

**STUDIES ON POPULATION DYNAMICS OF**  
*EUPATORIUM ODORATUM L., E. ADENOPHORUM*  
**SPRENG. AND *E. RIPARIUM* REGEL**

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To



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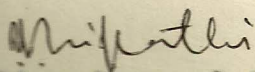
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I certify that the thesis entitled "Studies on population dynamics of Eupatorium odoratum L., E. adenophorum spreng. and E. riparium Regel." submitted by Shri Atar Singh, M.Sc. for the Degree of Doctor of Philosophy of the North-Eastern Hill University, Shillong embodies the record of original investigation carried out by him under my supervision. He has been duly registered and the thesis presented is worthy of being considered for the award of the Ph.D. Degree. This work has not been submitted for any Degree of any other University.

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The population of a species colonizing a new site passes through different growth phases with the passage of time. Initially, the population grows exponentially till the resources become limiting. Later on, if the birth and death rates become equal, the population size gets stabilized showing fluctuations around a mean value. The growth of species populations, however, brings about certain changes in the environment as well. The modified environment may prove to be unsuitable for the early colonizers whose populations may, therefore, decline and vanish due to increased mortality. How long the species will continue to grow on a given habitat, of course, depends on its capacity to adjust itself according to the changing environmental conditions. The changes in the environment may, however, be reflected in the fluctuations in population size. The study of these fluctuations in population size is referred to as the population dynamics, a term for the first time proposed by Elton (1927). According to him population dynamics concerns with the rate of increases, fluctuations and the influence of the environmental factors on the size of the populations.

The population dynamics of the animal populations has been extensively studied where-as little attention has been given to the study of plant populations. The main causes which hindered the study of plant populations are the plasticity and vegetative reproduction as pointed out by Harper (1961,1967). However, in the last two decades, some studies have been carried out on the population dynamics of certain plant species. Harper and White (1974) suggested that all the principles formulated for animal populations cannot be used in plant species because of difference in growth form and other features of higher plants and animals.

The rate of population growth depicts increase in number of individuals in a given population per unit time. Lotka (1931) and Volterra<sup>r</sup> (1931) proposed separately different theoretical equations for calculating the population growth rate which were experimentally confirmed by Gause (1934) through his classical work on Paramecium. Gause (1934) suggested that the two species having identical ecological niches cannot survive together for long and eventually one will replace the other. This was confirmed by Park (1954);

Frank (1957) and Tantaway & Soliman (1967). However, Kech(1974) for the first time suggested that two species can co-exist on one biotic resource which was also confirmed and supported by McGhee & Armstrong (1977) and Armstrong & McGhee (1980).

Verhulst (1838) proposed the first mathematical equation of population growth rate which was later on presented by Pearl and Reed (1920) as follows:

$$\frac{dN}{dt} = rN (K-N)/K$$

where N is the number of individuals, t- is time, r-intrinsic rate of population growth, K- the carrying capacity.  $\frac{dN}{dt}$  - represents rate of change in population size. Harper & White (1974) put forward a fundamental equation of population growth which is as under.

$$N_t - 1 = N_t - 1 + B - D - I - E$$

where  $N_t$  - is the number of individual of a population at time "t", and  $N_{t-1}$  - is the number of individual after some time, i.e. at "t-1"

The plant populations consist of two levels of population organisation as suggested by Harper & White (1974), one the number of individuals per unit area

(colonies) and the other, the number of shoots, or leaves, or axillary buds per plant (number of subunits per colony). The symbol  $Nn$  should be used to define the population size, where 'N' is the number of plants and 'n' represents number of subunits per individual plant of a population.

In some studies on plant population dynamics the different plant parts were considered as members of the population. Saeki (1960) in Phaseolus viridissimus and Nicotiana tabacum and Gill and Tomlinson (1971) in Rhizophora mangle studied the dynamics of leaf production. Bazzaz & Harper (1977) also studied the effect of light intensity and density on the branching pattern and leaf dynamics in Linum usitatissimum. Gill (1971) observed the dynamics of bud production in Fraxinus americana. Kays and Harper (1974) observed the change in population of Lolium perenne at the two levels of population organisation, i.e. change in number of genets as well as number of ramets per genet. This type of study was also carried out by Ogden (1974) in Jussilago farfara.

