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**Summary Sheet**

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In this paper, we are tasked to model the spread of dandelions on a plot of land. We are also tasked with coming up with a model to compute an impact factor for invasive plant species.

We developed a model for the spread of dandelions using a grid-based simulation technique to represent the spatial dynamics of dandelion populations. This includes parameters such as reproduction rates, seed dispersal mechanisms, and environmental factors affected by climatic conditions.

We then developed another model using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to assess the extent of invasiveness of invasive plant species by assigning a value of impact factor to a species. Environmental, economic, and social criteria are systematically identified for evaluating the impact of invasive species. The impact factor model is established through a multi-criteria decision analysis framework. The use of Analytic Hierarchy Process (AHP) gives the various criteria weightings based on their relative importance to calculate an overall impact score for each invasive species under consideration. This model is exemplified through the analysis of dandelions, *Mikania micrantha*, and *Acacia mangium*.

**Keywords:** Grid-based simulation, climatic conditions, TOPSIS with AHP, invasive species

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# 1 Introduction

## 1.1 Background

Dandelion (*Taraxacum officinale*) is a plant native to Eurasia that can now be found worldwide [1]. This plant is easily identifiable by its bright yellow flowers and its distinctive “puffball” seed head [1]. Each seed from this head is attached to a parachute-like structure, known as a “pappus”, which facilitates wind dispersal [1]. Besides the beauty of dandelions, the edible leaves, roots, and flowers of dandelions offer health benefits, including promoting liver health and fighting inflammation [2].

However, the plant’s ability to thrive in diverse environments makes it an invasive species in places such as Alaska and Oregon [3]. As such, it is imperative to develop a comprehensive model for the spread and distribution pattern of dandelions in order to monitor and control the spread of dandelions.

## 1.2 Problem Restatement

Due to the complicated biodiversity relationship between dandelions, humans and other flora, we propose a solution to quantitatively measure the impact brought about from the introduction of dandelions to a given plot of land and determine whether it is a friend or a foe.

Firstly, we need to identify the effects of the various climatic conditions on dandelion growth and analyse the spread of dandelions across an open one-hectare plot of land over different time periods.

Secondly, we need to establish criteria to evaluate the “impact factor” of an invasive species. We should take into consideration both the negative and positive impacts of dandelions and the extent of harms and benefits its introduction brings to the plot of land.

Lastly, we need to identify two other plant species deemed as invasive considering the region of our choice and apply our deduced mathematical model from the previous part to these newly identified plant species.

To solve the above problems, firstly, we make use of a grid-based **simulation** to model the changes in the spread of dandelions for a given time period.

Afterwards, another model is developed using the **Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)** method for Multiple-Criteria Decision Making (MCDM) to determine the impact factor for dandelions and two other invasive plant species.

## 2 Assumptions and Notations

### 2.1 Assumptions

In order to simplify the model and make it possible to be computed mathematically, assumptions would have to be made. These are the key assumptions that we made, and their justifications:

- The dandelion population is initially contained to a single puffball, at time = 0.

**Justification:** We are given that at the initial stage, there is only one single dandelion in its “puffball” stage.

- Dandelions have a constant seed production of 125 per month.

**Justification:** A dandelion plant produces between 1000 and 2000 seeds per year, which translates to an average monthly seed production of 125 [1].

- All dandelions have the same germination rate given the same weather conditions.

**Justification:** We do not account for anomalies in germination rate that are attributed to other unpredictable factors such as diseases or genetic mutation.

- The effects of competition and other unforeseen environmental factors such as droughts and floods are negligible.

**Justification:** It is difficult to account for anomalies. This also ensures that the differing rate of change in population is strictly due to weather conditions for better analysis.

- All dandelions survive throughout the year after successful germination.

**Justification:** Soil quality and planting depth are perfectly ideal for growth since it is suitable for germination.

- The ideal plot of land is flat enough such that the temperature, sunlight, humidity, and rainfall are the same for every square unit of the land.

**Justification:** The conditions should not vary much for a small plot of land. This also ensures every dandelion in that plot of land is subjected to the same conditions for a particular weather condition.

- The lifespan of dandelions remains the same for all weather conditions.

**Justification:** Dandelion is a perennial which means it can survive under almost any conditions [4].

- Maturing duration of dandelions to “puffball” stage is the same given a certain weather condition.

**Justification:** Dandelions are apomictic, giving similar offspring that have similar characteristics [5].

- The location of the initial single dandelion in its “puffball” stage relative to plot of land is directly opposite to wind direction. Afterwards, the wind blows in all directions at equal strength.

**Justification:** This ensures that the spread of dandelions initially is centralised around the plot of land for better observation and analysis.

## 2.2 Variables and Factors

- **Temperature, sunlight, humidity, and rainfall**

These climatic factors will affect the germination rate of dandelion seeds. Dandelions typically germinate best in temperate climates with moderate temperatures, adequate moisture, and full sun.

- **Wind speed and wind direction**

Wind is the primary mode of seed dispersal for dandelions. The speed and direction of the wind will determine how far and in which direction the seeds will travel, affecting seed dispersal patterns.

- **Ideality of growth conditions**

- **Probability of germination**

The probability of a seed germinating depends on temperature, sunlight, humidity, and rainfall.

This parameter will be highest in temperate climates with moderate temperatures, adequate moisture, and full sun. It will be lowest in arid climates with extreme temperatures, low moisture, and full sun.

- **Growth time**

Growth time of dandelions depends on the ideality of climatic factors, namely temperature, sunlight, humidity and rainfall.

