correspond to different climates, and the average wind speeds in subsequent growth cycles can be assumed to be 5.27 m/s, 5.76 m/s, and 4.23 m/s. The different geographical locations of dandelions result in different directions of seed propagation. Assuming that the geographical location of our research institute is always easterly, it can be assumed that 70% of the seeds will land within $\alpha \in [-\pi/3, \pi/3]$.

4.3.2 Experimental Results

From Figure 4-1, it can be seen that the vast majority of seeds of a dandelion will land within 8 meters of its parent after undergoing a wind dispersal. After one month, seeds successfully sown through wind vector transmission will be in the stage of about flowering, two months later in the stage of flowering and fruiting, and three months later, seeds successfully sown will have gone through a complete growth cycle, in the stage of puffer fish. The seeds they carry are about to fall off from their mother and undergo the next round of wind vector transmission. Under the interference of random factors, a total of 557 seeds were successfully sown and grew normally until the seeds matured in this round. The probability density map corresponding to its landing location is shown in Figure 4-2 (left), indicating that most seeds' landing locations are in the easterly direction of the parent body.

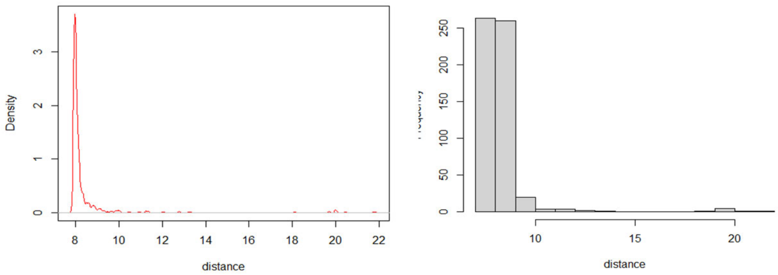

Fig. 4-1 Density and frequency plots of the first round of wind media propagation distance.

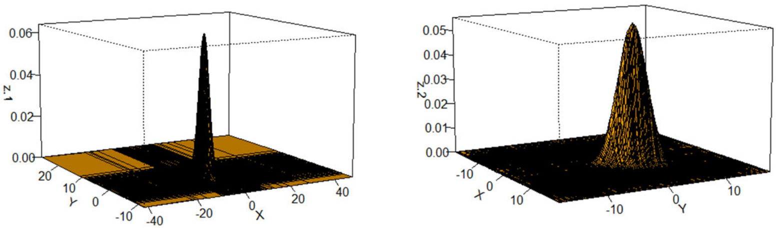

Fig. 4-2 Probability density plots of the distance traveled by wind media in the first (left) and second (right) rounds.

After six months, dandelion seeds have successfully completed two rounds of wind dispersal and are preparing for the third round of transmission. At this time, the probability density and frequency plots of the transmission distance of all dandelion seeds capable of wind dispersal are shown below. As shown in Fig.4-3, after the second round of propagation, the vast majority of seeds land about 15 meters away from the initial dandelion. Excluding the seeds that could not be successfully sown due to random factors and that bloomed normally, bearing fruit to maturity, a total of 273127 dandelion plants existed after the second round of propagation. The probability density diagram of the seed landing distance in the second round of wind vector propagation is shown in Fig.4-2 (right).

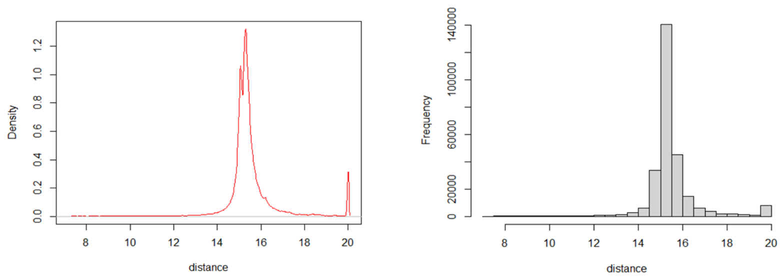

Fig. 4-3 Density and frequency plots of the second round of wind media propagation distance

After 9 months from the initial research time, dandelion seeds have completed the third round of wind vector transmission. In the third round, a total of 4465563 seeds were successfully sown and grew normally. From Fig.4-4, it can be seen that the vast majority (98.45%) of dandelions still grow within 23 meters from their mother body, and only a small portion (1.55%) of dandelions grow normally 30 meters away from their mother body and undergo the next round of wind vector transmission. By May next year, 12 months after the initial study, the seeds that can grow normally in the third round of transmission will have matured and are ready for the fourth round of wind vector transmission. From Fig.4-5, after the fourth round of transmission, there were a total of 10091337 dandelion plants, with most of the dandelion seeds falling within 30 meters of the mother plant.

