Analysis and Evaluation of Species Invasion

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Abstract. Invasive species, like dandelions, threaten biodiversity and bring economic and ecological risks. It is important to evaluate whether they are beneficial and their interactions with local species. This article stimulates the occurrence of invasion, evaluates the influencing factors of three species, and finally provides their invasive ranking. We used the Vensim model to dynamically simulate the intrusion process and supplemented it with an Agent Based Model (ABS). Under all other conditions, we found that for every 10% increase in birth rate, the number of dandelions increases by nearly 20%. We construct an Analytical Hierarchy Process (AHP) model to calculate the impact factor for different species. Our models have passed sensitivity tests. The model deepens our understanding of the dynamic process of species invasion and provides a theoretical framework for the identification and control of invasive species. In the future we will improve the models by collecting more comprehensive meteorological data to demonstrate the impact of seasons on seeding processes and try to displace number of Google search results to surveys on ecology experts to promote the scientific basis of our impact factor.

Keywords: Dandelions, Invasive species, System dynamics, Agent based model, AHP.

1. Introduction

1.1 Background

Dandelion not only has medicinal value, but also has good therapeutic effects, has a broad market, and can bring good economic benefits. Invasive species refer to those that appear outside their natural transmission areas and may use human activities to naturally spread to the areas they naturally reach. Invasive species can cause a decrease in species variation, damage ecosystems, and cause economic losses.

1.2 Our Work

Our first model called "Dandelion competition model based on system dynamics" is made using Vensim. The second model called "Dandelion spread model based on ABS" is made with Netlogo that shows the competition between native species and dandelions. The last model is called "Impact factor model based on AHP" it evaluates different species using APH that makes the evaluation into numbers and sees the differences. The flow chart of our work is shown below.
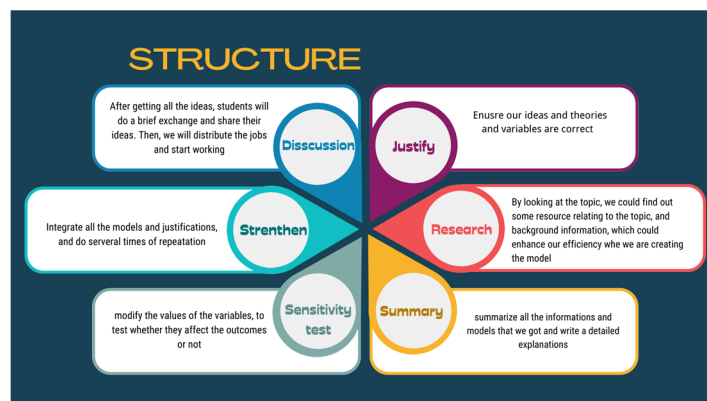

Fig. 1 Structure of our study

2. Assumptions and Explanation

Considering that practical problems always contain many complex factors, first of all, we need to make reasonable assumptions to simplify the model:

Assumption 1: All species of dandelions have a lifespan of between 8 and 12 months.

Explanation: Most dandelions are influenced by the environment in which they are grown, high altitude, perennially cold areas, and will have a much shorter bloom period of 3-4 months than dandelions grown at lower altitudes.

Assumption 2: All dandelion seeds have a lifespan of about 8 months.

Explanation: Dandelion can survive 10 to 12 months under normal artificial breeding, but in the natural environment without artificial intervention, Dandelion seeds are difficult to maintain dryness, leading to halving of life and even death.

Assumption 3: Seed life cycle is 2.

Explanation: The first cycle of a seed is germination - in the spring the seed hits the ground and begins to germinate. Dandelion seeds germinate in 1-2 weeks at the right temperature. The second cycle is the growth period - the seedling begins to germinate gradually in the soil.

Assumption 4: The effective number of seeds that can be dispersed per unit of dandelion is 50.

Explanation: The number of seeds of large-leafed dandelion is around 100 and the number of seeds of small-leafed dandelion is around 80-100. However, seed dispersal depends on wind, so here we consider the number of seeds that are not damaged during dispersal and survive intact.

