Team Control Number

14624

Problem Chosen

A

2023
HiMCM
Summary Sheet

Problem A laid out 2 questions with subsections. The first task was to create a model of the spread of dandelions in one hectare of land over various intervals of time. The second task was to create a model that can analyze the net impact of dandelions on the global ecosystem. This model would be used on dandelions as well as two other plant species using central New England as a reference location.

The team approached the first task by creating a model to represent the optimality of an environment's growing conditions for any plant with pappi as seeds. This was based on two blanket factors: the plant's preferred environmental conditions and the chosen environmental conditions of the location the plants are growing. The more optimal a plant's growing conditions, the more it will grow. Through thorough research, the assumption was made that as the growth rates increase, so does the number of pappi (seeds). Then, with a seed survival rate based on the growing conditions, and a physics based estimate of the probable seed spread area, the expected location and distribution of new dandelions could be calculated. These locations could then be applied to the first task and with a formulated time frame per seeding cycle, and the spread of a dandelion's seeds to a hectare of land in full sun, adjacent to a dandelion in the seeding phase could be calculated. Additionally, the expected population within the hectare could be calculated. Using this method, an effective model was created that considered temperature, humidity, growth season lengths, wind speeds and soil types and related those factors to optimal dandelion growing conditions to calculate the spread/expansion of a dandelion population. Results suggest that after 1 month, dandelions will spread through an area of $10m^2$ and have a population of 3 plants, after 2 months, $38m^2$ with a population of 8 plants, after 3 months, $87m^2$, 32 plants, and after 6 months and 12 months both at $274m^2$ with 796 plants.

The second task was approached in a similar way to the first. It was assumed that the impact factor of an invasive species had to take two main topics into consideration: how easily the plant spreads and how destructive a plant impacts organisms in its given environment. It was reasoned that as the environmental conditions improve in favorability, so does ease/rate at which the plants spread. Using the optimal growing condition formulas created in the first task, plant nutritional value, root depth and plant height, an environmental impact on a scale of -7 to 7 was created where negative results correlate to destructive effects. Results give dandelions a positive value of 0.00064, Southern Cattails a value of -0.46 and Cardoons a value of -0.37, suggesting that while dandelions have an almost net 0 impact, Southern Cattails and Cardoons have a negative impact on the environment.

All in all, both tasks were completed with comprehensive variable considerations and justifiable methodologies. The portion of the model representing optimal conditions was created adaptable for all plants and the physics based spread rate was made adaptable to all plants with pappi.

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Introduction

Plants serve a fundamental purpose in modern life. They have the ability to provide food, medicine, and beauty to the world. However, invasive plant species threaten these abilities by quickly taking over large amounts of land, hindering plant diversity. These species are defined as growing in a region other than their native region and causing harm to the surrounding ecosystem. *Taraxacum officinale*, otherwise known as the dandelion, have long been an object of fascination. Their ingenious method of spreading seeds through the wind propelled pappi is further supported by the unique physical response to humidity of pappi on the plant. As a result of this, the species is also considered to be a harmful invasive species. The ability of dandelions to quickly and efficiently spread seeds through small parachute-like structures (pappi) allows them to grow over great distances in short amounts of time, and their resiliency allows for them to pop up in many environments, even where they may not be native. The ability of dandelions to spread is vital to understanding their impact.

More generally, invasive species as a whole can take over large sums of land and consequently harm the environment. The design of a model to predict the impact of these plants and predict their spread is crucial to understanding the environment and the world's ability to protect it.

Assumptions:

1. **Better growing conditions correlate to better growth, which correlates to greater seed count.** Some growing conditions, like dry air or cold temperatures are not expected to have similar dandelion growth rates to more humid, warmer conditions. This assumption extrapolates that to allow for more manipulation of numbers to create a model limited by growing conditions.
2. **The maximum flower count is 10.** A typical dandelion has approximately 10 flowers (Meet, n.d.). Since this model is looking at dandelions on a large scale, this assumption can be made without detriment to the overall output of the model. It can be assumed that in perfect conditions, a dandelion plant will produce 10 flowers.
3. **The minimum flower count is 0.** The common dandelion is a perennial and it can retain its roots without having a flower. At the poorest conditions, the plant will not produce any flowers as it will be notably unhealthy.
4. **Greater wind speed means greater distance traveled by the seeds.** Greater wind speeds allow for the pappi of dandelions to travel further distances (Tackenberg, 2003). As a result, average wind speed can be used to approximate the distance traveled by the pappi.
5. **All attributes of considered plants are average (no outliers/unusual/abnormal dandelions).** All of the plants in the model are expected to act similarly to the patterns that were observed in cited articles. In this model outliers provide an unnecessary, non

representational level of complexity. Therefore outliers can be negated in order to make calculations more robust.

