2023 HiMCM

Problem A - Dandelions: Friend? Foe? Both? Neither?

Team: 14229

Summary

An invasive species is an introduced, nonnative organism (disease, parasite, plant, or animal) that begins to spread or expand its range from the site of its original introduction and that has the potential to cause harm to the environment, the economy, or to human health. ([What is an invasive species and why are they a problem? | U.S. Geological Survey (usgs.gov)](usgs.gov))

As the harm of invasive species grow greater within the growing weaker ecosystem, a clear understanding towards the typical invasive species such as dandelions is crucial. To reach such understanding, we must be able to answer these intermediate questions: what are the factors that affects the reproduction and population growth of dandelions; how could dandelions as an invasive species impact other invasive species within specific geographical and ecological settings.

For all the questions, we adopted the approach of discretizing continuous problems. For the first question, we divided it into two parts: population prediction and location prediction. For the population part, we developed a discrete difference equation. This allowed us to incorporate various influencing factors to simulate a continuous process. We conducted a large number of simulation experiments by repeatedly selecting values randomly, resulting in the probability distribution of the population for each month. As for the location part, we used a heatmap-like representation to simulate the geographic distribution of dandelions on a one-hectare land for different months. For the second question, we selected specific characteristics of invasive species to represent the macro impact of invasive species on the environment, economy, and humans. We also provided extensions of the model related to this question.

Key words: Invasive Species, Difference Equation Model, Dandelions Features, Simulation Experiments, Discretization Method, Geographical Distribution Prediction

Menu

1. Introduction

1.1 Harmfulness of Invasive Species

Invasive species pose significant ecological and economic threats when they establish themselves in new environments. They can disrupt ecosystems, threaten biodiversity, and lead to the extinction of native species. As our natural environment faces ongoing damage and development worldwide, disturbed ecosystems become more susceptible to invasive species taking advantage of newly available niches left by native species (Why Are Invasive Species a Problem? | Greentumble).

Direct threats from invasive species include predation on native species, competition for resources, disease transmission, and hindering native species' reproduction and survival. They can also have indirect effects by altering food webs, replacing native food sources, and changing habitat conditions (Invasive Species | National Wildlife Federation (nwf.org)).

Invasive species can encompass various living organisms such as amphibians, plants, insects, fish, fungi, bacteria, and their seeds or eggs. They don't necessarily have to come from foreign countries; even native species in one ecosystem can be invasive when introduced to another, causing harm and disrupting the natural balance (Invasive Species | National Wildlife Federation (nwf.org)).

1.2 Significance of the Model in this Research

The significance of the dandelion dissemination model lies in its ability to provide a holistic understanding of invasive species' impact. Among those models, by considering various factors and variables, including population dynamics, location distribution, and broader implications for the environment, economy, and human health, they offers a comprehensive assessment. It quantifies the impact, facilitates comparative analysis among different invasive species, and assists decision-makers in prioritizing resources for effective invasive species management. This model would be a valuable tool for research and practical decision-making in the field of invasive species control.

2. Establishment and Conclusions of Dandelion Dissemination Model

2.1 Significance of the Model in this Research

In the first question, it mentions "predict the spread of dandelions", which is a very broad question that can be approached from various angles. The term "spread" can be predicted in multiple aspects. Considering this, the first question can be divided into two aspects: predicting the population and predicting the distribution location; It is essential to elaborate on the relevant characteristics of dandelions. Below, we will explain the dissemination methods of dandelions and their interaction with ecosystems.

2.1.1 Dissemination Methods of Dandelions

The structure of the seed of dandelions enabled themselves to spread in great efficiency and help the colonies of dandelions to thrive. The most representative characteristic of the dandelions is the pappus on the top of its see. Using long-exposure photography and high-speed imaging, the researchers discovered that a kind of stable air bubble known as a vortex ring remained a fixed distance from the seeds. Experiments that imitated the aerodynamics of a dandelion pappus suggested the circular geometry and airy nature of the pappus is tuned precisely to stabilize these vortex rings, helping them deliver four times more drag than a solid disk with the same area (Cummins et al., 2018). Furthermore, a single dandelion could produce up to 150 seed heads per year that each produces 250 seeds (Stewart-Wade et al., 2002b). With such advanced seed structure made for spreading and such a large scale of seed production, dandelion seeds seem to be destined to disperse in a large scale.

However, a 2003 study at the University of Regensburg in Germany found that 99.5 per cent of dandelion seeds land within 10 meters of their parent. That's because the seed falls at about 30cm per second and dandelions only grow about 30cm high. Each seed could merely travel one second before it lands. (Villazon, n.d.-b). The overwhelming majority of seedlings come from recently dispersed seeds (Hacault & Van Acker 2006). In one experiment, a majority of seeds were consumed by ground beetles within 2 to 3 weeks after shedding, but the 2-4% of viable seeds that remained were sufficient to maintain high soil populations (Honek et al. 2005). However, it is these factors that balanced the population size and spread of the species.

