Leslie Matrix Model For Euphorbia Hirta L Population

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Abstract: - Invasive species management has developed into a highly specialized field utilizing a systems approach. It requires knowledge of their life history, growth requirements, and population dynamics that integrate their biology and control. The foundation of strategic planning for the management of invasive species is laid by demographic studies, which record the birth, growth, reproduction, and death of individuals within a population. The present study makes use of the Discrete Leslie Matrix Model to analyze the growth in the age-structured population of *Euphorbia hirta*, an invasive species in agrosystems, identify critical stages in the species' life cycle, and project the structure and size of future population.

Key-Words: Invasive species, Leslie Matrix, critical stage, management, future population

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1 Introduction

Invasive alien plant species are those that have been intentionally or unintentionally brought outside of their native habitat. They have an impact on human safety, habitats, biodiversity, ecology, and spread out of control [1; 2]. A biological invasion has been identified as one of the main causes of economic and environmental disruption, and biodiversity loss. Compared to native plants, invasive alien plants have advantages such as faster growth, greater photosynthetic rates, higher reproductive output, more biomass, lower carbon-to-nutrient ratios in tissue, stronger nutrient absorption capacities, and higher plasticity levels [3].

For efficient management and population regulation of invasive species, one must have a thorough understanding of the ecology, morphology, reproductive biology, physiology, and biochemistry of such species as a wide variety of factors regulate the density, growth, and competitive ability of these plants. According to Funk [4], invasive species have a greater strategic advantage for nutrient use over native plants. They are also more common along roadside and places with anthropogenic disturbances [5]. Plant invasions are detrimental to ecology and global biodiversity changing the landscapes. Many invasive weed species have invaded terrestrial crops worldwide [6] and drastically lowered agricultural output. Species invasions are a major component in global change resulting in habitat degradation, altering the biological diversity and environmental mechanism, causing extinction of local flora and fauna, modifying ecosystem functioning and services, and promoting subsequent invasions that exacerbate the damage. [7;8;9; 10;11]. Climate change and biological invasions represent two of the largest threats to biodiversity in the Anthropocene [12]. Early detection of invasive plants, can help in weed management by efficient eradication and billions of dollars for ongoing control to stem biodiversity loss [13].

Adaptation of weed management strategies reduce the incidence of invasive species, decrease their undesirable effects, and optimize land use thro ugh the combination of preventive and control practices [14].

Invasive alien plant species may have a major effect on global agriculture, which continues to have an impact on food security worldwide [15]. Globally, invasive weed species need to be controlled via mechanical, physical, biological, and chemical methods. Many invasive plant species do not have any biological control agents [16]. Climate change [17], deforestation, ecological degradation, and anthropogenic disturbances all worsen agricultural production worldwide.

1.1 Demographic models

Mathematical models significantly contribute to the prediction the spread of invasive species and directing the optimal allocation of resources for their prevention, control, or eradication [18;19]. Models are indispensable tools for managing invasive species. According to Baker and Bode [20], scientists can utilize them to calculate vital rates like the rate of spread, model the possible impacts of invasive species, and investigate the consequences of different strategies for controlling or eliminating them.

Introduced species may experience climatic niche shifts when moving to new continents because of changes to their fundamental or realized niche [21]. Whereas niche shifts are evaluated in 'climatic space'—usually with ordination techniques—the general goal of species distribution models (SDMs) is to project climatic niche models into geographic space using Matrix or other predictive models. Demographic models are useful for understanding population processes and stages in the life cycle of the species that could be most effectively targeted with management. The study carried out by Bogdan et al [22] in demographic data of an Israeli Carpobrotus population gives an Integral Projection Model and through the analysis of asymptotic growth rates and population sensitivities and elasticities demonstrated the population as stable, and reducing the survival of the largest individuals reduced the overall population growth.

Chung et al [23], developed an integrated spatial model to manage common ragweed (Ambrosia artemisiifolia var. elatior (L.,) Decs) using various models, including species distribution BIOMOD2, landchange LCM, dispersal MigClim and optimization model prioritize and proposed a new 'removal effect index' for evaluation in time series.