6. **Rainfall and humidity are generally correlated.** Rain generally coincides with relative humidity values (US Department of Commerce, n.d.). Therefore, if an area generally has a high humidity it can be inferred that the area will have wetter soil and provide more adequate levels of water to the plant through rainfall and dew.
7. **The four general soil types are sandy soil, humus soil, yellow-brown soil, and garden soil.** This assumption was made to allow for analysis of growth based on soil type using a referenced journal article (Quan, M., & Liang, J., 2017). These four types of soil encompass most areas in the world. They each feature various levels of nutrients, and abilities to hold humidity, among many characteristics, leading to growth rate differences for different plants.
8. **Most plants have similar trends in growth rates as Lycoris Aurea (L. Aurea) in corresponding soil types.** This assumption was made in order to apply research data from Quan, M., & Liang, J., 2017 to the system. L. aurea may not have characteristics identical to the general plant but its trends in growth rate per soil are assumed to be similar enough to allow for the model to follow those trends.
9. **The soil growth rates for Lycoris Aurea (L. Aurea) can be rounded because the specifics/decimals don't necessarily reflect the exact growth rates of the specific plants although the general plants do.** In order to generalize the data provided by Quan, M., & Liang, J., 2017, the growth rates were rounded. This is justified because the significant figures beyond two decimal places reflect very specific growing patterns of L. Aurea and do not necessarily represent the exact growth of all plants.
10. **Nutrient availability is implied by soil type.** Data from Quan et al. show a significant distinction in nutrients in soil based on the type of soil. This assumption allows for the model to remain robust while not separately factoring in the specific available resources for a targeted soil type.
11. **Soil does not have an effect on germination rates.** Since seeds have their own nutrients, they do not need nutrients from the soil to germinate. Therefore, the soil type does not relate to germination rates. Once germinated, soil is expected to have an effect, but only after germination.
12. **All plant growth variables (humidity, temperature, soil type) contribute equally to the successful growth of the dandelions.** This assumption was made to join all of the modes of data together. It can be justified because each variable is critical to the successful growth of a plant. With unacceptable values for any of these variables, a plant would not be able to survive.

13. **Grow season length correlates to the latitude of a location.** This is because at higher latitudes, the average temperatures are lower and as a result, the time frame containing acceptable growing conditions is smaller.
14. **The original plant is adjacent to the hectare plot and is fully grown and ready to disperse at the start of the growing season.** This is justified by the fact that the task stated that the dandelion was in its puffball stage, a stage where seeds are ready for dispersal.
15. **The situation given by the problem statement is at the beginning of a growing season.** This assumption was necessary in order to have a starting location for the model. Without a starting point in time, it would be impossible to accurately model this scenario. Since no starting point was provided, this assumption is critical to the model.
16. **The location of the initial dandelion is at the midpoint of one of the 100 meter long edges of the hectare growing region.** This assumption was necessary as no starting location was provided. The starting location defines the dandelion spread volume, into the 1 hectare region, therefore a starting location was created to allow for this model to function.
17. **The open hectare is a perfect square with side lengths of 100m.** This factor simplified the scenario in a reasonable manner. Since no dimensions were provided, it was only reasonable that the 1 hectare zone be square.
18. **Root length is representative of water consumption.** For most plants, roots are their primary method for water intake, as a result larger roots generally correlate to higher water intakes.
19. **The degree to which a plant impacts its environment depends on plant height, nutrient availability and water consumption.** The height portion is justified because the taller a plant is, the more sun it blocks for other plants in the ecosystem, and as a result, the more harmful it is. The smaller a plant, the less sunlight it blocks, the less harmful it is. Additionally, the nutrition qualities of a plant defines its positive effect on the environment as those nutrients are nutrients that the plant provides to the rest of the ecosystem, benefiting the areas around it. Lastly, plants with higher water consumption take resources away from others, having a negative effect on the environment.
20. **Cycles in which dandelions grow from seeds to when they release seeds don't have to be whole numbers.** This is justified as a smaller portion of the dandelions flowering faster than others do, allowing some seeds to be spread when there is only a partial cycle, while a full cycle still takes the average of 108 days.
21. **Shaggy Soldier has a neutral effect on the environment.** Since shaggy soldier is a native plant, it is already adapted to the environment and its factors are neutral.

Problem Restatement:

1. Create a mathematical model that predicts the spread of a single dandelion seed over an open hectare over the course of various months, taking into account different environmental factors.
2. Create a mathematical model that determines the impact that an invasive species has on the surrounding environment.

Variable Key

o_{Tgr} = Optimal growth temperature (Fahrenheit)
b_{Tgr} = Minimum tolerable growth temperature (Fahrenheit)
c_{Tgr} = Maximum tolerable growth temperature (Fahrenheit)
o_{Hgr} = Optimal growth humidity (decimal) (percent)
b_{Hgr} = Minimum tolerable growth humidity (decimal) (percent)
c_{Hgr} = Maximum tolerable growth humidity (decimal) (percent)
Z = Soil type value
H = Average growing season humidity (decimal) (percent)
T = Average growing season temperature (Fahrenheit)
b_{Tge} = Minimum tolerable germination temperature (Fahrenheit)
c_{Tge} = Maximum tolerable germination temperature (Fahrenheit)
o_{Tge} = Optimal germination humidity (decimal) (percent)
b_{Hge} = Minimum tolerable germination humidity (decimal) (percent)
c_{Hge} = Maximum tolerable germination humidity (decimal) (percent)
o_{Hge} = Optimal germination humidity (decimal) (percent)
A_{impact} = Impacted surface area of dandelions (square meters)
m_{seed} = Mass of the pappus (average) (kg)
m_{air} = Average mass of the air (kg)
a_{seed} = Acceleration of the pappus before terminal velocity
R = Specific gas constant ($\frac{J}{mol*K}$)
v_{wind} = Average windspeed (growth season) (m/s)
x = Maximum distance of pappus travel (meters)
a = Seed germination rate (seeds/growing period)
n = Number of growing periods
L = Latitude (degrees)
F = Growth season length (days)
r = Radius (meters)
f = Time allowed to grow (months)
o_{ge} = Optimal germination rate (percent)
o_f = Maximum number of flowers per plant (flowers)
G_r = Growth rate
G_e = Germination rate
G_l = Inputted grow time (days)
o_s = Maximum number of seeds per flower (seeds)
r_{pappus} = Length of one pappus hair (meters)
p_{width} = Width of a hair on the pappus (meters)
p_{amount} = Number of hairs on the pappus
p = Air density
ρ = Absolute air pressure (grow season average) (psi)

Part 1: Dandelion spread after 1, 2, 3, 6, & 12 months

To begin the first problem, it was deduced that there are two ways to measure the spread of dandelions: through population and spread area. To be able to calculate these two values, both an environmentally influenced growth factor and an environmentally influenced germination factor were necessary. The growth and germination factors are needed to factor in the effect of different climates on how much the dandelions grow and spread.