## 2.3 Notations and Definitions

Notation	Description	Units
$t$	Time	day
$T$	Temperature	°C
$T_i$	Ideal temperature for growth	°C
$\Delta T$	Boundary temperature for ideal growth	°C
$L$	Sunlight	hour/day
$L_i$	Ideal sunlight for growth	hour/day
$\Delta L$	Boundary light for ideal growth	hour/day
$H$	Relative humidity	%
$H_i$	Ideal humidity for growth	%
$\Delta H$	Boundary relative humidity for ideal growth	%
$R$	Rainfall	mm
$R_i$	Ideal rainfall for growth	mm
$\Delta R$	Boundary rainfall for ideal growth	mm
$v$	Wind speed	$\text{m s}^{-1}$
$\theta$	Wind direction	—
$P_G$	Probability of a seed germinating	—
$I$	Overall ideality of growth conditions	—
$GT$	Growth time	day
$GT_i$	Growth time under ideal conditions	day
$N(d)$	Probability distribution function for seed dispersal	—
$d$	Distance from parent dandelion plant	m

Table 1: Notation

### 3 Dandelion Spread Model

#### 3.1 Parameters

Nine parameters are unchanged, as shown in table 2.

Parameter	Value
$T_i$	15.5°C
$L_i$	6.0 hours/day
$H_i$	70%
$R_i$	1435 mm
$\Delta T$	11.2°C
$\Delta L$	1.5 hours/day
$\Delta H$	20%
$\Delta R$	1345 mm
$GT_i$	26 days

Table 2: Unchanged parameters and their values

Five parameters — temperature  $T$ , sunlight  $L$ , relative humidity  $H$ , rainfall  $R$ , and wind speed  $v$  — vary based on the type of climate: tropical, temperate, and arid. We refer to the annual mean data of Singapore as representative of tropical climates, England, UK for temperate climates, and Cairo, Egypt for arid climates [6][7][8]. These parameters are shown in table 3.

Climate type	Parameter	Value
Tropical	$T$	27.9°C
Tropical	$L$	5.3 hours/day
Tropical	$H$	80.4%
Tropical	$R$	2150 mm
Tropical	$v$	3.40 m s <sup>-1</sup>
Temperate	$T$	10.9°C
Temperate	$L$	4.9 hours/day
Temperate	$H$	85.0%
Temperate	$R$	1163 mm
Temperate	$v$	4.37 m s <sup>-1</sup>
Arid	$T$	22.1°C
Arid	$L$	9.4 hours/day
Arid	$H$	55.8%
Arid	$R$	18 mm
Arid	$v$	8.92 m s <sup>-1</sup>

Table 3: Climate conditions for different climate types

## 3.2 Model Formation

### 3.2.1 Ideality of growth conditions

We assign a value of *ideality* to each climatic factor. 1 represents the perfect ideality; values of ideality decrease as climatic conditions become less ideal.

The ideality of temperature can be modelled using a normal distribution. That is,

$$I_T(T) = \exp\left(-\left(\frac{T - T_i}{\Delta T}\right)^2\right) \quad (1)$$

Similarly, ideality of sunlight is given by

$$I_L(L) = \exp\left(-\left(\frac{L - L_i}{\Delta L}\right)^2\right) \quad (2)$$

ideality of relative humidity is given by

$$I_H(H) = \exp\left(-\left(\frac{H - H_i}{\Delta H}\right)^2\right) \quad (3)$$

and ideality of rainfall is given by

$$I_R(R) = \exp\left(-\left(\frac{R - R_i}{\Delta R}\right)^2\right) \quad (4)$$

Hence the overall ideality of growth conditions  $I$  is given by

$$I = \frac{I_T + I_L + I_H + I_R}{4} \quad (5)$$

### 3.2.2 Germination probability

Germination probability is related to ideality of growth conditions. That is,

$$P_G = I \quad (6)$$

Using this formula, we compute the germination probability of dandelions in tropical, temperate, and arid climates respectively, as shown in table 4.

Climate type	$P_G$
Tropical	0.65368
Temperate	0.73963
Arid	0.41153

Table 4: Germination probabilities in different climates



### 3.2.3 Growth time

Growth time  $GT$  is given by

$$GT = \frac{GT_i}{I} \quad (7)$$

Using this formula, we compute the growth times of dandelions in tropical, temperate, and arid climates respectively, as shown in table 5.

Climate type	$GT$
Tropical	40 days
Temperate	35 days
Arid	63 days

Table 5: Growth times in different climates

### 3.2.4 Probability distribution function for seed dispersal

Seeds are dispersed in the direction of wind; hence  $d$  only takes on positive values. The probability of seeds landing at a particular range from the parent plant can be modelled using a normal distribution. Let distance  $D$  be a normal random variable. Then  $D \sim N(\mu, \sigma)$ .

For the parameters of the normal distribution, we set mean  $\mu = 0$ , assuming the parent plant is located at  $d = 0$ . Standard deviation  $\sigma$  is directly related to wind speed  $v$ : the larger the wind speed, the larger the standard deviation; we let  $\sigma = kv$  where  $k$  is a scaling constant to be determined. We also assume that at least a seed is always dispersed at the exact location of the parent plant, i.e.  $N(0) = 1$ . That is,

$$N(d) = \exp\left(-\frac{1}{2(kv)^2}d^2\right)$$

For our model, we set  $k = 1$ . This gives us

$$N(d) = \exp\left(-\frac{1}{2v^2}d^2\right) \quad (8)$$

### 3.3 Results Analysis

To model the spread of dandelions, we used a simulation using a  $100 \times 100$  grid, where each square unit of the grid represents a  $1 \text{ m} \times 1 \text{ m}$  plot of land. We assume that one dandelion occupies one square unit of the grid.