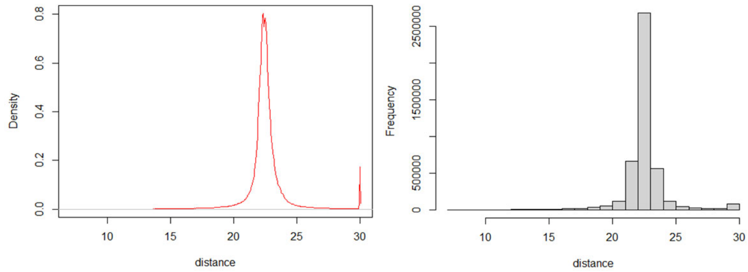

Fig. 4-4 Density and frequency plots of the third round of wind media propagation distance

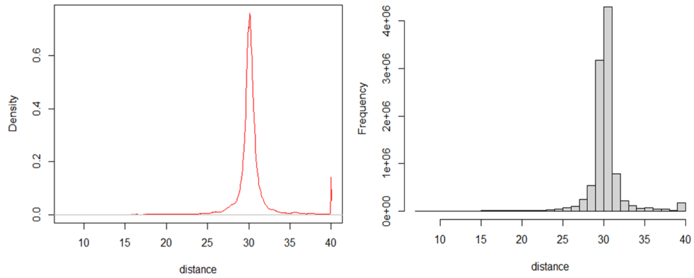

Fig. 4-5 Density and frequency plots of the fourth round of wind media propagation distance

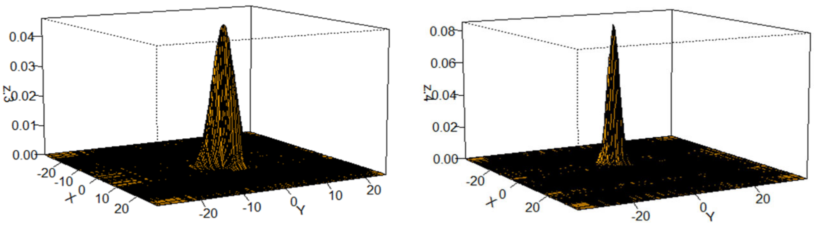

Fig. 4-6 Probability density plots of the distance traveled by wind media in the third (left) and fourth (right) rounds

5. A Risk Assessment Model for Species Invasion

This study draws on the Weber and Gut risk assessment systems to establish the risk analysis method used in this article [8]. Our research institute has established an assessment system that comprehensively considers three aspects: the characteristics of the species themselves, the natural environment, and the overview of human activities, and has set it as the overall goal. Then, this article uses AHP to assign weights to the different indicators mentioned above.

5.1 Construction of risk assessment system

In own species characteristics, six different secondary indicators and corresponding tertiary indicators will be established: (1) environmental adaptability, including species origin, global distribution range, and main natural distribution areas; (2) Growth status, including the growth status, number and range of escape organisms in outdoor environments; (3) Biological characteristics, including lifestyle, main reproductive methods under natural conditions, average number of seeds per plant, and seed germination rate; (4) The mode and ability of diffusion, including the main mode of seed transmission and the ability to spread and spread; (5) Potential hazards and impacts, including the ability to occupy habitats and whether they have allelopathic effects; (6) The possibility of being picked, including whether it can be consumed or used, and the brightness of the flowers.

In natural environment, two secondary indicators have been established: (1) geographical overview, including specific locations and the main types of surrounding areas and land forms; (2) Natural overview, including vegetation coverage and plant species richness.

In human activities, two secondary indicators have also been established: (1) Overview of human activities, including population density and degree of urbanization; (2) Transportation overview, including transportation status and degree of connection with surrounding areas.

5.2 Calculation of weights for each indicator layer

When using AHP to assign weights, there are mainly four steps.

Firstly, Building a Hierarchy. It is necessary to clarify the overall goal and various elements of the decision, and sort the elements that need to be compared in a hierarchical structure.

Secondly, Establish a judgment matrix. Based on expert opinions and actual situations, compare the importance of indicators at the same level in pairs and construct a judgment matrix as shown in Table 5-1. When comparing the importance level, it is measured using the 1-9 scale method provided by Saaty, as shown in Table 5-2 below.