Guetling et al [24], developed habitat susceptibility models (HSM) created within geographic information systems (GIS) to combine spatial environmental data at known infestations and predict areas likely to be invaded based on similar ground conditions [25] for meadow hawkweed and orange hawkweed. With known locations and environmental data, the predictive models were used to estimate habitat susceptibility for invaders by determining the indicator species.

Species distribution models (SDMs) are often used to produce risk maps to guide conservation management and decision-making with regard to invasive alien species (IAS). Davis et al [26] developed WiSDM, a semi-automated workflow to democratize the creation of open, reproducible, transparent, invasive alien species risk maps.

Worldwide, it is generally acknowledged that invasive species pose a serious threat to native biodiversity, ecosystem function, and economic interests at a global scale [27]. Structured population models (like matrix population models [28], integral projection models [29] of invasive plants provide a tool for producing comprehensive fitness estimates and identify sensitive vital rates (e.g. survival, growth) to target with management [28;30;31].

1.2 Population Dynamics of Invasive species

Invasive species management is concerned with maximizing mortality and lowering the reproduction and minimizing the loss of resources resulting from invasive species competition. In this context the role of natural and man-managed factors that regulate the size of invasive species population becomes of paramount importance. A classification of individuals by age in such a population provides reasonably accurate prediction of their demographic potential. Population dynamics of species helps in analyzing patterns related to growth, reproduction and mortality theoretically in mathematical terms. Demography studies help to learn empirically how the population grows in nature. They deal it by keeping the track of the birth, growth, reproduction and death of individuals in a population. It can then form the basis of strategic planning for invasive species control [32;33].

1.3 Matrix population models

Matrix population models are categorized into two types of models that are in vogue viz. Age structured models described by Leslie [34] and stage structured models described by Lefkovitch[35].

Sensitivity and elasticity assessments are also performed using matrix population models [36;37].

When an individual's attribute other than age is a stronger predictor of survival and reproduction, then according to Caswell [28] and Cochran and Ellner [38] the models that are preferred are stage structured matrix models.

In numerous research [39; 40;41; 42], vital rates in stage-structured population models can be inferred from age-structured vital rates, where age classes are grouped together to form a stage.

There has been an upsurge in the use of stage-structured population models, and a life table analysis is often used to estimate the vital rates in these models [43]. The relationship between the number of stages and different statistics derived from stage-structured population matrices is also covered by Salguero-Gomez & Plotkin [44]. Lebreton [45] suggests using models that are stage-structured, meaning that Stages are embedded within the age classes. The dynamics of stage-structured populations have been described by means of both stochastic and deterministic models. In her contribution. Pasquali [46] focuses on stage-structured demographic models, in which growth of an individual is described by its physiological age, which is governed by a stochastic differential equation.

1.4 INTEGRATING POPULATION DYNAMICS AND POPULATION STRUCTURE

Matrix population models that integrate population dynamics and population structure are a power tool for investigating population dynamics [47].
It has also been long known that age specific effects have a profound influence on overall population dynamics [48]. Matrix projection model based on age specific characteristics of individuals [49;50;34], have become a means of characterizing populations and predicting their future behaviour [51]. In some areas of resource biology, the sampling programmes are mobilized in order to obtain data to build life tables from which population dynamics models may be developed. The primary objectives of population dynamics modelling are twofold; to give insight into the biological mechanisms operating in the system being modelled and to produce a model of community interactions which predicts changes in abundances (numbers of community species). In recent years, there has been a remarkable expansion in the application of matrix models. Quantitative demographic analysis should be used more frequently to advise management, according to population ecologists [52;53;54].
The Discrete Leslie Matrix Model [55;34;56] has been used to analyze the growth in age structured populations. Matrix population models that integrate population dynamics and population structure are a power tool for investigating population dynamics [47]. It has also been long known that age specific effects have a profound influence on overall population dynamics [57].