Note that since the lifespan of dandelions is between 10 and 13 years [5], which is much longer than the targeted time duration for our model, we consider germinated dandelions to survive throughout the model.

For the initial condition, we assume that the single dandelion in its “puffball” stage is located at the bottom left corner of the plot of land and the wind is initially directed at an angle of  $45^\circ$ . After that, wind direction is randomised at each time step to account for changing wind patterns. This approach allows the model to capture the realistic dynamics of seed dispersal due to wind, considering both the initial wind direction and subsequent variations.

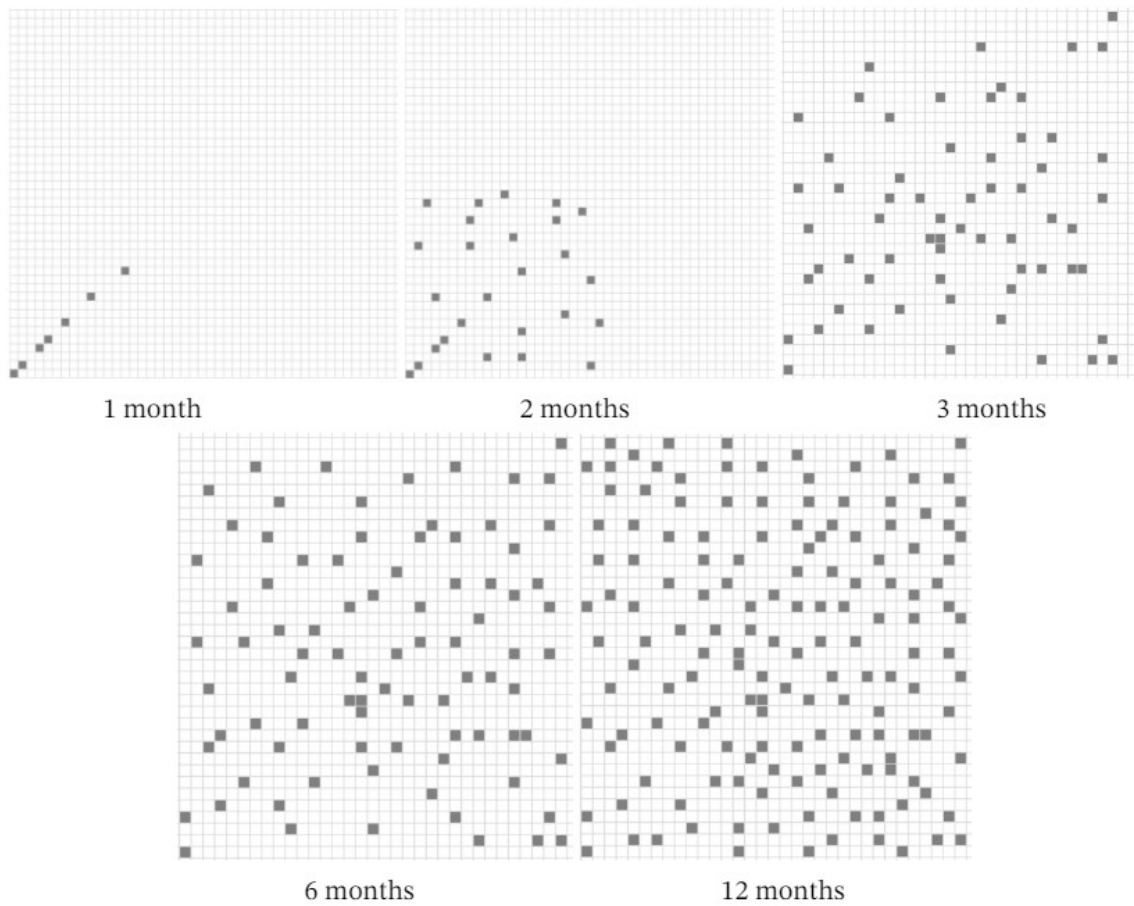


Figure 1: Spread of dandelions in tropical climates

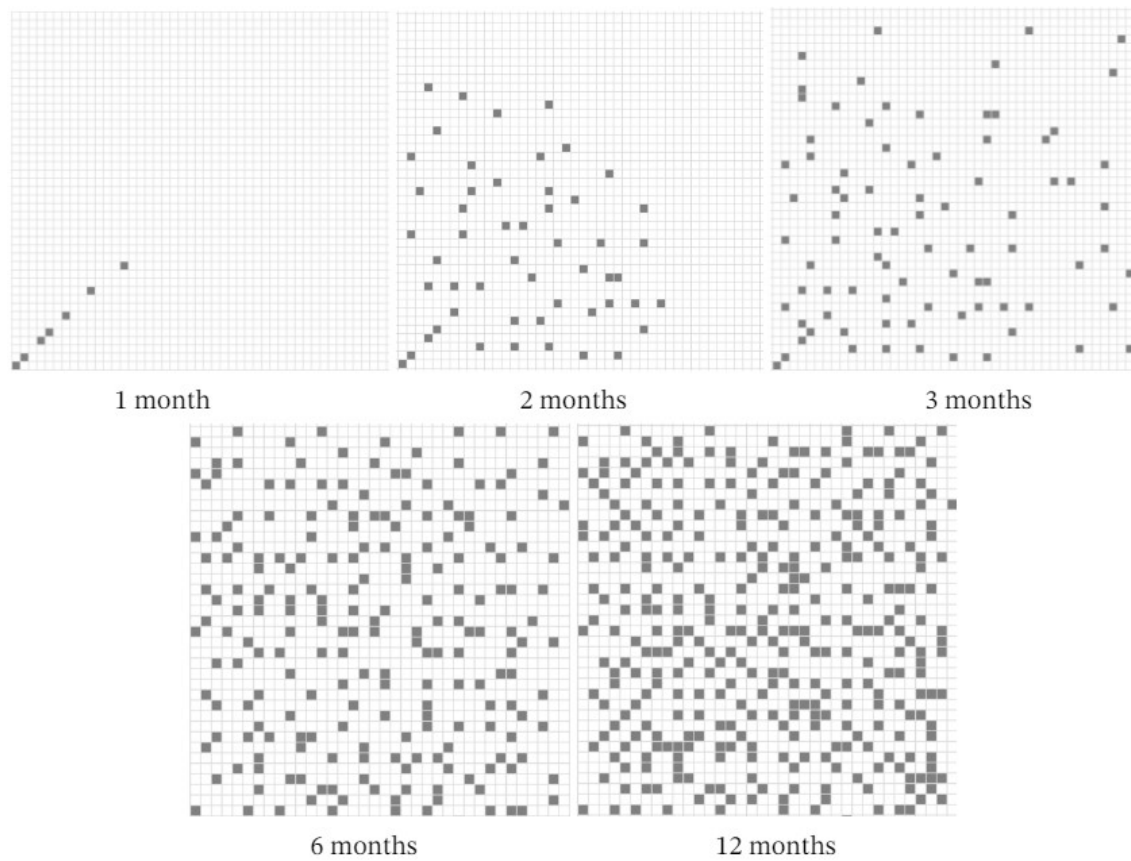


Figure 2: Spread of dandelions in temperate climates