Assumption 5: Time in months.

Explanation: it allows us to see the changes per month.

Assumption 6: the probability of spreading the seed is random.

Explanation: stimulates the local ecosystem's randomness.

Assumption 7: all adjacent blocks have the same probability to obtain a seed and grow into a plant.

Explanation: stimulates real life seed growth probability.

Assumption 8: we do not consider the natural death (aging) of plant.

Explanation: We use the "death rate" to determine the number of deaths each month. Additionally, the death rate is only related with level of competition.

Assumption 9: Black blocks stand for areas with no plants, blocks with plants can't be overtook.

Explanation: Emphasizes the status of the block.

Assumption 10: Intraspecific competition is greater than interspecific competition.

Explanation: Here, we take into account that the resources used by the same species are similar, and the resources used by different species are different, so there will be relatively more competition within the group

Additional assumptions are made to simplify analysis for individual sections. These assumptions will be discussed at the appropriate locations.

3. Variables

Some important mathematical notations used in this paper are listed in Table 1.

Table 1 Notations used in this paper

Variables	Description
$N(d)$	Number of dandelions
$G(d)$	Dandelions growing
$D(d)$	Dandelions death
$R(d)$	Death rate of dandelions
$N(s)$	Number of seeds
$G(s)$	Seeds growing
$D(s)$	Seeds death
$R(s)$	Death rate of seeds
L	Seeds life cycle

H(d)	Life expectancy of dandelions
H(s)	Life expectancy of seeds
T	Temperature effect
N(l)	Number of local species
G(l)	Local species growing
D(l)	Local species death
R(g)	Local species growing rate
C(l)	Local species compete rate
C(d)	Dandelion compete rate
A(l)	Local species competitiveness
A(d)	Dandelion competitiveness
S(l)	Ratio of local species gaining resources
S(d)	Ratio of dandelions gaining resources
M(l)	Resources of local species
M(d)	Resources of dandelions
W	All resources in the given area
Pcolor	(Patch color) represents the color of a block, green-native species, yellow-dandelions, black- none
Competition	Calculates the competition between native species and dandelions
Local-born	The probability of the seed of local species spreads
p-born	The probability of the seed of dandelions spread

4. Models and Results

4.1 Dandelion competition model based on system dynamics

4.1.1 Model Establishment

(1) Model 1.1: Dandelion growth model

We model the life cycle of dandelion by a system dynamic model. On the basis of the logical model of population growth, seed and temperature effects are introduced to improve it. The detail of the model is described as follows.

The number of dandelions, N(d), is positively correlated with the growth of dandelions, G(d). The number of dandelions, N, is at the same time negatively correlated with the deaths of dandelions, D(d). Therefore, we can construct the equation:

$$N(d)_{t+1} = N(d)_t + G(d)_t - D(d)_t \tag{1}$$

Then we can first consider the dandelion's death D(d) is determined by the dandelion's lifespan H(d), where we unify the lifespan of all dandelions to get the dandelion's death rate R(d) = 1/H(d).

Then we can get the equation for dandelion mortality D:

$$D(d) = N(d) * R(d) \tag{2}$$

Then we consider the change in dandelion growth G(d). Dandelion growth G(d) as an inflow variable for the number of dandelions depends entirely on the number of dandelions growing N(g). However, we still need to consider that the amount of dandelion growth is limited by time so we have to set a delay variable Delay1 with an input of the number of seeds N(s) divided by the seed period L, and a time delay of 2, thus giving us this equation:

$$Delay1 = \frac{N(s)}{L} \tag{3}$$

Next, we try to simulate the change of dandelion seeds. The number of dandelion seeds N(s) is positively correlated with the growth of dandelion seeds G(s) is negatively correlated with the death of dandelion seeds D(s), so we get this equation:

$$N_{t+1}(s) = N_t(s) + D(s) - G(s) \tag{4}$$

We also have to consider that the mortality rate of dandelion seeds D(s) is determined by the lifespan of dandelion seeds H(s), where we unify the lifespan of all dandelions to get the mortality rate of dandelions R(s)1/H(s).Then we can get the equation about dandelion seed death D(s)