In this study, the Discrete Leslie Matrix Model [55;34;56] has been used to analyse the growth in age structured population of *Euphorbia hirta* Linn, an invasive species in agrosystems with the following objectives:

i) to study the temporal dynamics of target weed population
ii) to investigate the transient dynamics and asymptotic characteristics of the population
iii) to project the structure and size of future populations and
(iv) to suggest the critical stages in the life cycle of the weed for management programme

2 Material and Methods

2.1 The Species

Euphorbia hirta Linn.selected for the present study, commonly known as Pill-bearing spurge, is a member of the Euphorbiaceae family. It is a little annual herb that is propogated by seeds. The species is currently found throughout tropical and subtropical regions, having originated in Tropical America. It is commonly observed inhabiting paths, roadside vegetation, grasslands, banks of watercourses, and open waste areas [58]. Due to increased trade, tourism, industry growth, transportation, technology advancements, and rising rates of urbanization, the invasion of species has expanded significantly [59]. According to Pauchard et al. [60], the invasion of various regions by alien species increase pressure on the natural environment.

Euphorbia hirta is an important agrestal weed with special affinity for paddy tracts, irrigated and garden crops. It has been documented that *Euphoria hirta* infestations occur in rice, mung-sesame system, chilli, maize, and mustard (*B. juncea*) crops [61;62; 63]. Aqueous extract of *E. hirta* at high concentration was found to impair the growth of maize and wheat seedlings, delayed germination, reduced chlorophyll and wheat protein content [63]. It exerts allelopathic effect on crops like potato, sugarcane, maize and sorghum by competing with native plants and discouraging grazing near it, the plant reduces forage production and interferes with pasture/rangeland and livestock [64]. This directly affects the land's suitability for livestock grazing.

Weeds on rangelands have an adverse effect on the livestock industry by reducing forage supply and its quality, obstructing grazing, poisoning animals, raising the expense of managing and producing livestock, and decreasing land value [65;66]. In pastures and rangelands, *E. hirta* easily outcompetes desirable vegetation [67].After establishing itself in pasture and rangeland habitats, it tends to displace all other vegetation [68;69].Found widely in moist and dry environments, *E. hirta* creates through allelopathy, essentially a single species stand by releasing the flavonoid compound Kaempherol glucuronide, the plant is poisonous to animals and presents a significant risk to the productivity of livestock on open rangelands [70]. *E. hirta* is selected for the present study.

2.2 Study Area:

The study was conducted around Imphal (24º75' N latitude and 93º85' E Longitude at an elevation of 782 m MSL) at Imphal valley, Manipur, North East India. The average maximum temperature ranges from 25.1ºC-31.1ºC (May - June) while the minimum temperature ranges from 11.8ºC to 19.4ºC. (December-January), the average annual rainfall being 1470 mm per annum. Humidity is highly variable during different seasons ranging from 45 to 100%.

2.3 Demographic Analysis:

Over two-year period, field study was conducted on pure natural population of forty randomly chosen $0.25m^{-2}$ plots demarcated for studying the demographic parameters. The number of individuals in 4 different functional stages called age groups were recognized in the field conditions and marked. These 4-age group comprised of seedling, juvenile, flowering adults and fruiting adults. Record of the individual plants in the above said area for each stage was made. New individuals becoming established at the time of each census were identified as per age group. The number of individuals in each age group were censused at monthly intervals and the observations were continued for more than 2 years (December 2020-December 2022). To assess the impact of nutrient supply on seedling emergence, soil samples were taken at 2-6 cm depth from ten adjacent plots and analyzed for Soil Moisture, pH, Organic Carbon, Total Nitrogen, Available Phosphorus and Exchangeable Potassium as per the standard methods given in Misra [71].

2.4 The Model

The equation,

$$Av = \lambda v$$

indicates that A = square matrix
ν = column vector and
λ = scalar.

For every Eigen value λ, there is an associated Eigen vector ν. The dominant Eigen value gives the rate at which the population size increases**.**

The Leslie matrix model take the general form of N(t+1) = A.N (t).