A study of the population attributes such as natality, mortality, longevity, seed dynamics, age-structure

and migration, and of the factors which influence these attributes is a pre-requisite for understanding the population growth of a plant species in time and space. In plants, the recruitment of new individuals takes place through the germination of seeds or sprouting of vegetative propagules. The cohort of new individuals is thus formed and the adult population that comes into existence is exposed to varied influences of different environmental factors.

A considerable amount of literature has been accumulated on the mortality rates of the plant populations over the last 15 years. Heavy juvenile mortality has been observed in the seedling populations of various woody species (Hett 1971; Sharitz & McCormick 1973; Sarathin & Harper 1973; Hett & Loucks 1976). Heavy mortality of seedling populations seems to occur at the transition stage between the dependence of seedlings on seed food reserve and their establishment when they start independent assimilation. A sudden change in the prevailing climatic conditions at this stage may cause heavy mortality of seedlings. The seedling mortality due to drought has been reported by Tazaki (1963), Friedman & Orshan (1975) and Maruta -

(1976). Peterken (1966), Cavers & Harper (1967),  
Saif El Din & Obeid (1971) and Miles (1972) observed  
the death of seedlings due to drought even in closed  
vegetation canopy. Pelton (1962) has studied in detail  
about the factors affecting the survivorship of  
seedlings.

In contrast to the seedling population, the  
established plant populations show, constant risk of  
mortality throughout their life span following Decey  
Type II (Decey 1946) survivorship curve ( Tamm 1956;  
Rabinov 1958; Sagar 1959; Foster 1964; Antonovics  
1972). Sarahan & Harper (1973) and Hawthorn & Cavers  
(1976) also observed constant mortality risk in  
established populations and suggested that high rates  
of mortality are observed in the active growing season  
and the mortality rates of the adult populations were  
independent of harsh climatic conditions. Bishop et.al.,  
(1971) reported that the survivorship of Hieracium  
glaberrimum population was considerably influenced by  
the climatic factors and observed high decay rates of  
population in the acidic and chalk soils. Antonovics  
(1972) suggested that the causes of death rates are

influenced by the environmental and genetic factors, and emphasized the importance of the population decay rates in the genetic adjustment at a varying and unpredictable environment. On the basis of his observations on Anthoxanthum odoratum he argued that during seedling establishment, there may be selection of characters which show differential survival rates in different years of the life-span of the individuals.

In most of the plant population studies the survivorship curves have been found to be of Deevey Type II which implies constant risk of death throughout the life-span of the population. However, some exceptions have been reported to this type of survivorship pattern. In Danthonia caespitosa, Williams (1970) has reported Deevey Type III survivorship curve with heaviest mortality in the young stage. In contrast to this, Canfield (1957) observed Deevey Type I survivorship curve with less risk of death in young and middle period of age and high mortality risk in old age in Trichache californica, Bouteloua hirsuta and B. chondrosioides.

The literature published on longevity of various plant species has been reviewed in detail by Harper & White (1974). The determination of the exact age of

of the perennial plant species is very difficult as no reliable technique for estimating the age has been found out. Various techniques used to determine the age are based on the anatomical and morphological features such as growth rings in stem or rhizome and leaf scars on the rhizome. Pigott (1955) found that the age of Cirsium acaulon can be accurately estimated by counting the number of leaf scars on the rhizome. Harster (1968), Levin (1973), Schaal & Levin (1976) and Schaal (1978) have considered the rings present in corm of Liatris aspera for the determination of its age. However, Werner (1978b) did not agree with them and suggested that there is no relation between the age and number of rings in the corm of Liatris aspera. The most reliable method for estimating the age of perennial herbs is to follow the fate of the labelled seedlings or tillers of known age in permanent quadrats. This method has been successfully used by Tamm (1956, 1972a, 1972b). Antonovics (1972) discussed by citing evidence from the crop plants that longevity may be increased or decreased by selection. In Anthoxanthum odoratum, Antonovics (1972) observed that the different populations have different longevity according to their adaptation

to a particular habitat, and suggested that difference in longevity of individuals of different populations may be related to the environmental conditions.

Age-structure of a population refers to the categorisation of individuals in various groups representing different age classes in a population. Age-structure of a species population may largely determine its survivorship. Williams (1970) and Antonovics (1972) observed differential decay rates for the individuals recruited at different times to the population. It also gives valuable information about the recruitment of new individuals to the population, the transition of individuals from one age-group to another age-group, the number of individuals reproducing and also the mortality rate as influenced by the age (Rabotnov 1978). Krebs (1972) defined two classes of age distribution; the stationary age distribution in which the population will achieve constant population size with equal mortality and natality, and stable age distribution of a growing population in which the birth and death rates are found to be age-specific.