$$D(s) = N(s) * R(s) \tag{5}$$

Finally, we have to consider the factors affecting the growth of dandelion seeds G(s). This is because dandelion seeds come from other already mature dandelions that are spread around by the wind of external conditions and have the opportunity to grow into new dandelions. The growth of Sony dandelion seeds G(s) is determined by the combination of the number of already existing dandelions N(d) and the number of seeds N(t) that can be spread per unit of mature dandelion. So, we get the following equation:

$$G(s) = N(t) * N(d) * \frac{T}{400} \tag{6}$$

where T a parameter representing the effect of temperature on dandelion seed growth G(s); 400 is a constant parameter representing the dependence of dandelion seed growth G(s) on temperature.

Along with the change of t, the variable month change from 0 to 11 in cycle. We use f(m) to depict the change of temperature effect in different months. This will affect dandelion seed growth G(s). There is the equation:

$$T = f(m) \tag{7}$$

$$m = \left(\frac{Time}{12} - INTEGER\left(\frac{Time}{12} \right) \right) * 12 \tag{8}$$

(2) Model 1.2: The dandelion invasion model.

In Model 1.2, the invasion model defines the dandelion as an invasive species in a defined area where a native species already exists, and we will then explore how the dandelion, as an invasive species, grows alongside the native species with limited resources and gradually "displaces" the native species. Examples of native species. We first set the number of native species N(l) in a defined area to be affected by the growth of native species G(l) and the death of native species D(l), so we get:

$$N_{t+1}(l) = N_t(l) + G_t(l) - D_t(l) \tag{9}$$

The native species had a population before the invasion, so we set the initial population of native species to 800. Similarly, we set the number of dandelions, N(d), which at this point, as an invasive species, can only have an initial number of 1.

The growth of native species G(l) is an inflow variable, which is jointly determined by the number of native plants N(l) and the growth rate of native plants R(g), so we get:

$$G(l) = N(l) * R(g) \tag{10}$$

Then we have to consider the competition coefficient C(l) for native species setting him to a constant 1; the competition coefficient C(d) for dandelions is a constant 1.5.

When a native species and an invasive species, the dandelion, compete for food resources and living space, the general outcome is that the relatively less competitive one will lose and become nearly extinct.

For the competitiveness of dandelion A(d) we can get: $A(d) = N(d) * C(d)$.

For the competitiveness of native species A(l) we can get: $A(l) = N(l) * C(l)$.

Based on the competitiveness of the two species, we can determine the proportion of resources that each of the two species obtains given a certain amount of resource:

For the proportion of resources acquired by the dandelion $S(d) = \frac{A(d)}{A(d)+A(l)}$.

For the proportion of native species accessing resources $S(l) = \frac{A(l)}{A(l)+A(d)}$.

So, we can get that the resource M(d) obtained by dandelions is determined by the total resource W and the proportion S(d) of resources obtained by dandelions, so we get:

$$M(d) = W * S(d) \tag{11}$$

Similarly, we get the resources received by native species $M(l) = W * S(l)$.

The mortality of native species D(l) is affected by the number of native species N(l), the mortality rate D(l) with N(l)/M(l), so we get the following equation:

$$D(l) = N(l) * D(l) * \frac{D(l)}{M(l)} \tag{12}$$

The settings for some of the variables are the same in model 1.1 as in model 1.2, but the dandelion death D(d) adds an N(d)/M(d) effect.