Where, N(t+1) and N(t) are vectors representing age or stage class distribution of individuals at time t+1 and t, A is the matrix defining the age or stage specific survival and fecundity values. The rate of emigration and immigration of propagules were assumed to be equal. The model was thus simplified. The asymptotic population growth rate λ is given by the dominant Eigen values of A_1 the stable age/stage distribution by corresponding Eigen vector. Rate of decay or death rate was designated as -μ and calculated at each time interval.

2.5 General mathematical formulation of the population dynamics Model:

As the number of individuals changes with time t,

$$\frac{dN}{dt}\ \alpha\ N$$

$$\frac{dN}{dt} = m.N$$

$$\frac{dN}{N} = m.dt$$

$$\int \frac{dN}{N} = m.\int dt$$

$$\text{Log } N = m.t + C$$
$$\text{at } t = 0,\ N=N_0$$
$$\text{Since } \log N_0 = C$$
$$\text{Log } N = mt + \log N_0$$
$$Log\ \frac{N}{N_0} = mt$$

So,

$N = N_0\ e^{mt}$
Put ^{emt} = λ = growth rate
$N= \lambda\ N_0$
or $N(t+1) = \lambda N_{(t)}$
where t = the initial observation year
t +1 = a time period of one year after the initial observations were recorded

When λ equals 1, the population size is constant but increases or decreases when λ is more than 1 or less than 1 respectively.

2.6 Application of the Model

The age distribution vector were derived from log graphs where the abscissae demarcated the length of span for each age group scaled in such a way that the length of life span for seedling stage equals one unit and on the ordinates the density of different age groups were plotted.

The contribution to the population at time t+1 can be obtained by multiplying N_t by the following matrix comprised of a×a as submatrices,

where, A_A to A_D represent the survivorship of 4 stages during the time interval.

$$\begin{pmatrix} A_A & & & 0 \\ & A_B & & \\ & & A_C & \\ 0 & & & A_D \end{pmatrix}$$

2.7 Groups and Cohorts

In weed population 4 stage classes were recognized which have specific longevity. Taking seedling state life span as the unit, all the other 3 stage classes were subdivided into a number of cohorts for projecting population structure of future time as it was assumed that the individuals in a particular ontogenetic stage with the experimentally derived longevity can be splitted over cohorts. Thus, taking the unit time interval of 5 days in case of *Euphorbia hirta* the total life span of the weed can be splitted into 17 cohorts. Thus, the column vector $N_{(t)}$ comprised of age classes (derived graphically on log scale.

2.8 Survival Coefficients

Survival coefficients were calculated for all stage classes and are regarded as the proportion of individuals borne at a given time, actually the survival schedule of the individual takes into consideration the number of individuals surviving to a particular stage. To obtain survival coefficients, it was seen that how many individuals borne at a particular time survived the first interval of time, how many the second, how many the third and so on until no more were alive. Thus probabilities of surviving from one age group to the next were calculated. The population structure at t+1 time can be derived by multiplying N(t) with a block diagonal matrix with diagonal submatrices AA, AB, AC and AD where AA to AD indicated the survivorship of four stage classes during the time interval through 17 age groups in *Euphorbia hirta*. The number of groups in seedling, juvenile, young and mature stage classes were 1,2,5 and 9 for *E. hirta*.

Based on age transitions the matrices were computed and equal to the proportion of plants that were in the j^{th} age class at time t that entered the i^{th} age class at time t+1.

2.9 Possibility of Seed Bank

The area had pure standing populations of the weed studied. The rate of migration and entrance (immigration) of propagules were assumed to be constant taking into consideration the fact that propagules had equal chance of dispersal in the field. The model was thus simplified as effect of wind velocity etc. on dispersal was not seen. The effect of the dispersal agencies if any, was supposed to be counterbalanced as the studied areas were located within the pure stands of the weed population.