Different conditions greatly affect the distance of dandelion's seed dispersal. Among all factors, climate factors, including humidity; wind intensity; air temperature affects the long-distance dispersal of dandelion seeds. According to Tackenberg et al. (2003), long-distance dispersal of seeds of herbaceous species with falling velocities $< 0.5 - 1.0$ m/s is mainly caused by convective updrafts. The greater these updrafts are, the further are dandelion seeds dispersed. In addition, (Kuparinen et al., 2009) found that the amount of long-distance dispersed seeds generally increased under the scenario of +3℃ warming. Furthermore, according to Seale et al. (2019), by changing the shape of the pappus when wet, detachment from the parent plant is greatly reduced and seed falling velocities are increased with a significant change in velocity deficit behind the seed.

2.1.2 Dandelions in the Ecosystems

They play a crucial role in the reproduction of many plant species by providing a source of nectar and pollen for bees and other pollinating insect. (Dock, 2023) (Leong, 2023). They are as well beneficial in facilitating healthy soil. They are able to restore soil mineral content. This is especially important in areas where soil has been degraded of essential minerals from industrial farming practices. (De Jong Meg De Jong Nutrition, 2019).

However, the presence of dandelions might be extremely detrimental to the local ecosystem when it becomes an invasive species. When native dandelions are mixed with attractive invasives, natives may suffer from reduced seed set because invasives deprive natives of pollinators or because pollinators frequently move between species, resulting in interspecific pollen transfer (Kandori et al., 2009).

Their interaction with other animals in the ecosystem is also noteworthy. The dispersal of dandelions can sometimes be influenced by other animals and plants. For example, when dandelions are obstructed by tall vegetation like trees, their flowers may not be detected by flying insects, limiting their pollination opportunities. Additionally, some animals such as rabbits may consume dandelions, which could potentially impact their population numbers, especially when dandelions are a primary part of their diet. Furthermore, certain animals like dogs may carry dandelion seeds attached to their bodies, which can contribute to the spread of dandelion seeds to more distant locations, thereby affecting their dispersal range.

Therefore, dandelions have complex interactions with other flora and fauna in the ecosystem, and these interactions can influence the way dandelions are dispersed and their population sizes.

The information above is of great importance, since it directly impacts the assignment of parameters and variables below.

2.2 Part 1: Population Prediction Model

2.2.1 Basic Assumptions

In the context of this question, it is assumed that dandelions exist within a complete ecosystem, and they interact with the ecosystem to varying degrees. This assumption allows the model to better simulate the spread of dandelions in reality. To align with this concept, the following basic assumptions were used in constructing the population prediction section of the model:

1. Initially, there is only one dandelion, and it is in the stage of "dandelion puff"; it is located at the center of the one-hectare open land.
2. each dandelion produces a fixed quantity of seeds every month, and these seeds have a certain germination rate.
3. There are no human activities or interventions within the predicted time frame of the model.
4. Dandelion seed dispersion and growth are influenced by macro climate conditions.
5. Dandelion growth is affected by seasonal factors, with the growth rate varying monthly due to seasonal changes.
6. Dandelion seed dispersion and growth are influenced by humidity.
7. Dandelion seed dispersion and growth are affected by other animals and plants within the ecosystem.
8. The one-hectare land considered in the model has a certain environmental carrying capacity.

The aforementioned basic assumptions are based on the research and investigations on the habits and living environment of dandelions, thereby they have considerable extent of credibility and rigor on the theoretical level. The next step, which is the transition from the conjectures that account for practical situations to the variables that could be quantified and manipulated, is of great significance to the whole mathematical modeling, as it enhances the model's predictive power and applicability by incorporating flexibility and nuance into the analytical framework. To define the variable table, we identified the factors that are most quantifiable and whose changes directly impact the dispersal of dandelion seeds.

2.2.2 Variable Table

Variable	Description
P_n	Current month's dandelion population
r	Intrinsic growth rate
K	Environmental carrying capacity
S_p	Seeds produced per dandelion per month
G_s	Germination rate of seeds
α	Impact of plant competition
β	Impact of animal competition
A_i	Constant positive impact of animals
C_f	Climate factor
S_f	Seasonal factors
H_f	Humidity factor
P_c	Competition factor

2.2.3 Model Construction

After breaking down the problem, we are prepared to address it by using the population growth models. Our initial consideration is to establish the model based on the exponential growth model below, which represents P, the population of dandelions at time t.

$$P(t) = P_0 e^{rt}$$

In this scenario, resources were assumed to be infinite. However, the simulated situation should take place within an ecosystem with limited resources and space. Therefore, we have incorporated the concept of environmental carrying capacity.

$$\frac{dP}{dt} = rP(1 - \frac{P}{K})$$

The addition of the model allows for a reduction in the growth rate of dandelions as they approach the upper limit of the carrying capacity. In the reality, the carrying capacity may not have a significant impact on the growth rate of dandelions because they do not occupy resources and space in the same way animals do (which the carrying capacity is often used for). Nevertheless, the inclusion of the environmental carrying capacity variable still serves the purpose of preventing over-prediction and indirectly simulating competition pressure among dandelions in later stages.