Table 5-1 Judgment matrix

	A1	……	Ai	……	An
A1	1	……	a_{1i}	……	a_{1n}
……		……	……	……	……
Ai	a_{i1}	……	1	……	a_{in}
……	……	……	……	……	……
An	a_{n1}	……	a_{ni}	……	1

Table 5-2 The Value and Meaning of Scale Method

Scale	Meaning
1	Ai and Aj are equally important
3	Ai is slightly more important than Aj
5	Ai is significantly important than Aj
7	Ai is more significantly important than Aj
9	Ai is extremely important than Aj
2，4，6，8	The median of the above two judgments
The reciprocal of the above values	$a_{ji}=1/a_{ij}$

Thirdly, calculate the weight coefficients using the eigenvalue method and normalize them. Calculate the continued product of each row of indicator values in the judgment matrix O_i：

$$O_i = \prod_{j=1}^{n} a_{ij} \tag{5}$$

where, O_i represents the continuous product of all n metric scale values in row i, a_{ij} is the j-th indicator in line i。

Process the continuous product O_i to the nth power:

$$O_i^{'} = \sqrt[n]{O_i} \tag{6}$$

Normalize the above vectors and obtain the corresponding weight vectors W_i:

$$W_i = O_i^{'} \Big/ \sum_{i=1}^{n} O_i^{'} \tag{7}$$

where, W_i represents the weight value of the indicator under the control of the upper-level indicators.

Fourthly, Consistency check. Consistency testing is required to ensure the rationality of its assigned weights. Calculate the maximum eigenvalue corresponding to the judgment matrix $\lambda_{\max}$:

$$\lambda_{\max} = \sum_{i=1}^{n} \left[A_i W_i / n W_i \right] \tag{8}$$

where, $A_i W_i$ is the i-th indicator vector and weight.

Next, calculate the consistency ratio CR:

$$CI = \left(\lambda_{\max} - n\right) / \left(n-1\right) \tag{9}$$

$$CR = CI / RI \tag{10}$$

where, *n* is the stage of the judgment matrix, *RI* is the random consistency indicator (Tables 5-3).

Table 5-3 RI

n	2	3	4	5	6	7	8	9	10	11
RI	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52

The judgment matrices and corresponding weight values for the three first level indicators are shown in Table 5-4 below. After calculation, it can be concluded that CR=0.018<0.1, which passes the consistency test. For the convenience of subsequent operations, adjust the weights to 0.7, 0.1, and 0.2, respectively. The second and third level indicators are also calculated using the above method until the indicators at each level pass the consistency test. For the convenience of operation, the total score of the system is set to 100 points, and the corresponding indicators at each level are multiplied by 100, and fine-tuned according to the actual situation.

Table 5-4 Judgment matrix and weight of primary indicators

Decision objectives	Characteristics of species themselves	natural environment	Human activities	Weight
Characteristics of species themselves	1	8	4	0.717
natural environment	1/8	1	1/3	0.078
Human activities	1/4	3	1	0.205

5.3 Assessment of the risk of dandelion invasion

This study takes Lijiang City, China as an example to conduct risk assessment analysis on the influencing factors of dandelion. The average annual temperature in Lijiang City is 14 degrees Celsius. According to relevant internet materials: Web of Science; China Plant Specifications Information Database; Global Biodiversity Information Facility; CABI Invasive Specifications Compendium. According to reliable media reports, the specific scores of dandelions are shown in Table 5-5.

Table 5-5 Risk assessment score of dandelions in Lijiang City

Index	1.1.1	1.1.2	1.1.3	1.2.1	1.2.2	1.2.3
Score	1.5	1	2	4	0.5	2
Index	1.3.1	1.3.2	1.3.3	1.3.4	1.4.1	1.4.2
Score	8	4	5	10	4	4
Index	1.5.1	1.5.2	1.6.1	1.6.2	2.1.1	2.1.2
Score	4	4	0	0	3	1
Index	2.2.1	2.2.2	3.1.1	3.1.2	3.2.1	3.2.2
Score	0.5	0.5	1	1	1	2

From Table 5-5 above, it can be seen that the total risk assessment score of dandelions in Lijiang City is 64 points. Overall, the score is not too high, but if introduced as a new species, regular monitoring and management are required to prevent its large-scale expansion from affecting the survival of other local plant species.

5.4 Assessment of Invasion Risk of Canadian Solidago

Canadian goldenrod, strong reproductive ability, fast spreading speed, strong adaptability, and ability to compete with surrounding plants for sunlight, water, nutrients, etc. until other plants die, posing a serious threat to biodiversity. This study takes the Qiannan region of China as an example to analyze the potential risks of Canadian goldenrod. The Qiannan regio, with an annual average temperature of around 15 degrees Celsius, abundant precipitation, complex landforms, and significant terrain fluctuations. Referring to relevant research materials [8], Table 5-6 below shows the risk assessment scores of Canadian Solidago in the southern Guizhou region.