2.10 Projecting Population Structure

Leslie Matrix [56] modified after Gupta [71] describing the contribution of each age group to every other group during the time interval (t, t+1) was employed with a column vector N(t) including the number of individuals in each group. Mostly emergent seedling population densities for 2021 were utilized as initial values in conventional Leslie Matrix form for simulation, the projected population structure and number of individuals in different age group was compared with the observed data in the field for the whole year. Relationship between seedling emergence and edaphic variables was regressed.

3 RESULTS AND DISCUSSION

3.1 Patterns of Growth

With experimental results available on *E hirta*, it was found that the time of onset of flowering was 16 days which continued for 25 days, the maximum fruiting period was 45 days, the limit age of individuals involved in reproduction was 41 days and the life expectancy was 11 weeks.

3.2 Fluctuations in Population

Dynamics of *E. hirta* population for 2021 and 2022 are reflected in Fig 1.In E hirta, the fluctuation range for seedling population varied from 47.3% to 37.5% in 2021 whereas54.36% to 41.97%in 2022,for juvenile population, the range was36.25 %-26.31%in 2021 and 36.56% to 26.1%in 2022for flowering adult population, the range was 23.45% to16.79%in 2021 24.13%-15.15 %in 2022,for flowering-fruiting adult, population range was from 7.89%-1.92 % in 2021 to 3.70%-1.94 % in 2022 respectively(Fig1).

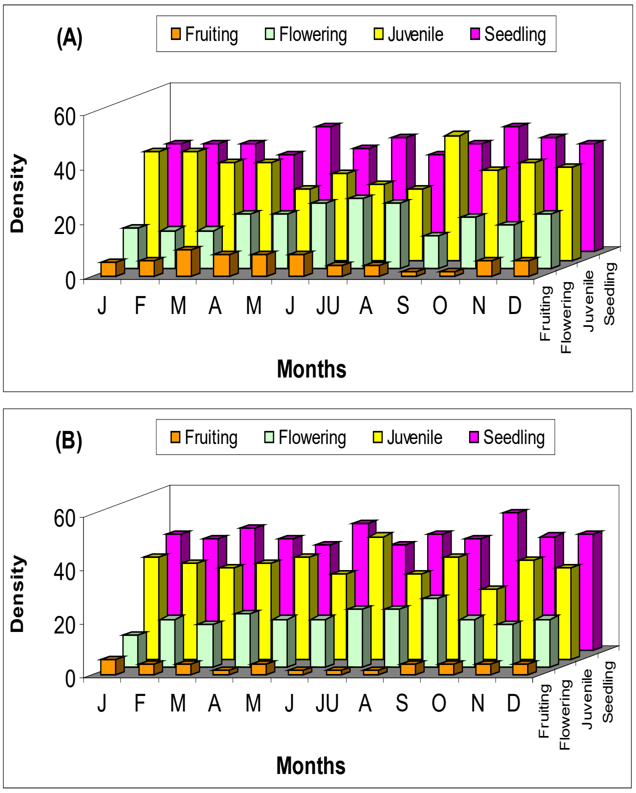

Fig.1: Dynamics of *Euphorbia hirta* population for (A) 2021 and (B) 2022((Density-Individuals 0.25 m^{-2}).

3.3 Recruitment, Nutrient status and seedling emergent population

The outbreak in seedling population was obtained in December-January months in E. hirta.

An invasive species establishes when repeated reproduction and survival of individuals result in a population capable of maintaining itself in the wild [72]. Survival and reproduction rely on many abiotic (nonliving) factors that can either promote or hinder invasive species establishment.

The multiple linear regression derived was
Y=-221.07+1.69 X1-16.51 X2+189.5 X3+820.73 X4-5.67X5 +0.59 X6

Where Y = seedling establishment
Numericals - 221.07 is the constant whereas other numericals are Regression coefficients.
X1- Soil Moisture, X2-pH, X3-Soil Organic Carbon, X4- Total Nitrogen, X5- Available Phosphorus and X6- Exchangeable Potassium

The multiple linear regression in *E. hirta* showed that the species responses were linear to the abiotic factors studied on seedling establishment and were significant both at 0.05 and 0.01 levels. (r^2=0.970, F=26.948 at df 6, 5).