According to Harper & White (1974), while studying the age structure of the population of a perennial species, the seedling population may or may not be considered depending upon the observation period of the year as the

seedlings tend to show 100% mortality in perennial grasses (Putwain et. al., 1968). Richards (1952), Emlen (1972) and Schaal (1978) suggested that the unstable age-structure of plant species may be observed due to large environmental fluctuations that may occur during critical periods in the plant's life. Rabotnov (1945, 1950a, 1950b, 1969) suggested that a coenopopulation is characterised by various age groups of individuals based on the four main periods of life of the plants reproducing by seeds. These periods are (i) the period of primary dormancy, (ii) the virginal period, (iii) the generative period and (iv) the senile period.

The study of seed dynamics is also important in understanding the population behaviour of a plant species. This aspect, however, assumes special significance for the secondary successional and early colonizing plant species where the seed population plays a major role in the regulation of their actively growing populations. The development of secondary vegetation in many communities depends upon the viable buried seed populations existing before the disturbances were caused (Oosting & Humphreys 1961; Egler 1954; Johnson 1975; Archibold 1979). The rapid development of the secondary vegetation following disturbance is due to the buried seed populations which

becomes active with the release of competition stress. Hayashi & Numata (1971) observed that in the grassland dominated by *Zoysia* stand, the natural regeneration of the vegetation is mainly dependent upon the viable buried seed populations. Similarly, the weed populations in pastures and agricultural lands are also regulated to a great extent by their soil seed populations. Thompson and Grime (1979) suggested four type of soil seed banks and emphasized the role of seed population in soil in the regeneration of the vegetation. Seed input to the soil and seed losses from the soil, thus, become an essential consideration in the study of plant populations.

The seed input to the soil seed pool depends upon the seed production by the growing plant populations every year and on the environmental factors which affect the number of seeds reaching the soil seed bank. A large fraction of total seeds produced by the vegetation is carried away by wind and water to distant places. Predation and grazing also affect the number of seeds entering the seed pool (Harper & Grime 1955; Harper 1957; Sarukhan 1958; Leeley & Sage 1976; Leeley 1977).

High buried seed populations have been reported in cultivated fields and grassland vegetation by various authors (Brenchley & Warrington 1933; Roberts 1958;

Robinson & Kust 1962 and others). Hayashi and Numata (1971) based on the data of buried seed populations of grasslands, suggested that, (i) the composition of above ground vegetation and composition of buried seed populations are not related, (ii) the soil in certain seral stages contains the seeds of species constituting the earlier communities, and (iii) the younger successional stages contain high population of seeds in soil which declines as the succession proceeds.

The seed population of certain undisturbed forests has been studied by Oosting & Humphreys (1940), Olmsted & Curtis (1947), Karpov (1960), Livingston & Alessio (1968), Ballant (1970, 1974), Johnson (1975), Marquis (1975), Strickler & Edgerton (1976) and Whipple (1978). From these studies it was concluded that the soils of forest communities contain low number of seeds and there was poor correspondence between the buried seed flora and the composition of growing vegetation. Alexander (1974) attributed the poor availability of seeds in forest soils to their high rates of losses both through germination and predation.

Roberts (1962, 1968) observed exponential decrease in buried seed populations of weeds in undisturbed areas when fresh input of seeds was stopped. This was also confirmed

by Sarukhán (1974) and Bowes & Thomas (1978). However, Bowes & Thomas (1978) observed slower decay rates of seed population of Euphorbia esula as compared to decay rates observed by Roberts (1962, 1968).

The survival of buried seed population was found to be different for different species (Roberts 1962, 1968, 1979; Arpud 1946; Roberts & Dawkins 1967; Kellman 1974; Walker et al., 1980). A large number of weedy species studied by Roberts & Feast (1972) and Roberts (1979) showed that the seeds lose viability rapidly and the seeds of only a few species could survive for more than 5 years. However, the seeds of certain species have been reported to remain viable for considerably long durations (Toole 1946; Chapil 1946; Darlington & Steinbauer 1961; Jones 1970; Lewis 1973).