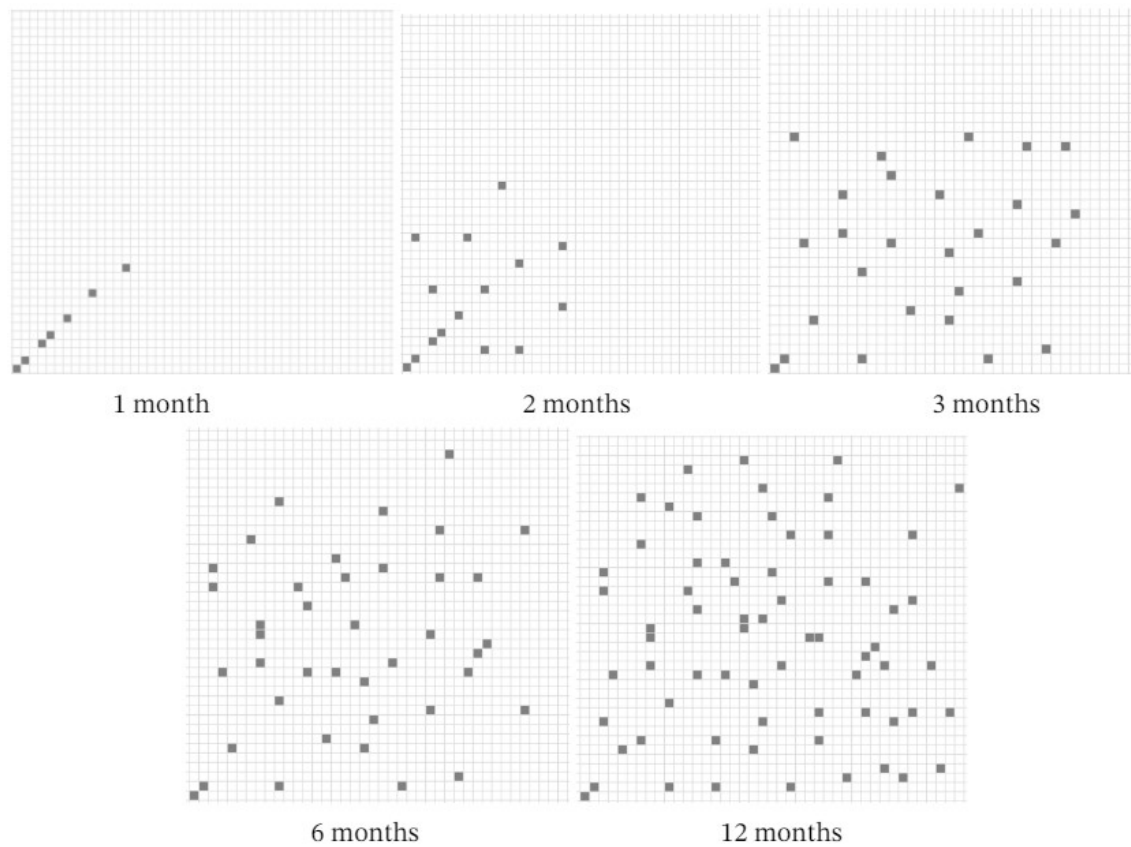


Figure 3: Spread of dandelions in arid climates

Our model shows that the spread of dandelions in temperate climates is the largest, followed by tropical climates, and is the smallest in arid climates. This result agrees with the fact that dandelions are most widespread in temperate regions as they exhibit the most prolific reproduction and widest dispersal due to the most favorable environmental conditions in temperate climates; on the other hand, dandelions face the greatest challenge to dispersal and growth in arid climates which has the most extreme environmental conditions.

## 4 Impact Factor Model

This model aims to assign an impact factor to an invasive species — a species that is non-native to the ecosystem, and whose introduction causes harm in various aspects [9]. We have identified the following three species, which we will use for our model.