The **relative** maximum percentage contribution on seedling establishment was exhibited by Exchangeable Potassium (59%) followed by pH (39.3%) in *E. hirta.*

3.4 Age Structure and Age Pyramids

The age structure into 4 age groups viz. seedling, juvenile, flowering adult and flowering –fruiting adult was expressed as a combination of total annual density in the studied area of corresponding age group resulting in age pyramid. The fluctuations of population age structure in the two years revealed the fate of various cohorts in *E. hirta* (Fig 2).

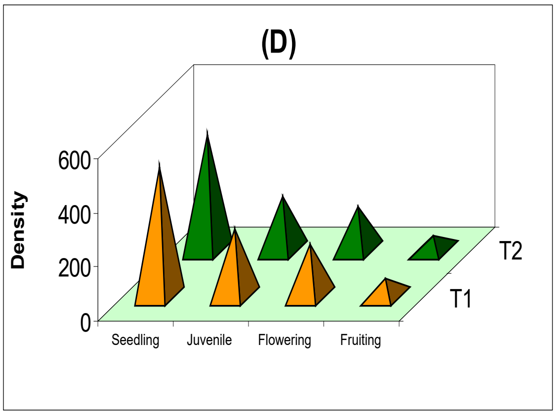

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Fig 2 Age pyramid for populations of Euphorbia *hirta*

3.5 Age Specific Survival and Mortality

The monthly survival and mortality percentages for seedling and juvenile age group of weed population for a period of 2 years were computed. During the study period, the maximum survival percentage by seedling population was exhibited in the month of June (96%) and July (95.56%) in *Euphorbia hirta* for the year 2021 and 2022 respectively. The maximum mortality % in seedling stage was exhibited in the months of April (55.56%) and September (46.67%) in the species for the year 2021 and 2022.

Whereas the population in juvenile stage showed the maximum survival percentage in the months of June (86.36% and 77.77%) for the year 2021 and 2022 respectively. The maximum mortality percentage in the months of May (64.04% and 60.53%) for 2021 and 2022 respectively.

3.6 Survival Coefficients

The survival coefficients showed a flux in various age groups within the same species. Fig 3 reveals the survival coefficients for different months on the basis of average of two years value in 4 age groups of weed population in Manipur. They are the possible transitional probabilities and reflected the temporal variation in population structure.

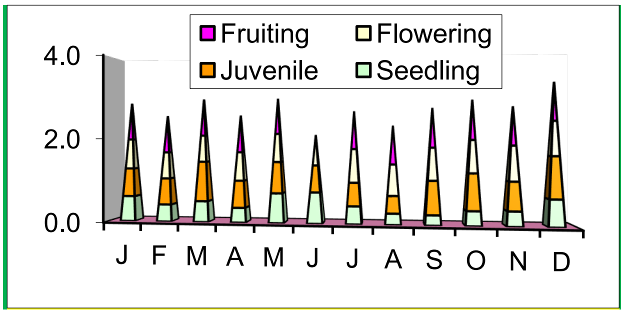

Fig 3 Survival coefficients for *Euphorbia hirta* L.for four different age groups

The lower value of survival coefficients was obtained for seedling population in Euphorbia hirta in September that revealed the risky nature of this stage in the life span.

3.7 Growth Rate (λ)

The weed population of Eurphorbia hirta exhibited an annual percentage gain of 10.55%. The number of new individuals in 2 years (2021 and 2022) revealed the fate of various cohorts and subcohorts in the weed species. The average survival and mortality percentages were 75.65% and 24.35% respectively hirta exhibited positive density dependent correlation, growth rate exceeded value 1.0 in the species, the annual decay rate was 0.235(Fig 4).