The soil seed populations decline due to the germination of some seeds with the onset of favourable conditions and their predation by soil micro-organisms (Sarukhán 1974). Chancellor (1968) attributed the absence of ambrosia sterilis populations from the arable soils to their non-dormant seeds. Thus, enforcement of dormancy is essential for the survival of seeds in soil (Roberts 1970). Densygas (1974) also suggested that enforced dormancy is one of the factors which control the germination of seeds

during burial. The seeds buried in soil acquire different types of dormancy as described by Harper (1957). The seeds lying on the surface of the soil may acquire enforced dormancy by the balance of infra-red and far red radiation filtering through the vegetation canopy (Naischke 1936; Barton 1965; Górski 1975; Górski et. al., 1977). The seeds buried in soil may undergo dormancy in response to the prevailing environmental factors such as relative concentrations of CO<sub>2</sub> and O<sub>2</sub> in soil atmosphere (Harper 1957) and availability of light (Wesson & Wareing 1967; Black 1969). In some species the seeds exhibiting enforced dormancy enter into induced dormancy at low temperature in winter season (Courtney 1968; Sarukhan 1974; Mukherjee et. al., 1980). Baskin & Baskin (1975) also suggested that the non-dormant seeds of Torilis japonica develop induced dormancy under low temperatures which could be overcome by raising the temperature.

Callaghan (1976) suggested that the growth, reproduction and death of the individuals in a plant population are affected by the environmental factors within the genetic limits of the population. The environmental factors are biotic and abiotic. The former includes the effect of other organisms including the individuals of the population

itself and other factors like grazing, predation, and competition for the limited resources while the latter includes the natural calamities like fire, sudden change in temperature, heavy precipitation, frost, storms, etc. which cause wide spread destruction to the population. The death caused by such abiotic factors has been called as "catastrophic" death by Warren Wilson (1967).

Fire which occurs frequently in some plant communities plays important role in the regulation of the population of many plant species. The fire of mild intensity may stimulate high seedling establishment and growth by raising the soil temperature and nutrient status, and by removal of plant litter and vegetation cover (Suell & Carlton 1953; Kelting 1957; Lemon 1967; Old 1969; Sharp 1970; Shelton & Main 1979). The high stimulation of seed germination after fire in Adenostoma fasciculatum dominated vegetation was also attributed to the destruction of allelochemicals released from the different parts of Adenostoma fasciculatum in burned chaparral in the Santa Ynez Mountains, California (Christensen & Muller 1975).

Grazing has been reported to decrease the longevity of primary range grasses and to increase the longevity of secondary range grasses (Canfield 1957; Williams 1968, 1969, 1970; Williams & Roe 1975). West et.al., (1979)

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observed that grazing increased the longevity of grasses while the longevity of shrub, Artemisia tripartita declined in grazed plots. The role of herbivores in the population regulation of plant species was observed by Watt (1962) and Connell (1971).

Other factors which influence the population behaviour of a species are population density, soil moisture, soil fertility and light intensity. The plant populations respond to these factors under stress conditions both through mortality (loss of individuals from the population) and plasticity (reduction in vegetative and reproductive growth of the individuals).

The effect of plant density on population growth has been studied by many workers (Sukatchev 1928; Tadaki & Shidei 1959; Harper & Gajic 1961; Harper & Mc Naughton 1962; Raynal & Bazzaz 1975; Tripathi & Gupta 1980). Yoda et al., (1963) established a relationship between the mean dry weight per plant and the density of surviving individuals, and propounded the well known -  $\frac{3}{2}$  thinning law, which was later on confirmed by White & Harper (1970) and Kays & Harper (1974). The influence of density on the reproductive potential has also been studied in many plant species (Palmbiad 1968; Tripathi 1968; Williams & Ingber 1977; Watkinson & Harper 1978; Weiss 1978; Tripathi & Gupta 1980).

However, not much attention has been given to the influence of other factors on population behaviour of plant species. Myerscough and Marshall (1973) observed that the survival and growth of Arabidopsis thaliana plants was reduced with increase in population density and decrease in nutrient level. Cook (1965) studied the role of abiotic factors and competition in the regulation of population of Eschscholzia californica. Palmblad (1968) observed the effect of seed sowing density, soil surface, fertilizer and moisture on the population behaviour of many weedy species in field and glass house conditions. He suggested that the self controlled germination, mortality or plasticity may contribute to the population regulation of weedy species which produce more seeds per unit area than required for their maintenance.