4.1.2Model Solving

We begin by defining a few initial values: N(d)=1, N(d) =800, N(s)=200, We observe a cyclical fluctuation in dandelion population that occurs every year, which is reasonable due to the periodic seasonal death rate and resource competition rate.
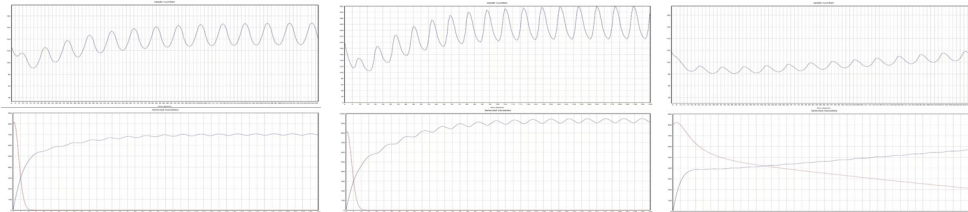

Fig. 2 Temperature effect (from left to right are arid, temperate, and tropical climate)

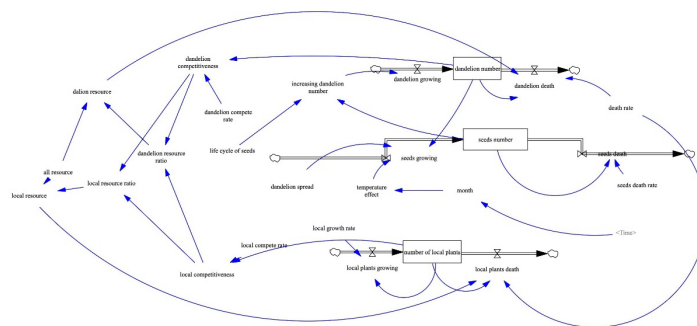Output: Temperature effect: differs from each season

Fig. 3 Output effect

4.1.3Analysis and Evaluation of results

Results: The 1.1 model cites the growth and death of dandelion seeds over a finite period of time under varying temperatures. In our model, we learned through simulation that the growth of dandelion seeds is most vigorous in the temperate zone from May to July, and then the growth is the best in the dry April-June, but the growth is slower in other times. In contrast, the impact of the tropics on dandelion seeds is not significant, because the temperature is relatively balanced throughout the year in the tropics, and the environment for dandelion growth is nearly constant. 1.2 The model simulates the competition between the most invasive species of dandelion and the native dandelion at a given time. Through simulation, we know that dandelions will gradually make native species extinct, but in natural ecosystems, native species will not completely disappear, so we introduce model 3 to supplement the competition between dandelions and native species.

4.2 Dandelion spread model based on ABS

Although the model 1 has already shown the process of dandelion taking over the resource and conquering the living space of local species, there is something different from the reality. Plants of the same species usually compete with each other fiercer than plants of different species, because they consume the same kind of resource. So, in this part, we use an agent-based model (ABS) to simulate the competition between dandelion and local species.

4.2.1Model Establishment

Yellow means dandelions, green means native species, and black means empty.

Simulate the behavior of native organisms: For each green plot, a competing value was calculated, taking into account the color of the surrounding plot and the presence or absence of other organisms. If the competition value exceeds the threshold (8), the color of the plot is set to black, simulating the process of the native creatures dying because of the competition. For each green plot, the process of

seeding by organisms is simulated, and new native organisms will be generated in the plot only if the surrounding plot is empty (black) and the random number meets certain conditions.

Simulate the behavior of dandelions: For each yellow plot, a competing value was calculated, taking into account the color of the surrounding plot and the presence or absence of other organisms. If the competition value exceeds the threshold (8), the color of the plot is set to black, simulating the process of dandelion death due to competition. For each yellow plot, the seed dispersal process of dandelions was simulated, and new dandelions were generated in the plot only when the surrounding plot was empty (black) and the random number met certain conditions.

Spread the seeds: Native species spread seeds to adjacent black patches if random conditions (random 100 > (100-local-born)) are met. Dandelions spread their seeds to adjacent black patches if random conditions (random 100 > (100-p-born)) are met.

Initialize: The initial colors of all plots are green and black, with green representing native species that have begun to grow and black representing unoccupied plots. Set the color of a random plot to yellow, representing an invading dandelion.

Simulated evolution process:

Native life: For each green plot, the competing value is calculated by checking the color of the neighboring plot. The competition value between green plots is larger, and yellow plots and plots with living creatures around them also increase the competition value.

If the competition value exceeds 8, the native species are removed from the plot.