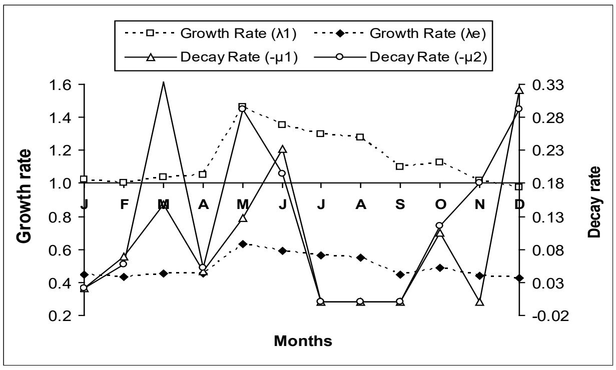

Fig 4 Growth Rate (λ) and Decay Rate (-μ) for the populations of *Euphorbia hirta*

3.8 Population behavior

Gupta (71;73;74;75;76) made attempts to combine age and structure stage into one and analysed the demography of herbaceous annuals by matrix model.

The Leslie matrix model take the general form of N(t+1) = A.N (t),

where, N(t+1) and N(t) are vectors representing age or stage class distribution of individuals at time t+1 and t, A is the matrix defining the age or stage specific survival and fecundity values. The rate of emigration and immigration of propagules were assumed to be equal. The model was thus simplified. The asymptotic population growth rate λ is given by the dominant Eigen values of A_1 the stable age/stage distribution by corresponding Eigen vector. Rate of decay or death rate was designated as (-μ and calculated at each time interval.

The age distribution vector was derived from log graphs where the abscissae demarcated the length of span for each age group scaled in such a way that the length of life span for seedling stage equals one unit and on the ordinates the density of different age groups were plotted in all the herbaceous annuals populations. It was assumed that individuals in a particular ontogeny with experimentally derived longevity can be splitted into subcohorts

The Column Vector N(t) comprised of: -

N(t) = (68.0, 56.0, 43.0, 35.0, 27.2, 21.0, 14.1, 8.0, 7.0, 5.3, 5.0, 4.0, 3.8, 3.6, 3.2, 3.0,2.8).

In *E hirta* through 17 cohorts (with Seedlings life span 5 days)

The contribution to the population at time t+1 can be obtained by multiplying Nt by the matrix defining the age or stage specific survival matrix. For simulations the monthly emergent seedling population for the initial year were analysed in case of all plants and multiplied with survivorship co-efficient.

3.9 Population Projection

The age structure of projected population for 2022 revealed its resemblance with observed age structure for 2022 population in field conditions. It indicated that the projection matrix is satisfactory in differentiating thee age specific characteristics of cohorts. In both the cases of projected and observed populations, the largest category of individuals was composed of seedlings followed by juveniles, then flowering stage and lastly fruiting adult stage plants. Thus, a remarkable similarity between projected and observed age group distribution curves were noticed (Fig.5).

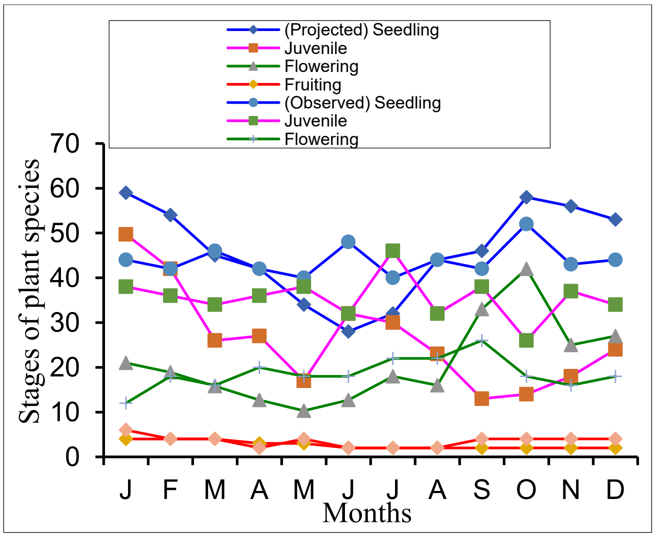

Fig 5 Projection for *Euphorbia hirta* L Population (Leslie Matrix Model)