Sheritz and McCormick (1973) studied the population dynamics of Sedum smallii and Minuartia uniflora and proposed the hypothesis that the population dynamics of these weedy species is mainly influenced by the interspecific competition for soil moisture. They further observed that abiotic factors tended to cause reduction in growth of the individuals while interspecific competition favoured mortality of the individuals.

Although the plant populations show reduced survival, and suppressed vegetative as well as reproductive growth in stressed conditions, the allocation of resources to reproductive structures in many species remains unaffected (Harper & Odgen 1970; Odgen 1974; Bradbury & Hofstra 1976; Keller & Abrahamson 1977; Abrahamson & Harshey 1977; Nagel 1979 ). However, the reproductive allocation in certain plant species has been observed to increase with increase in stress (Gadgil & Solbrig 1972; Hickman 1975). The adaptability of the species to have a tendency to allocate more resources to reproductive structures under stressed conditions provides them with the ability of producing more offsprings for the growth of the species population. On the contrary, the reproductive growth of certain plant species is drastically reduced in stressed situations, for example, Tripathi & Gupta (1980) observed 7 and 4 fold reduction in percentage of spike bearing tillers due to density stress in Bothriochloa pertusa and Dichanthium annulatum respectively.

The associated vegetation and established plant populations exercise great regulatory influence on the populations of newly recruited individuals. Poor seedling establishment has been reported in established communities by Tamm (1956), Cavers & Harper (1967) and Putwain & Harper

(1970). Putwain & Harper (1970) and Dwivedi & Tripathi (1980) found that amongst the associated species, grasses exercise greater regulatory influence as compared to the dicots. Sagar (1970) observed increased vegetative and reproductive growth of Plantago lanceolata when the associated vegetation was removed. Cronin (1976) reported that after the removal of tall lark spur (Delphinium barbevi) the forb dominated communities were converted to grass dominated communities. The established plant populations also affect the survival and growth of the newly recruited individuals (Friedman 1971). Gupta & Tripathi (1979) reported that when Bothriochloa pertusa was introduced to already established population of Dichanthium annulatum (established 30 days earlier) it showed substantial reduction in yield and complete suppression in reproductive growth. Patel & Saxena (1974) also observed suppressed growth of the seedlings of Chaenactis angustifolia with the associates and attributed the growth suppression to a keen competition for water between associated vegetation and seedling populations where the former happens to utilize the available resources more effectively.

A study of population dynamics of weed species providing information about the natality, mortality, survivorship and age-structure of the weed populations and the

environmental factors which influence these population attributes may prove quite useful in devising effective weed control measures. On the basis of data collected on various population parameters, working population models can be synthesized, through which the reaction of a particular environmental factor on the population behaviour of the weed can be predicted. Thus, a detailed demographic analysis of the three common exotic weeds viz., Eupatorium odoratum, E. adenophorum and E. riparium belonging to the family Asteraceae, was undertaken in the present work with a view to identify some of the factors which play major role in the regulation of the populations of these weeds.

All the three Eupatorium spp. are native to Mexico and have been introduced to other parts of the world by the early navigators. E. odoratum is reported to be a serious weed of the 23 countries of the world including India, Malaysia, Ceylon, Thailand (Holm et. al., 1977). In India it grows abundantly in the north-eastern region, and in Kerala and Madras (Rao 1974, 1977). E. adenophorum and E. riparium also grow in sub-tropical climates, in coastal regions of Australia (Auld, 1969), U.S.A. (Hosak and Thistle 1954; Fuller 1961). In India, both these weeds grow abundantly at higher altitudes in the hilly areas of the north-eastern region. E. riparium, however, shows restricted

distribution although it also grows abundantly in and around Shillong.

These weedy species grow luxuriantly in abandoned cultivated fields, on roadsides and wastelands, and in open pine forest stands, and have suppressed many useful and valuable species of the native flora. The rapidity with which these weeds are colonizing new deforested areas calls for proper control measures of these weeds. A study of the population dynamics of these weeds is essential for understanding their population behaviour in relation to various factors of the environment in time and space.

E. odoratum is a dominant ruderal weed at lower altitudes in Meghalya and adjoining Assam state, in Kerala and Madras (Rao, 1977). It infests tea, teak, rubber plantations and vegetable fields in India (Holm et. al., 1977). The plant grows very high, sometimes attaining a 3 meter height (Plate 1). It shows vegetative growth until October after which sporadic flowering commences attaining peak in December followed by fruiting. The fruits are dispersed soon after maturation in February-March. The seed germination commences in May. The reproduction in this weed occurs only through seeds.