Growth Factor:

The growth factor was calculated in terms of optimal temperature, humidity, and soil type and the temperature, humidity, and soil type of a given environment. This was then multiplied by the amount of seeds that dandelions produce at optimal conditions, as stunts in the growth of dandelions would mainly affect the spread by stunting the seed production.

Figure 1

Final Growth Factor Calculation:

$$G_r = ((\frac{T - b_{Tgr}}{o_{Tgr} - b_{Tgr}})^{\frac{o_{Tgr} - b_{Tgr}}{c_{Tgr} - o_{Tgr}}}(\frac{c_{Tgr} - T}{c_{Tgr} - o_{Tgr}}))((\frac{H - b_{Hgr}}{o_{Hgr} - b_{Hgr}})^{\frac{o_{Hgr} - b_{Hgr}}{c_{Hgr} - o_{Hgr}}}(\frac{c_{Hgr} - H}{c_{Hgr} - o_{Hgr}})) * Z$$

Temperature:

The first variable researched was temperature. This variable determines how growth speed is affected by the annual temperature. Assumption 1 allowed for temperature to be used as a variable for overall plant growth. The variable of temperature was approached by finding the minimum and maximum tolerable temperatures of dandelions, which were 14℉ and 95℉, and the optimal temperature of 77℉ (Common, n.d.).

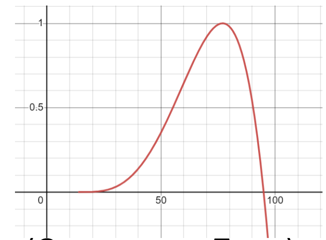
Modeling optimality of temperature was carried out by adapting a similar approach to that shown in *A nonlinear model for crop development as a function of temperature* by Yin et al. Figure 1 displays the adaptation of the equation. An equation with values for the dandelion is shown in Figure 2. The purpose of this equation is to provide a non-symmetrical curve where the x value (T) is the environment temperature and the y value is a number between zero and one, representing the percent optimality of the temperature. The abnormality of the curve shape is because of the fact that the optimal temperatures do not necessarily fall at the midpoint between the minimum and maximum temperatures, see Fig 1. This equation is applicable for a temperature within the acceptable range, otherwise the grow rate should be set to zero.

Figure 2

Adapted Optimal Temperature Equation and Graph

$$\left(\frac{T-b_{Tgr}}{o_{Tgr}-b_{Tgr}}\right)^{\frac{o_{Tgr}-b_{Tgr}}{c_{Tgr}-o_{Tgr}}}\left(\frac{c_{Tgr}-T}{c_{Tgr}-o_{Tgr}}\right)$$

for b<T<c, else the result should be set equal to zero.



(Grow rate vs. Temp)

Figure 3

Temperature Impact on Growth Final Equation (Dandelion)

$$\left(\frac{T-14}{77-14}\right)^{\frac{77-14}{95-77}}\left(\frac{95-T}{95-77}\right)$$

for 14<T<95, else the result should be set equal to zero.

Note: This equation uses established values for dandelions, they are different for other plants

Within this equation, the variables “c, b, T”, and “o” were used. The optimal temperature “*o”* was set to 77, the desirable temperature for a dandelion, and c (the max. temp.) and b (the min. temp.) were set to 95℉ and 14℉, respectively. “T” represents the environment temperature which is dependent on the environment in which the dandelion lives.

The goal of the equation was to set the temperature optimality value to be within a range above 0 whenever the temperature was above the minimum tolerable and to 1 whenever it was most optimal. The value increases exponentially approaching the optimal value since temperatures closer to the optimal value will be more beneficial than distant values. There is a relatively sharp decline of the values outputted between 77℉ and 95℉ since there is a relatively smaller range between the optimal and maximum tolerable temperatures compared to the range between the optimal and minimum temperatures. The decline was exponential to allow for values close to 77℉ to still remain near-optimal but for values closer to 95℉ to be close to, but not equal to zero. This equation outputs a coefficient between 0 and 1 which is factored into the growth rate equation. Other forms of this equation will be referred to as *the optimal curve model*.

Humidity:

Another variable researched was humidity. Using assumption #6 (rainfall and humidity are generally correlated), it was established that it would be helpful in determining the conditions for the growing of the dandelions.

This variable was approached by finding the minimum necessary humidity level for the dandelions to grow (25%) to and the maximum tolerable for dandelions (80%) (Temperature, n.d.). The optimal value for a dandelion was 60%. The optimal curve model was used to apply these variables as shown in Figure 3 to represent humidity as well (see Figures 4 and 5). Since these measures were based on average humidity over a long period of time, values above 0.8 (80%) or below 0.25 (25%) were considered to be detrimental to the dandelion, as that would indicate sustained unhealthy conditions for the plant, which would result in death of the plant. These values correlated to a growth rate of 0% whereas the optimal contributed to a 100% growth rate.

Figure 4

Optimal Growing Humidity Equation

$$\left(\frac{H-b_{Hgr}}{o_{Hgr}-b_{Hgr}}\right)^{\frac{o_{Hgr}-b_{Hgr}}{c_{Hgr}-o_{Hgr}}}\left(\frac{c_{Hgr}-T}{c_{Hgr}-o_{Hgr}}\right)$$

for b<H<c, else the result should be set equal to zero.