- **Dandelion** is invasive in the **US**. Native to Eurasia, it was introduced to North America in the mid-1600s. Since then, it has spread across the continent as a weed, colonising gardens, fields, pastures, waysides and waste places [1].
- **Mikania micrantha** is invasive in **Malaysia**. Native to tropical and temperate America, it was introduced to Malaysia in the 1950s as a non-leguminous ground cover for plantations of *Hevea brasiliensis* (rubber) [10].
- **Acacia mangium** is invasive in the **Dominican Republic**. Native to northeastern Australia, the tree is also cultivated in the Caribbean. Its extremely vigorous growth, tolerance of acidic and nutrient-depleted soils and its ability to compete with other vegetation makes it invasive [11].

### 4.1 Criteria Identification

To compute an impact factor for invasive plant species, we identified several criteria — positive and negative impacts of dandelions — which largely fit into three main categories: environmental, economic, and social.

- **Environmental criteria**
  - **Effect on native flora:** Referenced by *FL*. Measured in terms of percentage reduction in number of native species. Invasive species displace the native species that are unable to compete for sunlight, nutrients, and space. Consequently, the biodiversity of the sites they invade is drastically reduced because the less aggressive native species are unable to compete and the overall number of species in that habitat plummets [12].
  - Dandelions:** Possesses allelopathic ability and can inhibit the germination of seeds of other plant species [5]. Release ethylene affects the growth of neighbouring plants. The presence of dandelions in a California meadow reduced the number of native plant species by an average of 20% [13].
  - M. micrantha:** Smother native vegetation. Produces allelochemicals which inhibit the germination of a number of agricultural seeds [14]. *M. micrantha* reduced the number of native plant species in a forest by an average of 30% [15].
  - A. mangium:** Negatively alters native habitats by changing soil composition through nitrogen-fixation, outcompeting native species for water and light resources and crowding other vegetation by casting shade with its dense canopy. The species is allelopathic and prevents the germination of other species attempting to grow [16]. *A. mangium* plantations led to a 60% reduction in the abundance of native tree species compared to native forests [17].

- **Effect on native fauna:** Referenced by *FA*. Measured by presence or absence of impacts on native fauna.

**Dandelions:** The plants have some nutritive value in pasture and are relatively high in calcium, nitrogen, copper and iron. Dandelion leaves provide winter food for pigeons. The flowers are a rich nectar source for insects [5].

**M. micrantha:** Used as fodder for sheep and cattle [18].

**A. mangium:** None.

- **Resistance to herbicides:** Referenced by *RH*. Measured by the effectiveness, ineffectiveness, or partial effectiveness of herbicides in eradicating the species.

**Dandelions:** Maleic hydrazide has been used to control dandelions in apple orchards in the US [19].

**M. micrantha:** Application of the herbicides such as glyphosate or diuron provides temporary control of Mikania infestation, provided spraying is carried out before the initiation of flowering or seed setting [20].

**A. mangium:** Repeated chemical treatment using triclopyr herbicide mixed with an oil has been used on cuttings to prevent regrowth and reduce seed production [16].

- **Number of natural enemies:** Referenced by *NE*. Measured in terms of the extent of abundance of natural enemies. An invasive species that has more natural enemies has a more limited population, and thus a smaller impact.

**Dandelions:** Mammals, including both domestic and wild animals eat the leaves and seeds [21].

**M. micrantha:** Numerous species of arthropods and pathogens have been found attacking *M. micrantha* in Kerala State, India. However, all the species found were either polyphagous or not sufficiently damaging to control the weed [22].

**A. mangium:** The species is relatively free from serious pests and diseases and main threats include fungal infections of heartwood, roots and leaves [23]. Main insects that attack nursery seedlings include grasshoppers and bagworms, as well as termites that feed on roots and stems [23].

- **Economic criteria**

- **Crop losses:** Referenced by *CL*. Measured in terms of percentage of crop losses. Invasive species outcompete crops for nutrients and resources, leading to reduction in crop yield.

**Dandelions:** In the US, dandelions can cause corn yield losses of up to 25% [24].

**M. micrantha:** Reduced yields due to Mikania infestation in rubber, oil palm and cacao plantations are reported from Malaysia. The girth of rubber trees in the infested plantations was 27% smaller than in non-infested plantations. In oil palm, the weed caused a 20% reduction of the palm yield during the initial five years of production [20].

**A. mangium:** Reduce soil nutrient levels, particularly nitrogen and phosphorus, leading to a decrease in crop yields of up to 30% [25].

- **Economic value:** Referenced by *EV*. Measured in terms of million US dollars.

**Dandelions:** None.

**M. micrantha:** None.

**A. mangium:** Its hardwood and pulp can be used for paper, particle board, furniture, building materials, cabinetry and other carved wood products [26]. Considering the combined value of timber, pulpwood and fuelwood, the total economic value of *A. mangium* plantations is about \$12,500 per hectare per year [27].

- **Control and eradication costs:** Referenced by *EC*. Measured in terms of the financial resources in US dollars required to manage the growth of invasive species per hectare of land.

**Dandelions:** The average cost for weed control on a 1/4-acre lot is \$95, with prices ranging from \$65 to \$120 [28].

**M. micrantha:** The annual cost of controlling *M. micrantha* was estimated at US\$ 9.8 million for *H. brasiliensis*, *E. guineensis* and *Theobroma cacao* (cocoa) crops in Malaysia [22].

**A. mangium:** Removing *A. mangium* trees using tools such as axes, chainsaws, or bulldozers costs from \$100 to \$500 per hectare.