Due to the monthly forecasting approach, where the simulation result should be captured once every month and need to incorporate additional variables, we have decided to discretize the continuous problem. We have transformed the continuous model into a form suitable for computing over discrete time intervals. The converted equation is as follows, where P_n represents the population in the nth month:

$$P_{n+1} = P_n + rP_n(1 - \frac{P_n}{K})$$

Next, we begin to incorporate other influencing factors. The first ones we have included are climate factors. We introduce climate factor C_f and seasonal factor S_f to account for the impact of climate and seasons on dandelion propagation. After adjustments, the growth rate is modified as follows:

$$r_{new} = r \cdot S_f \cdot C_f$$

Dandelions use seeds to reproduce, so it is essential to involve the quantity of seeds produced per month and their germination rate in the model. We have incorporated the average number of seeds produced per dandelion per month, denoted as S_p, and the germination rate of seeds, denoted as G_s. The number of newborn dandelions added to the population of the last month is determined by:

$$S_p \cdot G_s \cdot P_n$$

Finally, we incorporate all competitive factors, including plant-to-plant competition, animal competition with dandelions (we believe that considering inter-species competition within the scope of the current model is unnecessary), and the continued positive impact of animals (even though animals can consume seeds, the presence of any animal is still advantageous for the dispersal of dandelion seeds). These factors are denoted as α, β and A_i. Competitive factors reduce the effective growth rate, while the animal impact factor A_i increases the seed production process.

Combining all the factors mentioned above, we have obtained the final model:

$$P_{n+1} = P_n\left(1 + \left(r \cdot S_f \cdot C_f\right)\left(1 - \frac{P_n}{K}\right)\left(\frac{H_f \cdot C_f}{1 + (\alpha \cdot P_c)}\right)\right)$$

$$+ \left(S_p \cdot S_f \cdot C_f\right) \cdot P_n \cdot G_s \cdot A_i\left(\frac{H_f \cdot C_f}{1 + (\beta \cdot P_c)}\right)$$

This model can predict the population of dandelion for each subsequent month, taking into account the intrinsic growth rate, environmental carrying capacity, climate influence, seasonal variations, seed production, germination rate, competition between species, and animal impacts.

Based on the earlier explanation of the principle of dandelion propagation, we have assigned values to the variables. According to the previous information, one dandelion can produce up to 150 seed heads per year, with each seed head producing 250 seeds. Therefore, the average number of seeds produced per month is 3125 seeds. Additionally, considering the previous materials, we have set the seed survival rate to be 4%.

Since the seasonal factor changes every month, it will be discussed later. Besides the seasonal factor, we have assigned values for the following variables:

Variable:	Value: Temperate	Value: Frigid	Value: Tropical
r	0.05	0.03	0.08
K	1000	800	1200
S_p	3125	3125	3125
G_s	0.04	0.02	0.03
α	0.05	0.03	0.07
β	0.05	0.03	0.07
A_i	1.2	1.1	1.3
C_f	1.0	0.8	1.2
H_f	random(0, 1)	random(0, 1)	random(0, 1)
P_c	random(0, 1)	random(0, 1)	random(0, 1)

In a temperate environment, all influencing factors are relatively moderate. Dandelions have a moderate growth rate; the land's carrying capacity is moderate; germination rate is consistent with the default value; competition among plants and animals is also at a moderate level. Considering dandelions' attractiveness to early spring pollinators, this enhances seed dispersal rates.

In a tropical environment, dandelion growth rates are higher, a richer variety of animals can aid in more effective seed dispersal, but a richer environment also brings fiercer competition, along with higher levels of plant hindrance to seed dispersal. Humidity is higher in temperate regions.

In a frigid environment, the natural growth rate is lower, competition among animals and plants is also lower, and frigid environments are typically drier with lower air humidity.

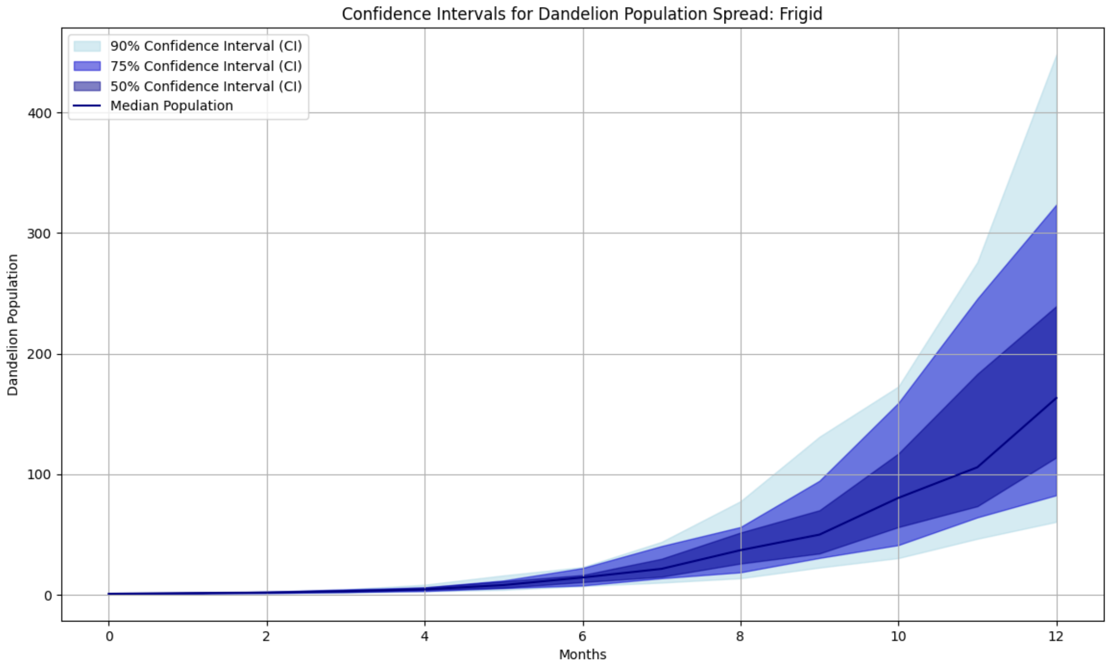
Again, considering all factors above, we have developed seasonal factors for each month in the three temperature zones. Their values are as follows:

Month	S_f: Temperate	S_f: Frigid	S_f: Tropical
1	0.7	0.3	1.1
2	0.7	0.3	1.1
3	0.8	0.4	1.1
4	0.9	0.5	1.1
5	1.0	0.6	1.0
6	1.0	0.7	1.0
7	1.0	0.8	1.0
8	0.9	0.7	1.0
9	0.8	0.6	1.1
10	0.8	0.5	1.1
11	0.7	0.4	1.1
12	0.7	0.3	1.1

2.2.4 Result of Predicting the Population

In this solution for the first question, we conducted simulations of dandelion population dispersal in different climatic zones (temperate, tropical, and frigid) using a carefully designed mathematical model. We considered a variety of influencing factors, including intrinsic population growth rate, environmental carrying capacity, seed production and germination rate, seasonal variations under different climate conditions, and competition between animals and plants. These factors were meticulously quantified and assigned values to ensure that the model accurately reflects population dynamics in the real world.

Through this approach, our aim is to uncover potential dispersal patterns of dandelions in different environmental conditions and how they are influenced by climate conditions and other environmental factors. Below is the presentation of the results:

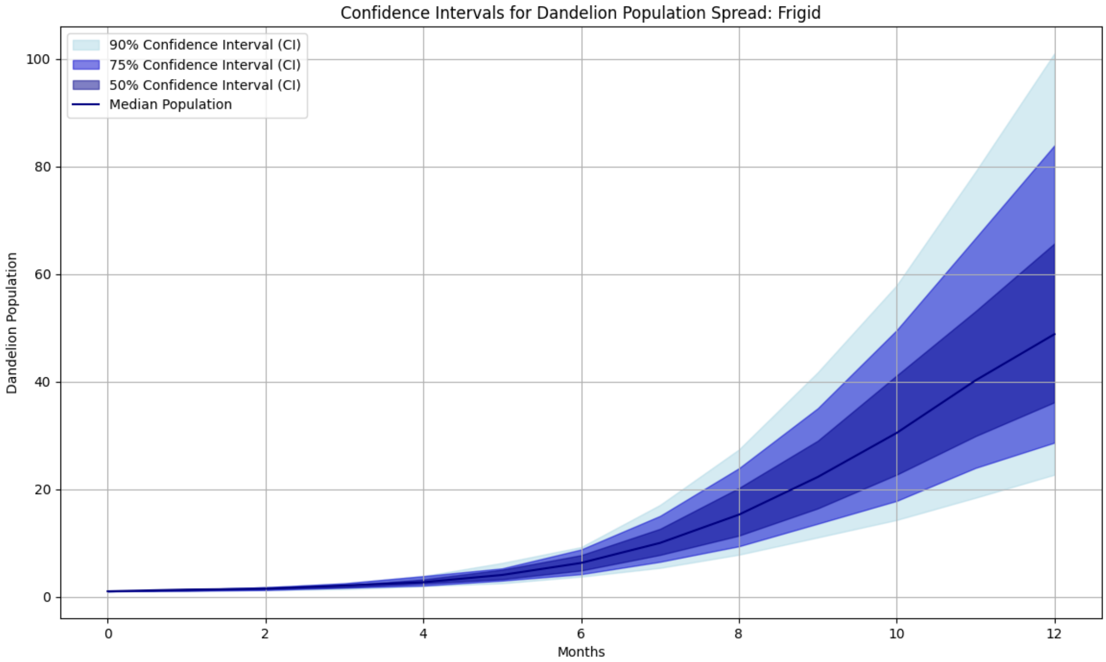


Raw Results

Month	Median	90% CI	75%CI	50%CI
1	1.64	[1.21, 1.64]	[1.21, 1.64]	[1.21, 1.64]
2	1.99	[1.47, 2.69]	[1.47, 2.69]	[1.47, 2.69]
3	3.44	[1.83, 4.67]	[2.47, 4.66]	[2.54, 3.45]
6	14.84	[7.46, 23.12]	[7.92, 22.40]	[10.72, 21.16]
12	163.90	[63.96, 450.42]	[84.60, 324.61]	[114.77, 240.90]