Figure 5

Optimal Growing Humidity Equation for dandelions

$$\left(\frac{H-.25}{.6-.25}\right)^{\frac{.6-.25}{.8-.6}}\left(\frac{.8-H}{.8-.6}\right)$$

for 0.25<H<0.8, else the result should be set equal to zero.

Soil Type:

Data was used from Quan, M., & Liang, J. (2017) to determine the impact that soil type would have on the growth of a plant (see assumptions 7 through 10). Quan, M., & Liang, J. (2017) provided growth rates for L. Aurea as they correspond to four general soil types. The growth values were scaled to a 0 to 1 scale so that they would have an equal impact compared to the other variables in the growth equation. This is because the output range of each of the two previous equations is a range of 0 to 1, in order to maintain equal value, the soil value must be between 0 and 1. These values were calculated in a study on Lycoris Aurea, however it was assumed (Assumption 8) that these values would be representative of all plants in general and therefore could be adapted to any plant including dandelions. The aforementioned values, depicted in Figure 6, are represented by the variable “Z” in the final equation. “Z” is equal to the optimality of an environment’s soil type.

Figure 6

Optimal Soil Type Values, variable "Z"

$\text{Humus} = 1$
$\text{Sandy} = 0.824$
$\text{Garden} = 0.882$
$\text{Yellow-Brown Soil} = 0.588$

Germination Factor:

Figure 7

Germination Factor Equation

$$G_e = ((\frac{T-b_{Tge}}{o_{Tge}-b_{Tge}})^{\frac{o_{Tge}-b_{Tge}}{c_{Tge}-o_{Tge}}}(\frac{c_{Tge}-T}{c_{Tge}-o_{Tge}}))((\frac{H-b_{Hge}}{o_{Hge}-b_{Hge}})^{\frac{o_{Hge}-b_{Hge}}{c_{Hge}-o_{Hge}}}(\frac{c_{Hge}-H}{c_{Hge}-o_{Hge}}))$$

The germination factor was calculated using the temperature and humidity of the environment. Each of these variables was given an expression; each expression was multiplied together to give a final germination factor. This factor could be used to determine the percentage of seeds created that are expected to survive and produce offspring.

Temperature:

The temperature optimality was calculated using the *optimal curve model*. The average grow season temperature, T, is the same value as was used for the growth calculation. The minimum and optimal values for germination were developed separately from growth optimality. The minimum value (b_{Tge}) was set to 50℉, and the optimal (o_{Tge}) was set at 77℉, based on the values for a dandelion (Dandelions, 2006). In absence of a maximum temperature value, the maximum value for growth (c_{Tge}), 104℉, was used for maximum tolerable temperature since it was the same distance from 77 as 50 was.

Figure 8

Germination Temperature Optimality Expression

$$(\frac{T-b_{Tge}}{o_{Tge}-b_{Tge}})^{\frac{o_{Tge}-b_{Tge}}{c_{Tge}-o_{Tge}}}(\frac{c_{Tge}-T}{c_{Tge}-o_{Tge}})$$

Humidity:

Figure 9

Optimal Germination Humidity Expression

$$(\frac{H-b_{Hge}}{o_{Hge}-b_{Hge}})^{\frac{o_{Hge}-b_{Hge}}{c_{Hge}-o_{Hge}}}(\frac{c_{Hge}-H}{c_{Hge}-o_{Hge}})$$

Note: for b<T<c, else the result should be set equal to zero.

Figure 10

Optimal Germination Humidity for dandelions

$$\left(\frac{H-.25}{.55-.25}\right)^{\frac{.55-.25}{.80-.55}}\left(\frac{.80-H}{.80-.55}\right)$$

Note: All percentages are represented in decimal form

Humidity was used in a similar fashion to the Growth Factor. The inputted humidity, H, is the same value as the value for growth, yet the optimal humidity for germination is different from the value for growth, as germination is simply whether the plant has enough humidity to emerge from its seed. The optimal curve model was used for this variable.

In order to find the optimal humidity for germination, the value for plants in general, 0.55 was used (*Optimal Temperature and Humidity Levels for Germination Guide*, 2023). The minimum and maximum values of 0.25 and 0.80 were retained from the growth calculations, as if a plant cannot grow it would also not be expected to germinate. Any values that were not within the range were considered 0 and no seeds would be expected to germinate.

Spread:

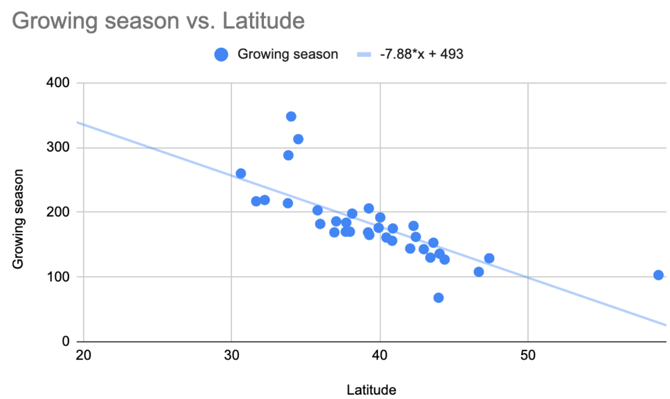
Growing Season:

An additional factor that was taken into account was the length of the growing season for different locations. This would affect the amount of time that the dandelions would be able to grow and spread.