By examining neighboring plots, we simulate the seeding process of organisms. If the neighbor plot is empty (black) and the random number is greater than a certain threshold (local-born), a native species is generated in that plot.

Dandelion:

For each yellow plot, the competing value is calculated by checking the color of the neighboring plot. The competition value between yellow plots is larger, and green plots and plots with living creatures around them also increase the competition value.

If the competition value exceeds 8, remove the dandelions from the plot (set the color to black)

The seed dispersal process of dandelions was simulated by examining neighboring plots. If the neighbor plot is empty (black) and the random number is greater than a certain threshold (p-born), new dandelions are generated in that plot.

4.2.2 Model Solving

Here we use netlogo to implement competition and evolution between dandelions and native species, and to visualize the data.
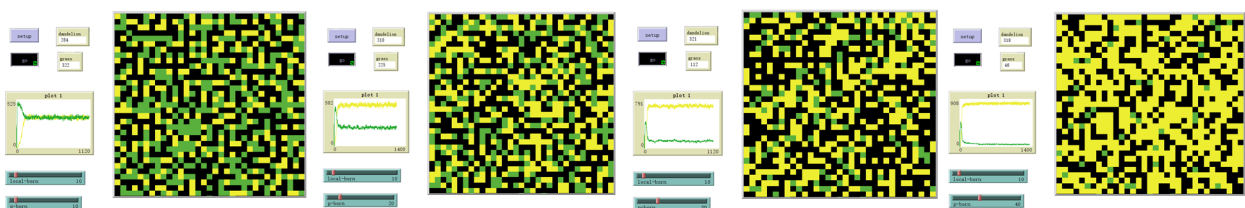

Fig. 4 Picture of netlogo

4.2.3 Analysis and Evaluation of results

The results are analyzed in combination with the reality. Local -born indicates the number of local-born people in each case. p-born (Dandelion born population) represents the number of foreign-born people in each case. The values of p-born are superimposed in each row, i.e. 10, 20, 30, and 40. Dandelion Ratio shows the proportion of Dandelion in each case. The percentages are given in the form of percentages of 49%, 67%, 86% and 93%, respectively. This set of data shows a trend that as the number of dandelion births increases, so does the proportion of dandelions.

Table 2 Dandelion proportion

Local-born	p-born	Dandelion ratio
10	10	49%
10	20	67%
10	30	86%
10	40	93%

Dandelions do not need pollination to produce fruit, the female part of the flower can produce its own seeds, so that's why in our model a single dandelion can successfully reproduce and invade a colony. In the first set of data, we can prove that when the birth rate is the same, the proportion of dandelions and native plants is about the same. But our model takes into account that dandelions are more fertile, so we adjust different values to test the proportion of dandelions. It turns out that for every 10 percent increase in births, the number of dandelions increases by almost 20 percent.

4.3 Impact factor model based on AHP

4.3.1Model Establishment

We will compare dandelion with water hyacinth and use Analytic Hierarchy Process to explore whether dandelion is an invasive species.The Analytic Hierarchy Process (AHP) is a combination of subjective weighting method and objective weighting method.

By collecting the information on invasive species, we set primary indicators as local impacts and their own capabilities, and secondary indicators as impacts on society, ecosystems, human health, reproductive capacity, seed dispersal, and adaptability. As shown below:
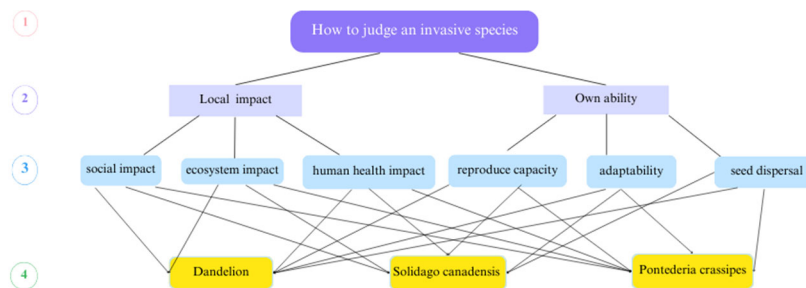
Fig. 5 Indicator setting