Processed Results (Rounded to the nearest integer)

Month	Median	90% CI	75%CI	50%CI
1	2	[1, 2]	[1, 2]	[1, 2]
2	2	[1, 3]	[1, 3]	[1, 3]
3	4	[2, 5]	[2, 5]	[3, 3]
6	15	[7, 23]	[8, 22]	[11, 21]
12	164	[64, 450]	[85, 323]	[115, 241]

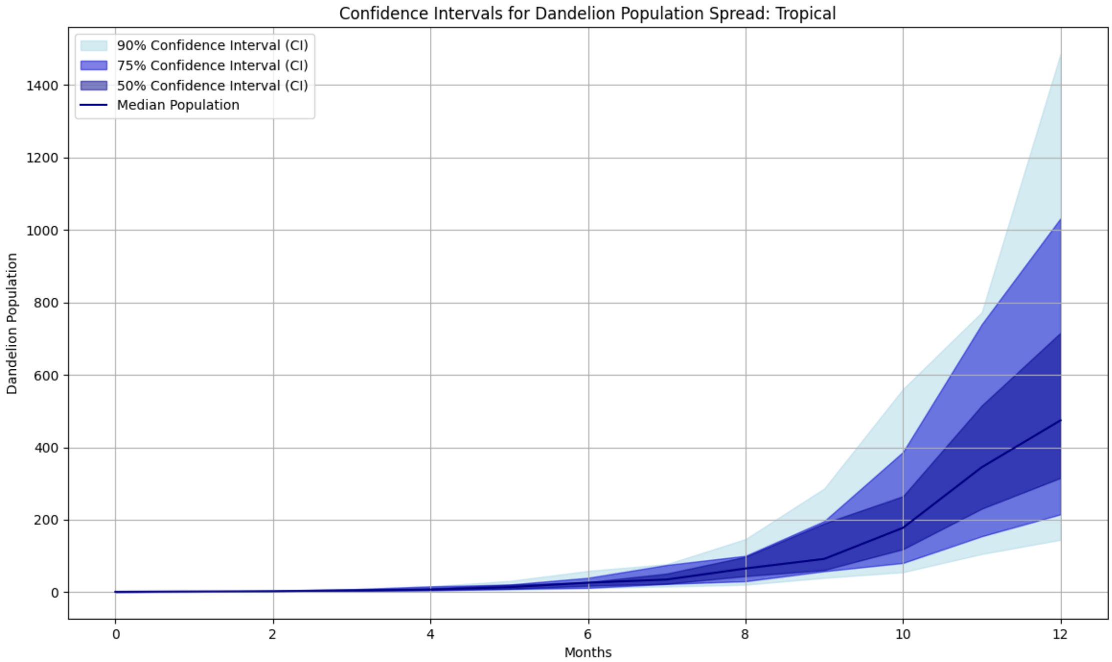


Raw Results

Month	Median	90% CI	75%CI	50%CI
1	1.32	[1.11, 1.32]	[1.11, 1.32]	[1.11, 1.32]
2	1.46	[1.23, 1.75]	[1.23, 1.75]	[1.46, 1.74]
3	2.08	[1.40, 2.49]	[1.67, 2.49]	[1.75, 2.09]
6	6.27	[3.73, 9.21]	[4.18, 8.77]	[4.86, 7.71]
12	48.79	[22.67, 101.00]	[28.64, 83.91]	[36.14, 65.67]

Processed Results (Rounded to the nearest integer)

Month	Median	90% CI	75%CI	50%CI
1	1	[1, 1]	[1, 1]	[1, 1]
2	1	[1, 2]	[1, 2]	[1, 2]
3	2	[1, 3]	[2, 3]	[2, 2]
6	6	[4, 9]	[4, 9]	[5, 7]
12	49	[23, 101]	[29, 84]	[36, 66]



Raw Results

Month	Median	90% CI	75%CI	50%CI
1	2.00	[1.13, 2.01]	[1.33, 2.01]	[1.34, 2.01]
2	2.68	[1.78, 4.03]	[1.78, 4.03]	[2.67, 4.02]
3	5.35	[2,38, 8.09]	[3.56, 8.06]	[3.58, 5.38]
6	26.19	[11.66, 58.67]	[11.94, 39.65]	[17.79, 27.59]
12	474.35	[144.70, 1485.97]	[214.92, 1032.10]	[315.49, 716.07]

Processed Results (Rounded to the nearest integer)

Month	Median	90% CI	75%CI	50%CI
1	2	[1, 2]	[1, 2]	[1, 2]
2	3	[2, 4]	[2, 4]	[3, 4]
3	5	[2, 8]	[4, 8]	[4, 5]
6	26	[12, 59]	[12, 40]	[18, 28]
12	474	[145, 1486]	[215, 1032]	[315, 716]

We conducted simulation experiments using a probabilistic forecasting approach, with each scenario simulated 100,000 times (Computer Configuration: CPU: 13th Gen Intel(R) Core(TM) i7-13700KF; RAM: 128GB 4000Mhz). We did not consider whether the results in the model are integers. Since the number of plants must be integers, we processed the results by rounding them. In each prediction, humidity and competition environment were randomly selected and combined. The large number of random simulations allows the model to cover a wide range of possible humidity and competition levels that may occur, thereby enabling the prediction results to encompass various natural environments without specifying precise humidity and competition values.