To find these values of a growing season a data set of all US zip codes with their corresponding latitudes, and took a sample of 34 zip codes spread out across different latitudes (*Us Zip Codes Database | Simplemaps. Com*, n.d.). Then a website that was able to find the closest information to that zipcode for the growing season, the length of days between last frost and the first frost (*Frost Dates for Sturbridge, Ma | Almanac. Com*, n.d.). This let a data set with latitude and the corresponding growing season be composed, with which a line of best fit was found to be -7.88 times the latitude then adding 493 to find the corresponding days (Figure 11). For latitudes that are less than approximately 16.2 degrees, the days of growing season would be above 365 days, so for those latitudes a growing season of 365 days is used.

Figure 11

Dataset of latitude vs length of growing season



Cycles of Flowering:

It was found that on average it took a dandelion 108 days from the germination of the seed to be able to release seeds (*How to Grow Dandelions*, 2016). This means that the dandelions release a set of seeds for every 108 days of the growing season. To find the amount of times that the dandelion would be able to complete these cycles, the length of the growing season would be divided by 108 days, allowing for partial cycles (Assumption 20). The variable n is used to define this number of growing periods.

Pappus Dimensions:

In researching, it was discovered that the pappus, which is usually in the shape of an umbrella, closes as a result of higher humidity. Data from Seale et al. provided data suggesting a pappus closure rate of 10 degrees on each side at 70% humidity and 25 degrees at 80% humidity. A logarithmic function was created to find the angle of the pappus at "H" humidity.

Figure 12

Diagram of pappus with variable open angle

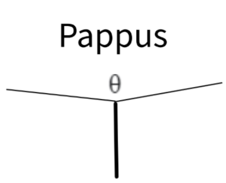


Figure 13

Equation for opening angle of pappus in terms of Humidity

$$\frac{450}{9+e^{0.54\cdot(100H-66.6)}}+130$$

The opening angle was then related to the original radius of the pappus (when the opening angle is 180). With the opening angle, the general cross sectional surface area of the pappus, which is similar to the equation for the area of a circle, could then be calculated. Using the following equation:

Figure 14

Equation for cross sectional area of pappus as it relates to original pappus radius and and humidity.

$$\pi\left(r_{pappus}\cdot cos\left(90-\frac{\frac{450}{9+e^{0.54\cdot(100H-66.6)}}+130}{2}\right)\right)^{2}$$

To find the true cross sectional area of the pappus, the presence of gaps between the pappus hair had to be accounted for. The following equation solving for the percent of pappus area occupied by the hairs was calculated where P_{width} is the width of the pappus hair, P_{amount} is the quantity of pappus hairs on the cross sectional of the pappus and the r_{pappus} is the original pappus radius/length of the pappus hairs (Meng et al., n.d.).

Figure 15

Percent of cross sectional surface area with hairs

$$\frac{p_{width}\cdot p_{amount}\cdot r_{pappus}}{\pi\cdot r_{pappus}^{2}}$$

When all of the previous equations are multiplied together, the result is the cross sectional surface area of the pappus hairs as it relates to humidity: the true cross sectional surface area of the pappus with humidity in mind.

Figure 16

True cross sectional area of the pappus as it relates to the original pappus radius, hair dimensions and humidity.

$$A_{impact}=\frac{p_{width}\cdot p_{amount}\cdot r_{pappus}}{\pi\cdot r_{pappus}^{2}}\pi\left(r_{pappus}\cdot cos\left(90-\frac{\frac{450}{9+e^{0.54\cdot(100H-66.6)}}+130}{2}\right)\right)^{2}$$

Wind Force:

Wind is one of the leading factors when it comes to the spread of pappi as it determines how far they would travel and at what speed (Assumption 4). By using this information, an equation was made to calculate the acceleration of the pappi until they reach wind speed, which they could not surpass due to drag, and a lack of force to push them at a higher speed. The following development of physics equations solves for the force of the wind on a pappus and then, the acceleration of the pappus.

Figure 17: Calculating acceleration of pappus due to wind, in terms of absolute air pressure (ρ in pascals, generally equal to 101325 Pascals), pappus dimensions, gas constant (R), temperature (Kelvin) and wind velocity.

$F = ma$ This is a general equation for Force in terms of mass and acceleration.

$F_{wind} = m_{air} \cdot v_{wind}^2$ (Blaettler, 2020)

$F_{wind} = A_{impact} \cdot p \cdot v_{wind}^2$ Expand m_{air} to $A_{impact} \cdot p$

$F_{wind} = A_{impact} \cdot \frac{\rho}{RT} \cdot v_{wind}^2$ Expand p to its value based on absolute pressure, temperature, and the gas constant (Czernia and Szyk, 2023)

$m_{seed} \cdot a_{seed} = A_{impact} \cdot \frac{\rho}{RT} \cdot v_{wind}^2$ Set the mass times the acceleration of the seed to the force we got for wind

$$a_{seed} = \frac{\frac{p_{width} \cdot p_{amount} \cdot r_{pappus}}{\pi \cdot r_{pappus}^2} \pi \left(r_{pappus} \cdot cos \left(90 - \frac{\frac{450}{9+e^{0.54 \cdot (100H - 66.6)}} + 130}{2} \right) \right)^2 \cdot \frac{\rho}{RT} \cdot v_{wind}^2}{m_{seed}}$$

Solve for acceleration

Amount of Plants:

The amount of plants that would reproduce is another important thing to consider. With each new season having new plants, the amount of plants reproducing would increase. Something else that is important while considering the amount of plants is their survival rate. Not every plant would survive each season, so the number of plants reproducing would not be exactly the number of "parent" plants with their offspring.

Area:

The area that the pappi can fly to for each plant is an important thing to consider while calculating spread rate because it is the maximum range that the seed can go for each plant. This was calculated using how much wind force was applied on each pappi and as a result of that, how far they could go.

Step by Step for Part 1:

This model will give us the amount of plants and the area covered for the plants.