- **Social criteria**

- **Human usage:** Referenced by *HU*. Measured by the presence or absence of human uses. Plant species can be used by human for a wide range of aspects, such as food and medicine.

**Dandelions:** Used for medicinal purposes for centuries to treat a myriad of conditions [29], including to improve liver function [30], lower cholesterol, lower blood pressure, decrease body weight in obese patients and treat gall bladder ailments [31].

**M. micrantha:** Used as a medicinal herb as the plant is known to have antibacterial and antimicrobial properties [14].

**A. mangium:** Used for furniture and cabinet-making [32], light structural works, agricultural tools, boxes and crates.

- **Human health:** Referenced by *HH*. Measured in terms of the presence or absence of toxicity to humans.

**Dandelions:** Its pollen has been identified as an allergen in honey [33] and can cause allergic contact and photoallergic contact dermatitis [34].

**M. micrantha:** It was shown to cause hepatotoxicity when consumed [35].

**A. mangium:** None.

The above information is summarised into table 6, which shows the data set for the three invasive plant species.

Criterion	<i>FL</i>	<i>FA</i>	<i>RH</i>	<i>NE</i>	<i>CL</i>	<i>EV</i>	<i>EC</i>	<i>HU</i>	<i>HH</i>
<b>Dandelion</b>	20	1	1	1	25	0	939	1	1
<b>M. micrantha</b>	30	1	0.5	0	23.5	0	1.73	1	1
<b>A. mangium</b>	60	0	1	0.5	30	75	300	1	0

Table 6: Data values for invasive plant species

## 4.2 Analytic Hierarchy Process

We made use of the Analytic Hierarchy Process (AHP) — a weighting method that uses paired comparison to determine the relative weights of various criteria, and then transfers them across each level of criteria to calculate overall weightings [36] — to determine the weights of the criteria identified above to be used for the TOPSIS model.

Using the Three Decision Methods (3DM) Software Web [37] to conduct AHP gives us the following weights for the criteria, as shown in table 7.

Criterion	<i>FL</i>	<i>FA</i>	<i>RH</i>	<i>NE</i>	<i>CL</i>	<i>EV</i>	<i>EC</i>	<i>HU</i>	<i>HH</i>
<b>Weight</b>	0.3074	0.0354	0.0757	0.0522	0.2185	0.1086	0.1544	0.0239	0.0239

Table 7: Weights of criteria

## 4.3 TOPSIS

TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) is a multi-criteria decision-making method used to evaluate the best alternative from a set of available options [38]. TOPSIS chooses the alternative of shortest Euclidean distance from the positive ideal solution (PIS) — the best alternative that maximises the criteria — and longest Euclidean distance from the negative ideal solution (NIS) — the worst alternative that minimises the criteria.

To apply the method, a set of criteria is first defined. Weights are then assigned to each criterion based on the criterion's relative importance. Then, a matrix including each alternative and criterion is constructed. The matrix is also normalised to account for differences in the scale of the criteria. Finally, the distance between each alternative and the best and worst solutions is measured, and the alternatives are ranked based on their closeness to the positive ideal solution.

### 1. Identification of criteria:

A criteria is a beneficial attribute (which we want to maximise) or a cost attribute (which we want to minimise). We call the set of beneficial attributes  $J_1$  and that of cost attributes  $J_2 = J_1^c$ .

### 2. Weighting:



From the Entropy Weight Method, we have assigned a weight to each criterion based on its relative importance, as shown in table 7.

Calculating the weighted normalised ratings,

$$v_{ij} = w_j r_{ij}$$

where  $i = 1, 2, \dots, m$  and  $j = 1, 2, \dots, n$ .

### 3. Identification of PIS and NIS

We denote PIS by  $A^*$  and NIS by  $A^-$ .

$$A^* = \{v_1^*, v_2^*, \dots, v_n^*\}$$

$$A^- = \{v_1^-, v_2^-, \dots, v_n^-\}$$

where

$$v_j^* = \begin{cases} \max(v_{ij}) & j \in J_1 \\ \min(v_{ij}) & j \in J_2 \end{cases}$$

$$v_j^- = \begin{cases} \min(v_{ij}) & j \in J_1 \\ \max(v_{ij}) & j \in J_2 \end{cases}$$

where  $i = 1, 2, \dots, m$  and  $j = 1, 2, \dots, n$ .

### 4. Distance calculation:

The Euclidean distance from the PIS  $A^*$  and NIS  $A^-$  are denoted by  $S^*$  and  $S^-$  respectively.

$$S_i^* = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^*)^2}$$

$$S_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2}$$

where  $i = 1, 2, \dots, m$  and  $j = 1, 2, \dots, n$ .

Using this we calculate

$$C_i^* = \frac{S_i^-}{S_i^* + S_i^-}$$

## 4.4 Results Analysis

Using the Three Decision Methods (3DM) Software Web [37] to conduct TOPSIS, we rank the three invasive plant species in descending order according to their  $C^*$  values — now known as *impact factor* — as shown in table 8.

Species	$S^*$	$S^-$	$C^*$
<b>Acacia mangium</b>	0.1526	0.1876	<b>0.5514</b>
<b>Dandelion</b>	0.1867	0.1835	<b>0.4957</b>
<b>Mikania micrantha</b>	0.2013	0.1297	<b>0.3919</b>

Table 8: Impact factor of invasive species

Based on our model, A. mangium has the highest impact factor. This means that Acacia mangium has the most overall impact on the environment compared to the other two invasive plant species.

This has several implications for the management of invasive plant species. For example, plantation owners or land owners may want to prioritise controlling and preventing the spread of A. mangium first, as it has the highest impact factor and thus the most significant impact.