The germination and growth behaviour of the populations of E. odoratum collected from 7 localities from Old &

Plate 1. A plant of E. odoratum growing in field situation.

Plate 2. E. riparium (A) and E. adenophorum (B) showing growth habit.



PLATE 1



PLATE 2

New World Tropics have been studied by Edwards (1974a, 1974b, 1975). He observed that these populations represent different ecotypes adapted to different climatic conditions. Edwards (1974b, 1977) also established edaphic ecotypes in E. odoratum growing under different soil moisture conditions. Seeds of E. odoratum require light for germination (Sharma 1974). The development of embryo and female gametophyte has been described by Ghosh (1969). Ghosh & Singh (1968) reported that E. odoratum is a polyploid with chromosome number 60 and is apomictic. It is used as green manure in Cambodia in rice fields and for black pepper cultivation (Garry 1963; Litzberger & de Long 1963). However, the manure of this weed was found to be poisonous to fishes, and increased the crop production indirectly by preventing the attack of nematodes and pathogens on the crop.

E. odoratum is a many stemmed perennial weed growing abundantly in open areas with high soil moisture content (Plate 13). The mature shoots that dry up in April after seed setting, sprout from their tops again in May-June every year while the new shoots are produced in small number. The plant grows vegetatively till November-December attaining a height of 80-150 cm. Flowering starts in middle of December and seeds mature by March-April. The seeds are dispersed

soon after maturation and germination commences with the onset of rains in April-May. The reproduction through vegetative propagation is almost nil. Auld (1969a) studied the distribution of this weed in Australia, and found that the growth of the weed is favoured by high rainfall, open areas and steep slopes. Auld and Martin (1972) observed that the seeds require light for germination. They also found a large number of scarified and empty seeds that may be similar as reported by Selmgren (1919), Baker (1928) and Khonglam & Singh (1980). The seedlings of E. adenophorum can tolerate shading at 10% day light intensity which makes this weed a superior competitor as compared to its other associated species (Auld and Martin 1972). The incidence of damage by organisms such as a gall fly, Proscidochares utilis; a fungus, Cercospora spathulata and a crown boring cerambycidae, Dihammus spathulata has been observed by Auld (1969b). The control of weed population by application of herbicides has also been tried by Auld (1972). Khonglam and Singh (1980) reported that E. adenophorum growing in Meghalaya is an endopolyploid with chromosome number 51.

Another species, E. riparium is a scrambling herb attaining 30-70 cm height in moist and shady habitats (Plate 2a). Most of the old shoots of this species dry up

established where plants of the three weeds are  
vegetation of the seedling populations of the  
three weeds.

after seed production in April and a large number of new shoots arise from the base of the old shoots in May-June. Some of these shoots grow horizontally on the soil surface and when they come in contact with the soil, produce new shoots from their nodes. These shoots become partially independent by giving away adventitious roots from their bases. Thus, vegetative propagation occurs in E. adenophorum. Choudhary and Singh (1980) found that E. adenophorum is also an octotriploid with chromosome number 8x and shows apogametic form of reproduction. The biology of this weed has not been studied in detail so far.

The present study on the population dynamics of the three Eragrostis spp. has been made to cover the following aspects:

- (i) The demographic analysis of the three weed populations with respect to recruitment, mortality and survivorship over a two year period.
- (ii) The effect of burning on the population dynamics of E. adenophorum and E. riparium.
- (iii) The seed population dynamics of the three weedy species with emphasis on soil seed bank and the fate of buried seeds in soil over a two year period.
- (iv) The effect of associated plant species and the established mature plants of the three weeds on regulation of the seedling populations of the three species.

(v) The effect of factors such as seed-sowing density, population density, soil moisture, soil nitrogen and light intensity on the population regulation of E. adenophorum and L. rigidum under controlled conditions.

The second and last aspects, however, could not be studied with respect to L. rigidum populations due to practical problems as the study site was far off from the department and so, the culture experiments needing constant watch could not be carried out.

The experimental data on various aspects mentioned above have been presented in Chapters II-VII which are preceded by a chapter on the climate, soil and vegetation of the study sites. The "General Introduction" sets out the objectives of the thesis and reviews the present status of the subject in light of the earlier published work. The results of the individual chapters have been discussed separately in each chapter. However, an integrated discussion of the results contained in various chapters has been given in "General Discussion" of the thesis.