1. Calculate growth factor.

$$G_r = \left(\left(\frac{T - b_{Tgr}}{o_{Tgr} - b_{Tgr}}\right)^{\frac{o_{Tgr} - b_{Tgr}}{c_{Tgr} - o_{Tgr}}} \left(\frac{c_{Tgr} - T}{c_{Tgr} - o_{Tgr}}\right)\right)\left(\left(\frac{H - b_{Hgr}}{o_{Hgr} - b_{Hgr}}\right)^{\frac{o_{Hgr} - b_{Hgr}}{c_{Hgr} - o_{Hgr}}} \left(\frac{c_{Hgr} - H}{c_{Hgr} - o_{Hgr}}\right)\right) * Z$$

2. Calculate Germination Factor

$$G_e = \left(\left(\frac{T-b_{Tge}}{o_{Tge}-b_{Tge}}\right)^{\frac{o_{Tge}-b_{Tge}}{c_{Tge}-o_{Tge}}}\left(\frac{c_{Tge}-T}{c_{Tge}-o_{Tge}}\right)\right)\left(\left(\frac{H-b_{Hge}}{o_{Hge}-b_{Hge}}\right)^{\frac{o_{Hge}-b_{Hge}}{c_{Hge}-o_{Hge}}}\left(\frac{c_{Hge}-H}{c_{Hge}-o_{Hge}}\right)\right)$$

3. Calculate number of seed to seed cycles:

$$G_l = 30.5t$$
$$n = \frac{-9.88 \cdot L + 493}{108} \text{ or } \frac{G_l}{108} \text{ (whichever is less)}$$

4. Calculate seeding numbers:

$$a = o_s \cdot o_f \cdot G_r \cdot o_{ge} \cdot G_e$$

5. Calculate population of the seeds after "n" growing cycles:

$$\frac{1+(a+1)^n}{2}$$

6. Calculate the surface area of the seed

$$A_{impact} = \frac{p_{width} \cdot p_{amount} \cdot r_{pappus}}{\pi \cdot r_{pappus}^2} \pi \left(r_{pappus} \cdot cos \left(90 - \frac{\frac{450}{9+e^{0.54 \cdot (100H - 66.6)}} + 130}{2} \right) \right)^2$$

7. Calculate the acceleration that the seeds go until they reaches wind speed

$$a_{seed} = \frac{A_{impact} \cdot v^2 \cdot \frac{\rho}{287 \cdot \left((T-32) \cdot \frac{5}{9} + 273.15 \right)}}{2 \cdot m}$$

8. Calculate the time until the pappus reaches wind speed

$$t = \frac{v}{x}$$

9. Calculate the distance the pappus goes (the total fall time is 1 second (How Far, n.d.), that justifies (1-t))

$$r = \frac{1}{2} \cdot a_{seed} \cdot t^2 + v \cdot (1-t)$$

10. Calculate the area that the dandelions will cover

$$A = \frac{1}{2}\pi(n \cdot r)^2$$

(V = wind speed, T = temperature, m = .0000005 kg, p is pressure in pascals,
x is the acceleration)

Since Central New England is the reference for this model, the environmental conditions of Central New England were plugged in (Appendix 3), along with the dandelion specific variables (Appendix 1 and 2). The results were the conquered area in the 1 hectare area (step 10) and the population within the area could be calculated (step 5). Results are presented and discussed in the

Part 2: Impact Comparisons

For the second part, cattail and cardoon were compared to the dandelions. To determine which plant was statistically better, different factors were accounted for that promoted the plants, and others that made them harmful. To make the comparison completely unbiased, a control plant was used: shaggy soldier. All four of the plants selected reproduce with pappi, and, aside from the shaggy soldier, they are all invasive. A value within the range: -1 to 1 was calculated for the impact of height, water usage, and nutrients provided by the invasive plant in comparison to the control, so that each factor has equal significance on the impact. A negative value for one factor means that the subject plant has a worse effect on the environment than the control whereas a positive means the opposite. When two is separately put to the power of these values, it will equal a value between 0.5 and 2. When all of these values, one for each factor (root length, height, nutrients) are multiplied together, depending on the sign of the exponent, the final result will either increase or decrease in magnitude. In order to compensate for the control, 1 must be subtracted from the equation. This sets the impact of the shaggy soldier equal to zero, which is in agreement with Assumption 21. Then, the result can be multiplied by the growth factor to determine the final magnitude. The resulting range with a perfect growth factor of 1 is between -⅞ and 7. To remedy this, if the result is negative, its value must be multiplied by 8 to give a final range of -7 to 7.

Growth Factor:

The growth factor, in the first part of the final equation, was used as a multiplier for the total impact factor. This is because the growth of a plant determines the intensity of its effects on the environment. For example, if a plant has a higher growth factor, it will be taller, consume more water and have longer roots. The equation for the growth factor for the second task is the same as the growth factor in the first task. Figure 18 is the growth factor from task one.

Figure 18

$$G_r = \left(\left(\frac{T_{Tgr}-b_{Tgr}}{O_{Tgr}-b_{Tgr}}\right)^{\frac{O_{Tgr}-b_{Tgr}}{C_{Tgr}-O_{Tgr}}} \cdot \left(\frac{C_{Tgr}-T_{Tgr}}{C_{Tgr}-O_{Tgr}}\right)\right) \cdot \left(\left(\frac{H_{Hgr}-b_{Hgr}}{O_{Hgr}-b_{Hgr}}\right)^{\frac{O_{Hgr}-b_{Hgr}}{C_{Hgr}-O_{Hgr}}} \cdot \left(\frac{C_{Hgr}-H_{Hgr}}{C_{Hgr}-O_{Hgr}}\right)\right) \cdot Z$$

Height:

Another factor taken into account was height. The taller a plant is, the more sunlight it would block for other plants (Assumption 14), and if so, be harmful to the environment, whereas the smaller a plant, the less harmful it would be. This was taken into account by calculating a logistic curve with an output between -1 to 1, so as the height gets higher and higher it approaches the top of the range of 1 (Figure 19). The value 1.5 originates from the height from the shaggy soldier plant, which if the plant matches, has no effect (Assumption 21).