Our results indicate that the temperate environment provides moderate conditions for dandelions to grow steadily, but there is no occurrence of rapid expansion at a particular time point. The frigid environment exhibits limitations on dandelion propagation. The tropical environment offers relatively favorable growth conditions for dandelions and has the potential for rapid expansion once dandelion populations reach a certain threshold. Additionally, within each temperature zone, the range of population numbers that may occur at different times is extensive. This phenomenon is due to the outcomes of different combinations of competition conditions and humidity levels. If humidity is suitable and the competition level is just right for dandelion development, their numbers can experience significant growth.

2.3 Location Distribution Prediction Model

2.3.1 Basic Assumptions

1. This model is separated from the population prediction model and focuses solely on predicting the probability of occurrence at specific areas.
2. The factors of animal and plant influences are eliminated, and the only influencing factor considered in this model is wind.

3. A two-dimensional normal distribution function is used to represent the dispersal range of individual dandelion seeds.

2.3.2 Variable Table

Variable	Definition
$S_{i,j}^{(t)}$	The number of dandelions at grid point (i, j) at time t.
N	The quantity of seeds produced per month
P	The probability of seed germination into a dandelion
$f_{norm}(i-k, j-l;\ \mu_{wind}, \sigma)$	A two-dimensional normal distribution function centered at (i, j), taking into account wind direction μwind and diffusion standard deviation σ.
μ_{wind}	The direction of wind influence,
σ	The standard deviation of seed dispersion

2.3.3 Model Construction

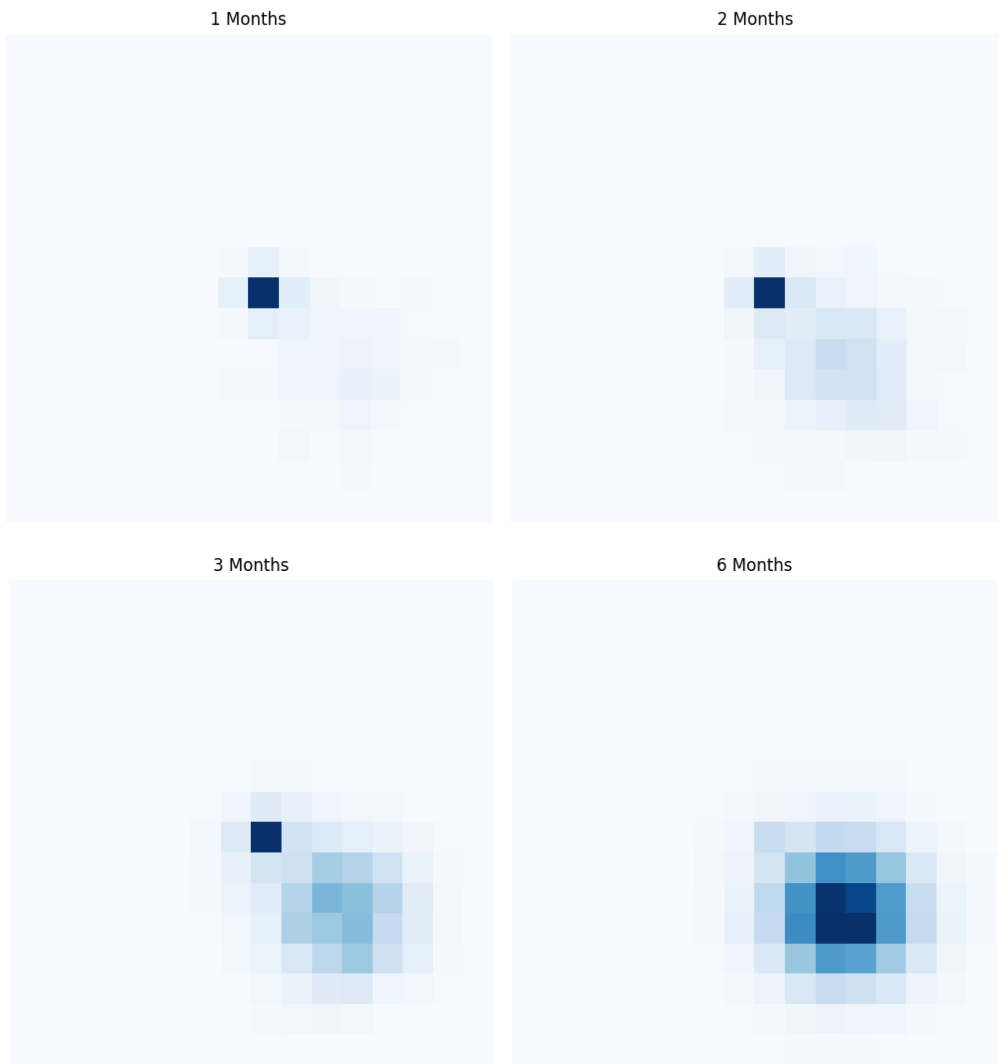
Each mature dandelion produces N seeds per month. This step assumes a constant seed production for each dandelion. The seed dispersion process is considered a random process that can be simulated using a normal distribution. At each time step, each seed has the potential to disperse into the surrounding area. The distance and direction of dispersion are influenced by wind and environmental randomness. The seeds that land have a certain probability P of germinating into new dandelions. This probability depends on various factors such as soil conditions and humidity.