## 5 Model Analysis

### 5.1 Strengths

For our first model, we use a simulation to observe the spread of dandelions which is an accurate representation of real-life situations. This is done so by accounting for the various variables and factors affecting the growth of dandelions which is directly proportional to the population of dandelions and also the wind direction and speed which affects the population density and position of centre of cluster on plot of land. By taking account for a wide range of variables and factors, our model provides a more holistic view to closely simulate the spread of dandelions under real-life conditions.

Our second model makes use of TOPSIS along with AHP. We obtained the relative weightings of the various criteria using AHP which ranks the criteria based on their relative importance in measuring the impacts brought about from the introduction of a particular invasive plant species, using a systematic and organised approach. TOPSIS is then used to obtain the “impact factor” which can then be used to compare between the three different invasive plant species. This provides a more insightful understanding of the extent of harm or benefit the invasive species brings quantitatively and at the same time allows us to test whether our model is applicable to the diverse plant species.

### 5.2 Weaknesses

Our first model does not factor in the survival rate of dandelions, which can have significant short-run impact on the total population and thus spread of dandelions. Our model is based on the assumption that there are no disastrous events which might annihilate the population, such as pandemic and perilous predators. Furthermore, due to simplistic considerations, the model assumes a constant climatic conditions throughout the year, which may not accurately reflect the actual spread.

For our second model, it may be difficult and hence inaccurate to assign quantitative values to some criteria, such as human use and human health. In addition, the pairwise comparison of criteria under the Analytic Hierarchy Process of criteria may be rather subjective.

## 6 Conclusion and Future Work

In this paper, we developed a comprehensive framework for addressing the complex challenges associated with the spread of dandelions and invasive species management. The two main tasks undertaken — developing a mathematical model for dandelion spread and formulating an impact factor model for invasive species — significantly contribute to the field of ecological modeling and decision analysis.

The first task, focusing on the mathematical model for dandelion spread, exhibits a meticulous integration of population dynamics and spatial considerations. The adoption of a grid-based simulation technique, coupled with the incorporation of factors such as reproduction rates and seed dispersal mechanisms, reflects a sophisticated approach to understanding and predicting the spatial dynamics of dandelion populations over various time frames.

For the second task, the formulation of an impact factor model for invasive species introduces a multi-criteria decision analysis framework, with the use of TOPSIS. The identification and systematic weighting of environmental, economic, and social criteria contribute to a holistic evaluation of the impact of invasive species. The practical application of this model to dandelions, *Mikania micrantha*, and *Acacia mangium* underscores its versatility and adaptability to different invasive species scenarios.

To improve on our current models, future work can consider the incorporation of additional ecological factors such as climate influences, soil composition, and human activities. Expanding the scope of the impact factor model for invasive species could involve a more comprehensive analysis of environmental, economic, and social criteria, ensuring a more accurate model for assessing the impacts of invasive species.

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## 8 Appendices

### 8.1 Python Code for Dandelion Spread Model

---

```

1  import numpy as np
2  import random
3  import matplotlib.pyplot as plt
4
5  # Define parameters
6  T_i = 15.5 # Ideal temperature for growth
7  L_i = 6.0 # Ideal sunlight for growth
8  H_i = 70 # Ideal humidity for growth
9  R_i = 1435 # Ideal rainfall for growth
10 Delta_T = 11.2 # Range of temperature
11 Delta_L = 1.5 # Range of sunlight
12 Delta_H = 20 # Range of humidity
13 Delta_R = 1345 # Range of rainfall
14 GT_i = 26 # Ideal growth time
15
16 # Define climate conditions
17 climate_data = [
18     ['Tropical', 27.9, 5.3, 80.4, 2150, 3.40], # climate type, temperature, light, humidity, rain, wind speed
19     ['Temperate', 10.9, 4.9, 85.0, 1163, 4.37],
20     ['Arid', 22.1, 9.4, 55.8, 18, 8.92]
21 ]
22
23 climate_type = int(input()) # input 0 for Tropical, 1 for Temperate, 2 for Arid
24 time_period = int(input()) # input time period, in months
25
26 # using values from the climate_data list,
27 T = climate_data[climate_type][1] # temperature
28 L = climate_data[climate_type][2] # sunlight
29 H = climate_data[climate_type][3] # relative humidity
30 R = climate_data[climate_type][4] # rainfall
31 v = climate_data[climate_type][5] # wind speed
32
33 # Calculate ideality of growth conditions
34 I_T = np.exp(-(T - T_i)**2 / Delta_T**2)
35 I_L = np.exp(-(L - L_i)**2 / Delta_L**2)
36 I_H = np.exp(-(H - H_i)**2 / Delta_H**2)
37 I_R = np.exp(-(R - R_i)**2 / Delta_R**2)
38 I = (I_T + I_L + I_H + I_R) / 4
39
40 # Germination probability