Then SPSSAU was used to construct the judgment matrix. In this process, 1-9 scale method was used, as shown in the figure below:

Table 3 1-9 scale method

Intensity Of Importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	For compromises between the above
Reciprocals of above	In comparing elements, i and j -if i is 3 compared to j -then j is 1/3 compared to i

We summarized all the collected data into excel tables, summarized the order of each indicator in the paper, observed the proportion of each indicator, and then scored. As is shown in the picture.
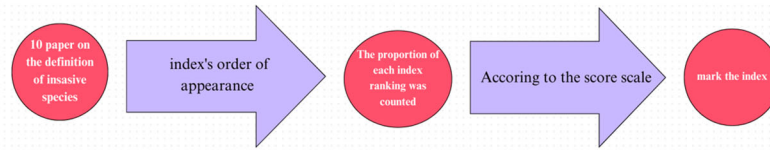
Fig. 6 the order of each indicator

4.3.2 Model Solving

We read 30 different papers, reproduce all the indicators involved using the letters A (local impact), B (own ability), C (social impact), D (ecosystem impact), E (human health impact), and F(reproduce) respectively ability), G (seed dispersal), H(adaptation). The sequence of indicators A and B presented in the following 11 papers is as follows:

Fig. 7 sequence of indicators A and B

Therefore, we can conclude that A precedes B 9 times, and B precedes A 2 times. We can consider A to be extremely important relative to B. The judgment matrix is constructed as follows:

Table 4 judgment matrix

	Local impact	Own ability
Local impact	1.000	7.000
Own ability	0.143	1.000

After calculation, the CR value is less than 0.1, and the consistency test shows that there is no inherent contradiction in the judgment matrix.

Table 5 CR value

Maximum feature root	CI value	RI value	CR value	Consistency test results
2.000	0.000	0.000	null	pass

By the following 10 papers, we can see the relationship between C, D and E:

Fig. 8 relationship between C, D and E

We can conclude that C precedes D by 2 times, D precedes E by 9 times, and C precedes E by 7 times. We can say that D is significantly more important than C, D is extremely important than E, and C is slightly more important than E. The judgment matrix is constructed as follows:

Table 6 judgment matrix

	Social impact	Ecosystem impact	Human health impact

Social impact	1.000	0.200	3.000
Ecosystem impact	5.000	1.000	7.000
Human health impact	0.333	0.143	1.000

And after calculation, CR value is less than 0.1, through the consistency test, indicating that there is no logic problem in the judgment matrix.

Table 7 CR value

Maximum feature root	CI value	RI value	CR value	Consistency test results
3.066	0.033	0.520	0.063	pass

Finally, with the 9 papers above we get the relationship between F, G and H:

Fig. 9 the relationship between F, G and H

We can conclude that F precedes G 8 times, H precedes F 6 times, and H precedes G 9 times. We can say that F is obviously more important than G, H is more important than F, and H is more important than G. The judgment matrix is constructed as follows:

Table 8 judgment matrix

	Reproduce ability	Seed dispersal	adaptation
Reproduce ability	1.000	5.000	0.333
Seed dispersal	0.200	1.000	0.143
adaptation	3.000	7.000	1.000

And after calculation, CR value is less than 0.1, through the consistency test, indicating that there is no logic problem in the judgment matrix.

Table 9 Summary of conformance test results

Maximum feature root	CI value	RI value	CR value	Consistency test results
3.066	0.033	0.520	0.063	pass

On this basis, we calculate the weight through SPSSAU, and the results are as follows:

Table 10 weight

	Eigenvector	Weighted value	Maximum Eigenvector	CI Value
Social impact	0.580	19.319%	3.066	0.033
Ecosystem impact	2,.171	72.351%	3.066	0.033
Human health impact	0.250	8.331%	3.066	0.033
Reproduce ability	0.849	28.284%	3.066	0.033