Based on the above process, we propose a mathematical formula to simulate the spread of dandelions at specific geographical locations. In the formula, the position of each dandelion in the grid is updated to reflect seed dispersion and the germination of new dandelions.

$$S_{i.j}^{(t+1)} = S_{i,j}^{(t)} + P \cdot \sum\nolimits_{k,l} (N \cdot f_{norm}(i-k, j-l;\ \mu_{wind}, \sigma))$$

We added a northwest wind vector to the model to simulate the effect of wind on the spread of dandelions. This allows us to extrapolate the distribution of dandelions under the influence of winds in different directions.

2.3.4 Result of Location Distribution Model



From the simulated distribution result images, it is evident that dandelions are significantly influenced by the wind. The concentration of the dandelion population initially shifts in the direction of the wind and then forms an approximately circular settlement. In the center of the settlement, dandelions are more concentrated, while they become sparser as you move towards the periphery.

3. Establishment and Conclusions of Dandelion Dissemination Model

3.1 Location Distribution Prediction Model

After we analyzed the problem, we believe that we should establish a model that outputs a single value to measure the extent of the invasive species' impact. This single value should take into account the elements defined in the invasive species definition, considering the impact on the environment, economy, and human beings. At the same time, we aim to minimize the assessment of variable magnitudes before using the model, replacing macro factors directly with known values.

3.2 Variable Table

Variable	Definition
S	The newly produced plants each month

ω_s	Weight of S
C	Management and control costs per month
ω_c	Weight of C
A	Whether it is an allergen
ω_a	Weight of A

3.3 Model Construction

By collecting relevant data about invasive species, it is possible to calculate impact scores for each dimension. Then, applying the formula mentioned above with the determined weights, a composite impact factor can be computed. This factor can be used to assess and compare the overall impact of different invasive species. This numerical value offers a convenient way to quantify the overall impact of invasive species and can assist decision-makers in making more informed choices regarding resource allocation and management strategies.

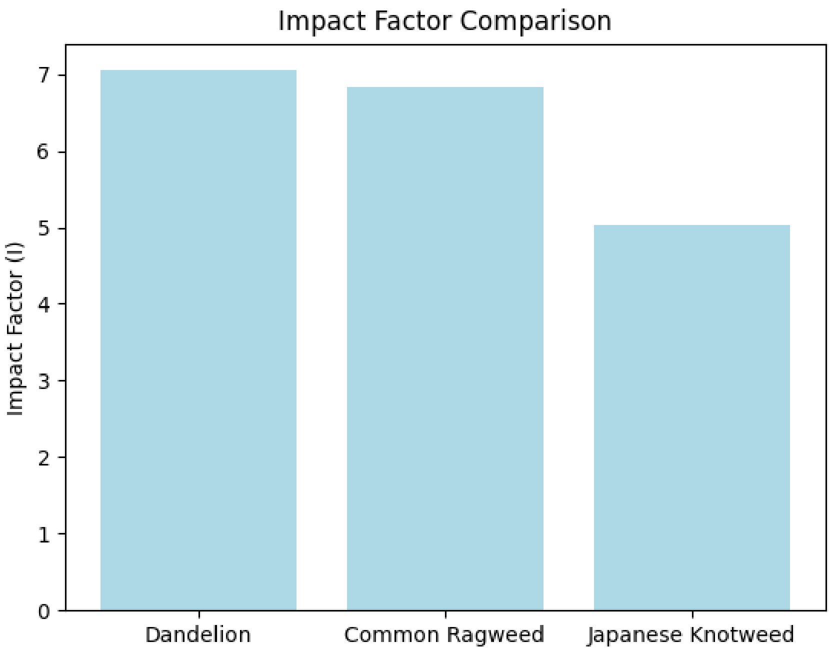
$$I = 1\% \, (\omega_s \cdot S + \omega_c \cdot C + \omega_a \cdot A)$$

3.4 Model Testing

We selected **dandelion** (as required by the question) for **Australia**, **common ragweed** for **North America**, and **Japanese knotweed** for Ireland to test the model. If a species only spreads but is not harmful, its overall impact should not be too high. Therefore, we set its spreading factor to a relatively small value. At the same time, to balance the impact of allergies, we added a multiple of 1000 to its weight. This is because whether someone is allergic or not is a Boolean value, and directly calculating it would have a negligible effect on the result. Meanwhile, allergenic symptoms can have a significant impact on humans, so they share the remaining weight equally with economic losses. Notably, Japanese knotweed was chosen to reflect its impact as an allergen. Here are our values for variables:

Variable	Dandelion	Common ragweed	Japanese knotweed
S	3125	815	1520
ω_s	0.2	0.2	0.2
C	200	300	500
ω_c	0.4	0.4	0.4
A	0	1	0
ω_a	0.4*1000	0.4*1000	0.4*1000

The calculated results for them are as follows: **7.05, 6.83, 5.04**. This indicates that in our model, an invasive species that spreads widely but causes only minor harm and an invasive species with a slower spread but more severe impact has similar levels of impact. Species with low scores in both categories have less overall impact.