```



```

41 P_G = I
42
43 # Growth time
44 GT = int(GT_i // I)
45
46 def distance(original,target):
47     return ((original[0]—target[0])**2+(original[1]—target[1])**2)**0.5
48 # coordinates are in the form of a list
49
50 # Probability distribution function for seed dispersal
51 def prob_dispersion(v,d):
52     return np.exp(—1 * d**2 / (2 * v**2))
53
54 # Initialise grid
55 grid = np.zeros((100, 100)) # grid of 100*100 zeros
56 # Zeros represent no dandelions, non—zeros represent dandelions
57
58 angles = [0, 45, 90, 135, 180, 225, 270, 315] # in clockwise direction, measured from North
59
60 def disperse(grid,o,t):
61     d = distance(o,t)
62     random_no = random.random()
63     if random_no < prob_dispersion(v,d):
64         grid[t[0]][t[1]] = 's'
65     return grid
66
67 def seed(grid,k): # function for seed dispersal and germination
68     # seed dispersal
69     for i in range(99):
70         for j in range(99):
71             if grid[i][j] >= GT: # dandelion in puffball stage, ready to disperse seeds
72                 original = [i,j] # coordinates of original cell containing parent plant
73                 target = [i,j] # coordinates of target cell
74                 if grid[target[0]][target[1]] == 0: # check if cell is empty
75                     if theta == 0:
76                         while target[0] >= 0 or target[0] <= 99 or target[1] >= 0 or target[1] <= 99:
77                             target[0] += 1
78                             grid = disperse(grid,original,target)
79
80                     elif theta == 45:
81                         while target[0] >= 0 or target[0] <= 99 or target[1] >= 0 or target[1] <= 99:
82                             target[0] += 1
83                             target[1] += 1
84                             grid = disperse(grid,original,target)

```

```

85         elif theta == 90:
86             while target[0] >= 0 or target[0] <= 99 or target[1] >= 0 or target[1] <= 99:
87                 target[1] += 1
88                 grid = disperse(grid,original,target)
89         elif theta == 135:
90             while target[0] >= 0 or target[0] <= 99 or target[1] >= 0 or target[1] <= 99:
91                 target[0] += 1
92                 target[1] -= 1
93                 grid = disperse(grid,original,target)
94         elif theta == 180:
95             while target[0] >= 0 or target[0] <= 99 or target[1] >= 0 or target[1] <= 99:
96                 target[0] -= 1
97                 grid = disperse(grid,original,target)
98         elif theta == 225:
99             while target[0] >= 0 or target[0] <= 99 or target[1] >= 0 or target[1] <= 99:
100                 target[0] -= 1
101                 target[1] -= 1
102                 grid = disperse(grid,original,target)
103         elif theta == 270:
104             while target[0] >= 0 or target[0] <= 99 or target[1] >= 0 or target[1] <= 99:
105                 target[0] -= 1
106                 grid = disperse(grid,original,target)
107         elif theta == 315:
108             while target[0] >= 0 or target[0] <= 99 or target[1] >= 0 or target[1] <= 99:
109                 target[0] -= 1
110                 target[1] += 1
111                 grid = disperse(grid,original,target)
112         grid[i][j] = 0
113
114     # germination
115     for row in grid: # rows
116         for cell in row: # cell
117             random_no = random.random() # generate random float between 0 and 1
118             if cell == 's': # identify cells containing seeds
119                 if random_no <= P_G: # germinate
120                     cell = 1
121                 else: # does not germinate
122                     cell = 0
123     return grid
124
125 def growth(grid): # growing
126     for i in range(99):
127         for j in range(99):
128             if grid[i][j] > 0 and grid[i][j] < GT:

```

```
129         grid[i][j] += 1 # add 1 to the number until dandelion reaches puffball stage
130     return grid
131
132 for t in range(30*time_period): # implement the two functions across the given time period
133     k = t
134     if t == 0:
135         grid[99][0] = GT # initially there is one dandelion in puffball stage
136         theta = 45 # set initial angle to be 45 degrees to blow seeds upwards and rightwards
137     else:
138         theta = random.choice(angles) # generate random angle
139     grid = seed(grid,k)
140     grid = growth(grid)
141
142 for row in grid:
143     for cell in row:
144         if cell > 0:
145             cell = 1
146
147 # Create reversed grayscale colormap
148 cmap = plt.get_cmap('gray_r')
149
150 # Create plot
151 fig, ax = plt.subplots()
152 ax.imshow(grid, cmap=cmap, vmin=0, vmax=1)
153
154 # Hide grid lines and ticks
155 ax.grid(False)
156 ax.set_xticks([])
157 ax.set_yticks([])
158
159 # Display the plot
160 plt.show()
```

---

## 8.2 Report on Use of AI

### 1. OpenAI ChatGPT (Nov 9, 2023 version, ChatGPT-3.5)

**Query:**

What are some positive and negative impacts of dandelions?

**Output:**

Dandelions, while often considered weeds, have both positive and negative impacts on the environment.

Positive Impacts:

- **Pollinator Support:** Dandelions produce nectar, serving as an early food source for bees and other pollinators, contributing to the overall health of ecosystems.
- **Medicinal Uses:** Some traditional medicine systems use dandelion extracts for various health benefits, such as supporting liver function and promoting digestion.
- **Edible Greens:** Dandelion leaves are rich in vitamins and can be used in salads or cooked as a nutritious green vegetable.
- **Soil Improvement:** Dandelions have deep taproots that can help break up compacted soil, allowing for better water penetration and nutrient absorption.

Negative Impacts:

- **Invasive Nature:** Dandelions are often considered invasive, spreading rapidly and outcompeting other plants in lawns and gardens.
- **Aesthetic Concerns:** Many people consider dandelions unsightly in well-maintained lawns, leading to efforts to control or eliminate them.
- **Competition with Crops:** In agricultural settings, dandelions can compete with crops for nutrients and water, potentially reducing yields.
- **Allergies:** Some individuals are allergic to dandelion pollen, causing allergic reactions such as hay fever.

In conclusion, the impact of dandelions depends on the context. While they offer some ecological benefits, their invasive nature and perceived negative aesthetic qualities can pose challenges in certain environments. Balancing their positive and negative aspects requires careful consideration based on specific circumstances.