Seed dispersal	0.221	7.377%	3.066	0.033
adaptation	1.930	64.339%	3.066	0.033

After determining the indicator weights, we hypothesize that the more prominent a species is in a certain "index," the more searches will be made on Google Scholar using that species' "name and index." On the other hand, we use the keyword "name and Ecology" to get the basic search amount of the organism in an ecological domain. The following data are obtained:

Table 11 Name and index

species	Itself and Ecology	Social impact	Ecosystem impact	Human health impact	Reproduce ability	Seed dispersal	adaptation
Solidago canadensis	22,300	822	19,100	7,070	12,600	9,840	1,870
Dandelion	31,400	15,900	20,600	45,300	24,000	21,000	8,690
Pontederia crassipes	2,790	335	6,040	3,630	5,530	3,150	1,960

Table 12 Average the sum of the three

species	Social impact	Ecosystem impact	Human health impact	Reproduce ability	Seed dispersal	adaptation
Solidago canadensis	0.055571943	0.232908	0.103581	0.170628	0.19707	0.078878
Dandelion	0.763406943	0.178399	0.471341	0.230816	0.29869	0.260321
Pontederia crassipes	0.181021114	0.588693	0.425078	0.598556	0.50424	0.660801

4.3.3 Analysis and Evaluation of results

We calculate the scores:

$$SCOREbj = wfj * scorebj, fj + wjt * scorebj, jt + \cdots \tag{13}$$

$SCORE\ solidago\ canadensis$

$$= 72.351\% * 0.856502 + 19.319\% * 0.036861 + 8.331\% * 0.31704$$
$$+ 28.284\% * 0.565022 + 7.377\% * 0.441256 + 64.339\% * 0.083857$$
$$= 0.899536 \tag{14}$$

$SCORE\ dandelions$

$$= 72.351\% * 0.656051 + 19.319\% * 0.506369 + 8.331\% * 1.442675 + 28.284\% * 0.764331$$
$$+ 7.377\% * 0.66879 + 64.339\% * 0.276752$$
$$= 1.136252 \tag{15}$$

$SCORE\ water\ hyacinth$

$$= 72.351\% * 2.164875 + 19.319\% * 0.120072 + 8.331\% * 1.301075$$
$$+ 28.284\% * 1.982079 + 7.377\% * 1.129032 + 64.339\% * 0.702509$$
$$= 2.793785 \tag{16}$$

The score is: Water hyacinth > Dandelion > Solidago canadensis.

In addition, combined with the collection of other data, it can be obtained: Canadian yellow flower is a highly reproductive invasive weed. This is consistent with the score of the Solidago people in Canada in terms of human health. Dandelion is also considered an invasive species (introduced from North America) due to its strong ability to grow and survive in drought and compete with other weeds.

It poses a threat to the survival of other organisms, which corresponds to its scores in adaptability and ecosystem. Among the total scores of these three species, the scores are relatively high. Water hyacinth is one of the fastest growing plants in the world. Its reproductive ability is consistent with the data score. Its seeds can be very long, with a survival time of about 5-20 years, and are extremely tenacious. In addition, it has strong adaptability, cold resistance, and can still grow under extremely cold conditions.

Through the collation of the above data, we can conclude that the data is consistent with the data. Dandelion is an invasive species.
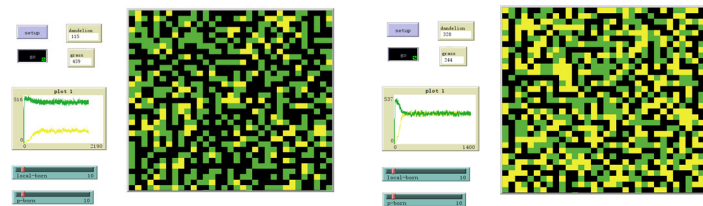
5. Sensitivity Analysis

Fig. 10 Sensitivity Analysis

We adjusted the rate of competition between dandelions to see changes in the data, and the results showed that the rate of competition did not have a significant effect on the competition between plants, but the value of competition should not exceed 50 percent, and the difference between the number of dandelions and the native plants increased.

Therefore, our parameter has passed the sensitivity test, and the result of simulation is reliable to a remarkable extent.

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