If we don't consider whether the model's data can be filled in this paper, the model can be further enhanced by introducing additional variables and nonlinear relationships. This way, we can capture the impact of invasive species on the environment, economy, and society in greater detail.

$$I = \omega_s \cdot f(S) + \omega_c \cdot g(C,E) + \omega_a \cdot h(A,H)$$

Where the functions *f*, g and h represent different nonlinear relations.

$$f(S) = \alpha \cdot \log(1+S):$$

Non-linearly mapping the propagation speed S

$$g(C,E) = \beta \cdot C \cdot \sqrt{E}:$$

Considering the combined impact of economic costs C and environmental vulnerability E

$$h(A,H) = \gamma \cdot \frac{A}{1+e^{-H}}:$$

Combine the allergenic effect A and the impact on human health H

By using actual data to fill in these variables and determining the weights and parameters based on specific contexts, we can calculate a comprehensive impact factor, "I." However, due to the lack of online data, many parameters cannot be directly assessed. The weights can be adjusted based on expert opinions, and model parameters should be set using existing databases for reference.

While we cannot directly provide a value for the impact factor based on this extended model, it still serves a substantive purpose. It leaves the potential for further research by experts and provides more reference value to the numerical results.

4. References List

Cummins, C., Seale, M., Macente, A., Certini, D., Mastropaolo, E., Viola, I. M., & Nakayama, N. (2018). A separated vortex ring underlies the flight of the dandelion. *Nature*, *562*(7727), 414–418. https://doi.org/10.1038/s41586-018-0604-2

De Jong Meg De Jong Nutrition, M. (2019, May 21). *Dandelion benefits biodiversity, soil and your health – Mother Earth News*. Mother Earth News – the Original Guide to Living Wisely. https://www.motherearthnews.com/natural-health/dandelion-benefits-biodiversity-and-health-zbcz1905/

Dock, A. (2023, April 30). *Dandelion*. BritishLocalFood. https://britishlocalfood.com/dandelion/

Hacault, K. M., & Van Acker, R. C. (2006). Emergence timing and control of dandelion (*Taraxacum officinale*) in spring wheat. *Weed Science*, *54*(1), 172–181. https://doi.org/10.1614/ws-05-083r.1

Honěk, A., Martinková, Z., & Saska, P. (2005). Post-dispersal predation of Taraxacum officinale (dandelion) seed. *Journal of Ecology*, *93*(2), 345–352. https://doi.org/10.1111/j.1365-2745.2005.00987.x

Honěk, A., Martinková, Z., Saska, P., & Koprdová, S. (2009b). Role of post-dispersal seed and seedling predation in establishment of dandelion (Taraxacum agg.) plants. *Agriculture, Ecosystems & Environment*, *134*(1–2), 126–135. https://doi.org/10.1016/j.agee.2009.06.001

Kandori, I., Hirao, T., Matsunaga, S., & Kurosaki, T. (2009). An invasive dandelion unilaterally reduces the reproduction of a native congener through competition for pollination. *Oecologia*, *159*(3), 559–569. https://doi.org/10.1007/s00442-008-1250-4

Kuparinen, A., Katul, G. G., Nathan, R., & Schurr, F. M. (2009). Increases in air temperature can promote wind-driven dispersal and spread of plants. *Proceedings of the Royal Society B: Biological Sciences*, *276*(1670), 3081–3087. https://doi.org/10.1098/rspb.2009.0693

Leong, M. (2023, April 25). *The benefits of dandelions: How these weeds help our environment*. ShunCy. https://shuncy.com/article/are-dandelions-good-for-the-environment

Seale, M., Zhdanov, O., Cummins, C., Kroll, E., Blatt, M. R., Zare-Behtash, H., Busse, A., Mastropaolo, E., Viola, I. M., & Nakayama, N. (2019). Moisture-Dependent morphing tunes the dispersal of dandelion diaspores. *Social Science Research Network*. https://doi.org/10.2139/ssrn.3334428

Stewart-Wade, S. M., Neumann, S., Collins, L., & Boland, G. J. (2002a). The biology of Canadian weeds. 117. *Taraxacum officinale* G. H. Weber ex Wiggers. *Canadian Journal of Plant Science*, *82*(4), 825–853. https://doi.org/10.4141/p01-010

Tackenberg, O., Poschlod, P., & Kahmen, S. (2003). Dandelion Seed Dispersal: The Horizontal Wind Speed Does Not Matter for Long-Distance Dispersal - it is Updraft! *Plant Biology*, *5*(5), 451–454. https://doi.org/10.1055/s-2003-44789

Villazon, L. (n.d.-b). *How far can dandelion seeds travel?* BBC Science Focus Magazine. https://www.sciencefocus.com/nature/how-far-can-dandelion-seeds-travel