The value of 80 originates in that the height of a tall treeline is around 80 ft, so as the height in feet goes past 80, its difference is less and less consequential (admin, 2020).

Figure 19

$$\left(1 \cdot \frac{1}{1+e^{\frac{4}{80}(h-1.5)}} - 0.5\right)$$

Water Consumption:

A factor that was taken into account was the water consumption of each plant. This was analyzed based on the root length. The longer the roots, the greater water consumption the plant would have, and vice-versa (Assumption 15). Water consumption was taken to have a negative effect on the surrounding environment because it would prevent other animals and plants from acquiring water. The shaggy soldier plant was used as a baseline and example of a plant that had no effect on the environment. Then, a logistic curve that accounts for as the root length becomes larger, would have more impact on the impact factor, with an impact of zero when the root length is equivalent to the shaggy soldier (Figure 20). The value 300 ft comes from the average depth of the bedrock used for a realistic maximum length of the roots (Shangguan et al., 2017). The value 2.36 comes from the length of the shaggy soldier roots in feet.

Figure 20

$$\left(1 \cdot \frac{1}{1+e^{\frac{4}{300}(w-2.36)}} - 0.5\right)$$

Nutrients:

The last factor that was taken into account was the nutrients that each plant provided. The more nutritions that a plant provides to the environment, the more of a positive impact that the plant has on the environment as it gives humans and other animals a good source of these nutrients. The nutritional values for lipids, protein, potassium, calcium, and magnesium, as well as the amount of calorie for all of the plants were collected (per 100g)(Figure 21).

The shaggy soldier plant was used as a baseline for a native plant that had no effect on the environment. Then a logistic curve that accounted for as the nutrients become larger and larger, they would have less and less effect on the impact factor (Figure 21), with the amount not having much effect past the recommended daily value of the nutrient (Nutrition, 2023). This equation gives a value from -1 to 1 with the variables N_{dv} as the recommended daily value amount for the nutrients, N being the amount of a nutrient for the plant being looked at (Table 1), and $N_{control}$ being the amount of nutrients that shaggy soldier provides. This value was calculated for all 6 nutrients that were taken into account then averaged.

Figure 21

$$\left(1 \cdot \frac{1}{1+e^{-\frac{4}{N_{dv}}(N-N_{control})}} - 0.5\right)$$

Table 1

Nutritional Content of Different Plants

Dandelions		**Shaggy Soldier**		**Cardoon**		**Cattail**	
Potassium	397mg	Potassium	58mg	Potassium	400mg	Potassium	58.7mg
Calcium	187mg	Calcium	384 mg	Calcium	70mg	Calcium	10.3mg
Magnesium	36mg	Magnesium	60mg	Magnesium	42mg	Magnesium	12mg
Calories	45	Calories	37	Calories	17	Calories	5
Fat	0.7g	Fat	0.4g	Fat	0.1g	Fat	0g
Protein	2.7g	Protein	3.2g	Protein	0.7g	Protein	0.22g

Final Plug-in and Results:

Once all factors (root length, height, nutrients) and the final growth factor are calculated for, 2 is individually put to the power the expressions for nutrients, water and height and each phrase (2^{factor}) can be multiplied together. From that point, 1 should be subtracted from the equation to set the control equal to zero. After ($2^{\text{Height factor}} * 2^{\text{Root Factor}} * 2^{\text{Nutrient factor}}$-1), the result should be multiplied by the growth factor to weight the result by how the plant is expected to grow. The resulting possible range is unnormalized and is from -⅞ to 7, so to normalize the data any negative value is multiplied by 8, resulting in a range from -7 to 7 for the impact factor.

Step by Step for Part 2:

1. Calculate the Growth Factor:

$$G_r = \left(\left(\frac{T_{Tgr}-b_{Tgr}}{O_{Tgr}-b_{Tgr}}\right)^{\frac{O_{Tgr}-b_{Tgr}}{C_{Tgr}-O_{Tgr}}} \cdot \left(\frac{C_{Tgr}-T_{Tgr}}{C_{Tgr}-O_{Tgr}}\right)\right) \cdot \left(\left(\frac{H_{Hgr}-b_{Hgr}}{O_{Hgr}-b_{Hgr}}\right)^{\frac{O_{Hgr}-b_{Hgr}}{C_{Hgr}-O_{Hgr}}} \cdot \left(\frac{C_{Hgr}-H_{Hgr}}{C_{Hgr}-O_{Hgr}}\right)\right) \cdot Z$$