Table 5-6 Risk assessment scores of Canadian Solidago in Qiannan region

Index	1.1.1	1.1.2	1.1.3	1.2.1	1.2.2	1.2.3
Score	2	2	2	4	2	2
Index	1.3.1	1.3.2	1.3.3	1.3.4	1.4.1	1.4.2
Score	8	8	8	10	4	4
Index	1.5.1	1.5.2	1.6.1	1.6.2	2.1.1	2.1.2
Score	4	4	0	0	3	1
Index	2.2.1	2.2.2	3.1.1	3.1.2	3.2.1	3.2.2
Score	0.5	0.5	5	4	2	2

From Table 5-6 above, it can be seen that the total score of Canadian Solidago is 82 points, with a high score, indicating that this species will bring significant risks and harmful effects to the southern Guizhou region. This is consistent with previous research on Canadian Solidago, which also indicates that the risk assessment system established in this article is effective.

5.5 Assessment of Invasion Risk of Ambrosia Trifida

Trilobed ragweed, commonly found in fields and wetlands by rivers. Seeds can be carried to new habitats through humans, animals, or water currents, resulting in widespread transmission. And compared to other plants, they have a strong ability to compete for light and water, which has a huge environmental impact on local plants and crops. The three lobed ragweed initially spread in Liaoning Province, China, and later spread to areas such as Hebei and Beijing. This article takes Beijing as an example to evaluate the invasion risk of the three lobed ragweed. Beijing is located in 390 26 '-410 03' N, 1150 25 '-1170 30' E, with a temperate monsoon climate, with an annual average temperature of around 10 degrees Celsius, and uneven distribution of precipitation seasons. Table 5-7 shows the risk assessment values of Ambrosia trifid in Beijing. From Tables 5-7, it can be seen that the total risk score of the three lobed ragweed is 96.5, indicating that this species is highly invasive and poses significant harm.

Table 5-7 Risk assessment score of Ambrosia trifecta in Beijing

Index	1.1.1	1.1.2	1.1.3	1.2.1	1.2.2	1.2.3
Score	2	2	3	4	2	2
Index	1.3.1	1.3.2	1.3.3	1.3.4	1.4.1	1.4.2
Score	8	8	8	10	4	4
Index	1.5.1	1.5.2	1.6.1	1.6.2	2.1.1	2.1.2
Score	4	4	2	2	3	3
Index	2.2.1	2.2.2	3.1.1	3.1.2	3.2.1	3.2.2
Score	1	0.5	7	7	3	3

6. Strengths and Weakness

6.1 Strengths

This article uses the WINDISPER-L model to measure the propagation distance of dandelion when it spreads with the wind. This model considers the impact of aerodynamics on propagation distance, and also includes different factors such as seed settling height, settling rate, horizontal wind speed, and vertical wind speed. It can be used to describe the different propagation distances caused by different wind speeds in different climates and seed growth and development in different regions.

We also used AHP to conduct risk assessment analysis on dandelion in Lijiang City, Canadian Solidago in Qiannan District, and Ambrosia trifida in Beijing. This intrusion model comprehensively considers the potential invasion risk of a certain species from three aspects: the characteristics of the species themselves, the natural environment, and human activities. In addition, this model can also be used to measure the risk of plant species invasion in other regions.

6.2 Weakness

When predicting the growth of dandelion within a year, this article is based on historical data of temperate monsoon climate. The distribution range of temperate monsoon climate is relatively wide, which may bring certain errors to the research and analysis of seed propagation and spread.

When assessing the risk of invasive species, the weighting of indicators and the evaluation of the scores of dandelions, Canadian Solidago, and Ambrosia trifida have a certain degree of subjectivity. However, this method still has the advantages of reducing the difficulty of evaluation and making the evaluation results more effective.

7. Conclusion

Firstly, dandelion seeds have strong reproductive ability. After the first growth cycle, there were 557 dandelions. After four growth cycles, a total of 10091137 dandelion seeds landed at a distance of about 30 meters from the mother plant.

Secondly, when conducting a risk assessment of dandelion, it was found that the risk of its invasion in Lijiang City was not high, but certain monitoring and management were needed for large-scale cultivation; The risk value of Canada's single flower and three lobed ragweed is relatively high, and various regions should increase their control to prevent their indiscriminate spread and cause huge economic losses and devastating disasters to the natural environment.

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