The simulation indicated a striking similarity between observed and projected populations. It indicated that the projection matrix was satisfactory in differentiating the age specific characteristics of cohorts and sub-cohorts. The present study also substantiated the earlier works [71;73;74;75;76]. The matrix model provided a path elucidating the dynamics of population in which reproduction and survival coefficient for seedling stage suggested it a critical stage in life cycle of *E. hirta.* Thus, the lower value of survival coefficients obtained for seedling population in the month of September revealed that the mortality risk was highest at seedling stage suggesting to have the control measures at seedling stage In, *Portulaca oleracea* [75;76], the seedling stage was also regarded as risky due to minimum survival coefficient value. Earlier works [71;73] on *Parthenium hysterophorus* revealed flowering stage a critical stage in the life cycle of this notorious weed that approved that the effective control of the weed may be brought about by regulating it at flowering stage.

Similarly, for *Tridax procumbens*, Linn., flowering was obtained as a sensitive stage. Thus, it appears that a division of resources between vegetative and reproductive organ is important for it [74;75], whereas in *Bidens pilosa* survival co-efficient of juvenile stage was found to be low indicating that competition for nutrient and space (Dense turf) is an important factor in regulating it [74;75].

The study reveals that seedling stage is one of the riskiest phases in the life-history of *E. hirta*. It is considered to be the most vulnerable stage in the life of the plant [77]. Fenner & Thompson [78] owe this to reduction in biomass, if even reduced in small amount may lead to the death of the plant. Seedlings face threats to their establishment from natural enemies to resource limitations and insufficiencies in sites suitability [79]. Seedling recruitment can depend on abiotic and/or biotic variation at very small scales (e.g. meters or weeks), yet be a major demographic driver of community dynamics and species distributions [80;81] Burkey and Stenseth [82] demonstrated with a seasonal model how the value of the resource to each individual may be reduced due to its patchy distribution. It was concluded that the difference among population of various weed species depend on the difference of their transition probabilities of matrices in the same year and on the difference in stochastic processes. As also observed by Aberg [83], the difference was reflected in value of λ and -μ rates.

4 Conclusion

Matrix population models offer a tool for identifying the demographic processes that have the greatest impact on population growth rates in order to better understand population dynamics and potential management strategies for invasive plant species. I demonstrate that the population under study has a higher growth rate and is demographically stable through the examination of asymptotic growth rate and demographic parameters. Population declines of invasive species may be achieved by focusing control on demographic processes (survival) to target for reductions in population. Reducing the survival and growth of the species would have the biggest impact on lowering the overall population growth rate. Invasive species can experience population losses by concentrating management on demographic processes. Applying density thresholds to a transient invasive species (E.hirta), I examined how population density affected population projection and offered for management recommendations.

As invasive species management is concerned with maximizing mortality and lowering the reproduction and minimizing the loss of resources resulting from invasive species competition with crops, it is suggested to target the population for management measures at seedling stage so as to eliminate the probability of reaching the adult stage thereby setting seeds for further infestation and spread. Our results provide a first evaluation of the demography of *E. hirta*, a species of economic concern, and provide the first structured population model of a representative of the *Euphorbiaceae* family, thus contributing to our global knowledge on plant population dynamics.

5 Recommendations and Future work

Invasive species, a global threat due to climate change and human disturbances, require urgent management strategies. Early detection and swift action are crucial for eradicating these species which disrupt ecosystems, impact adversely biodiversity, introduce diseases, and cause financial burdens. Matrix models provide the tools that can identify high-risk stage in the life cycle, prioritizing management and population eradication.
Recruitment from seed banks impacts population structure in time and space, with age structure resulting from long-term persistence in the seed bank. Changes in age structure and population size significantly influence demography, necessitating inclusion of age-structured seed bank dynamics in demographic models that I intend to include in my future work.

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