2. Calculate the Height Factor

$$\left(1 \cdot \frac{1}{1+e^{\frac{4}{80}(h-1.5)}} - 0.5\right)$$

3. Calculate the Water Factor

$$\left(1 \cdot \frac{1}{1+e^{\frac{4}{300}(w-2.36)}} - 0.5\right)$$

4. Calculate the Nutrients Values
   a. Potassium

   $$\left(1 \cdot \frac{1}{1+e^{-\frac{4}{2700}(k-58)}} - 0.5\right)$$

   b. Calcium

   $$\left(1 \cdot \frac{1}{1+e^{-\frac{4}{1300}(c-384)}} - 0.5\right)$$

   c. Magnesium

   $$\left(1 \cdot \frac{1}{1+e^{-\frac{4}{420}(mg-60)}} - 0.5\right)$$

   d. Calories

   $$\left(1 \cdot \frac{1}{1+e^{-\frac{4}{2000}(C-37)}} - 0.5\right)$$

   e. Fat

   $$\left(1 \cdot \frac{1}{1+e^{-\frac{4}{78}(F-0.4)}} - 0.5\right)$$

   f. Protein

   $$\left(1 \cdot \frac{1}{1+e^{-\frac{4}{50}(P-3.2)}} - 0.5\right)$$

5. All the nutrient values are added and divided by 6 to find the average. That average is then multiplied by the edibility percentage (E) for a specific plant to find the nutrient factor

   $$\left(E\frac{\Sigma nutrients}{6}\right)$$

6. Finally, the control (in this case 1) is subtracted from 2 to the power of each factor (height, water, and nutrients) and the whole thing is multiplied by the growth factor

   $$G_r \cdot \left(2^{heightfactor} \cdot 2^{waterfactor} \cdot 2^{nutrientfactor} - 1\right)$$

7. If the result is negative, it must be multiplied by 8 to establish a data range of -7 to 7. If it is positive, the result is correct by default. The meaning of the value is the impact factor of the subject plant on a scale of -7 to 7 where negative numbers have a negative impact and positive numbers have a positive impact. The distance from zero is the magnitude of the impact.

Results:

Part 1:

According to the solution of task one, after 1 month, dandelions will spread through an area of $10m^2$ and have a population of 3 plants, after 2 months, $38m^2$ with a population of 8 plants, after 3 months, $87m^2$, 32 plants, and after 6 months and 12 months both at 274m2 with 796 plants. The lack of difference between the 6 and 12 month section is due to the indifference in growth cycles. Due to winter, there are the same number of growth cycles 6 months after the starting month and 12 months after. Resultantly, the values are the same. Variables used are available in Appendices 1, 2, and 3.

Part 2:

When all variables from Appendices 2 and 3 are plugged in for each plant (dandelions, Southern Cattails and Cardoon) and the control (Shaggy Soldier) plugged in as well, the results give dandelions a positive value of 0.00064, Southern Cattails a value of -0.46 and Cardoons a value of -0.37, suggesting that while dandelions have an almost net 0 impact, Southern Cattails and Cardoons have a negative impact on the environment. This makes sense due to Dandelions a relatively small footprint yet a dense nutritional value whereas the other two plants are much larger with a poorer size to nutrition ratio.

Conclusion

This mathematical model predicted the spread impact of dandelions over the course of 1, 2, 3, 6, and 12 months. It is able to predict this impact for various different climates and soil types to allow for numerous different values to be inputted, which provides more accurate data and a more accurate prediction for the spread of dandelions.

Strengths

This mathematical model is able to encompass several variables like wind speed, soil type, humidity percentage, and temperature, which greatly increase its accuracy. Furthermore, it approaches the three different phases of the dandelion (germination, growth, and spread) as well as the average survival rate to account for the number of dandelions that will be reproducing per season. Moreover, this model factors in growth seasons. This is important because it enables it to adapt to different regions of the world and account only for the time a dandelion will grow and reproduce. Another strength of the model was the precision of the physics equations used to calculate dandelion spread distance. Humidity, wind speed, cross sectional surface area of the hairs pappi, and the terminal velocity of the pappus in the wind were all factored into the equation for pappus travel distance.

Weaknesses

The largest weakness of this model is in part one. The equation defining the expansion area within the 1 hectare range only works if nr_{spread} (number of seed to seed growing periods*radius of seed spread) is less than 50 (half the side length of the 1 hectare range). If nr_{spread} is greater than 50, part of the expansion circle of the dandelions will leave the hectare. However this would need a high length of the growing season as well as a high wind speed to be applicable . The second major weakness of this model is that it does not account for clouds over the dandelions, which could affect the light duration and thus growth of the dandelions. Another weakness is that the model does not account for uplift wind, which could slow down the fall rate of the pappi and allow them to travel farther.

Future Work

With an extended timeframe, this model could be expanded to include more complex variables and run as a program. Variables such as direction of wind (horizontal and vertical) and its effect on pappi time in the air, considered flaws such as direction of wind, clouds, light intensity, and outliers were mostly negated by the model, but could be added to provide incremental increases in precision. These equations could also be inputted into a program in order to avoid the time needed to complete the calculations. Furthermore, a simulation of dandelions based on experienced values could be created to test the actual spread rate compared to the calculated spread rate and refine the equations if needed.

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Appendix

Appendix 1: Dandelion Information

- Maximum flowers: 10
- Average seeds at optimal: 200
- Optimal germination rate: 25%
- Pappus radius: 0.5cm
- Pappus weight: .0000005 kg
- Optimal germination temp: 77F
- Min. germination temp: 104F
- Max. germination temp: 50F
- Optimal germination Humidity: 0.55
- Min. germination temp: 0.25
- Max. germination temp: 0.8

Appendix 2: Optimal conditions for each plant

	Dandelion	southern cattail	Shaggy Soldier	Cardoon
Average height (in)	7.5	90	18	60
Optimal Grow temp (F)	77	80	80	78
Max (F)	95	105	105	95
Min (F)	14	15	15	50
Optimal Humidity (%)	0.6	0.8	x	0.7
Max (%)	0.8	1	x	0.85
Min (%)	0.25	0.5	x	0.4
Average Root length (in)	12	31	2.36	275

***Appendix 3:* New England Stats (Input)**

T = 62℉

H = .693

L = 42 degrees

P = 14.73 psi

Soil Type = Humus

V_{wind}= 8.9 m/s