ECOLOGICAL STUDIES ON SEED PRODUCTION, DISPERSAL, GERMINATION AND SEEDLING FITNESS OF RUDRAKSH (*Elaeocarpus ganitrus* Roxb.)

By
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DECLARATION

I, Putul Bhuyan, hereby declare that the subject matter of this thesis entitled "**Ecological studies on seed production, dispersal, germination and seedling fitness of Rudraksh (*Elaeocarpus ganitrus* Roxb.)**" is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/ Institute.

This is being submitted to the North-Eastern Hill University, Shillong for the award of the degree of Doctor of Philosophy in Botany.

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GENERAL INTRODUCTION

Rudraksh is a conjugate word related to Lord Shiva. The ancient Indian scriptures describe the importance of Rudraksh. "Rudra" means "Shiva" and "Aksh" means "Eyes" where the two words combine to form Rudraksh and literally it means "the eyes of Rudra". According to mythological story in Puranas, Rudra (Lord Shiva) had fought for a long time by keeping his eyes wide open in order to kill dangerous "Asur" named "Tripur" of Himalayas. In prolonged struggle the eyes of Lord Shiva got tired and tears rolled down on the earth and took the shape of a plant. Lord Brahma, the creator of Universe directed that this plant should be called Rudraksh as it was formed from Lord Shiva's flowing tears.

Many rare plants and their parts are used in Tantric (Hindu occult Science) system. Nature has created many things, which destroy negative planetary forces, get rid of evil auras in our homes, protect us from enemies or opposition around and create powerful friendly auras for health, wealth, success and happiness. The holy Rudraksh does this - a unique link between the material world and occult world. Its powerful presence keeps away all evil and negative *forces. Rudraksh is the fruit stone of the Rudraksh tree (Elaeocarpus ganitrus).* When fruit pulp is removed, the Rudraksh bead is found inside. The bead is rough in texture, with the surface divided into segments by ridges running from top to bottom. These form the faces of Rudraksh. The number of faces ('mukhi') ranges from 1 to 14, however, a major percentage of beads have 5 or 6 faces.

There are twin beads (beads joined together) called *Gaurishanker*, which are considered to be very auspicious. Natural beads have configurations on them. Such beads are extremely rare. Moreover one 'mukhi' Rudraksh is very rare while two to three and from nine to fourteen 'mukhi' Rudraksh are also difficult to find. One 'mukhi' Rudraksh has more importance, it is more effective and regarded as highly powerful. Quality of all other Rudraksh beads is cumulatively available in one 'mukhi' beads. It is believed that the person, who is lucky enough to get it, becomes wealthy in all respect. One 'mukhi' Rudraksh is related to the sun; by wearing it, a person can alleviate his bad effect to a large extent. According to Kalidas Vajpeyi, the author of *The Science of Mantara*, the five 'mukhi' Rudraksh is the best among all the other Rudraksh (cited in Hazarika 2001).

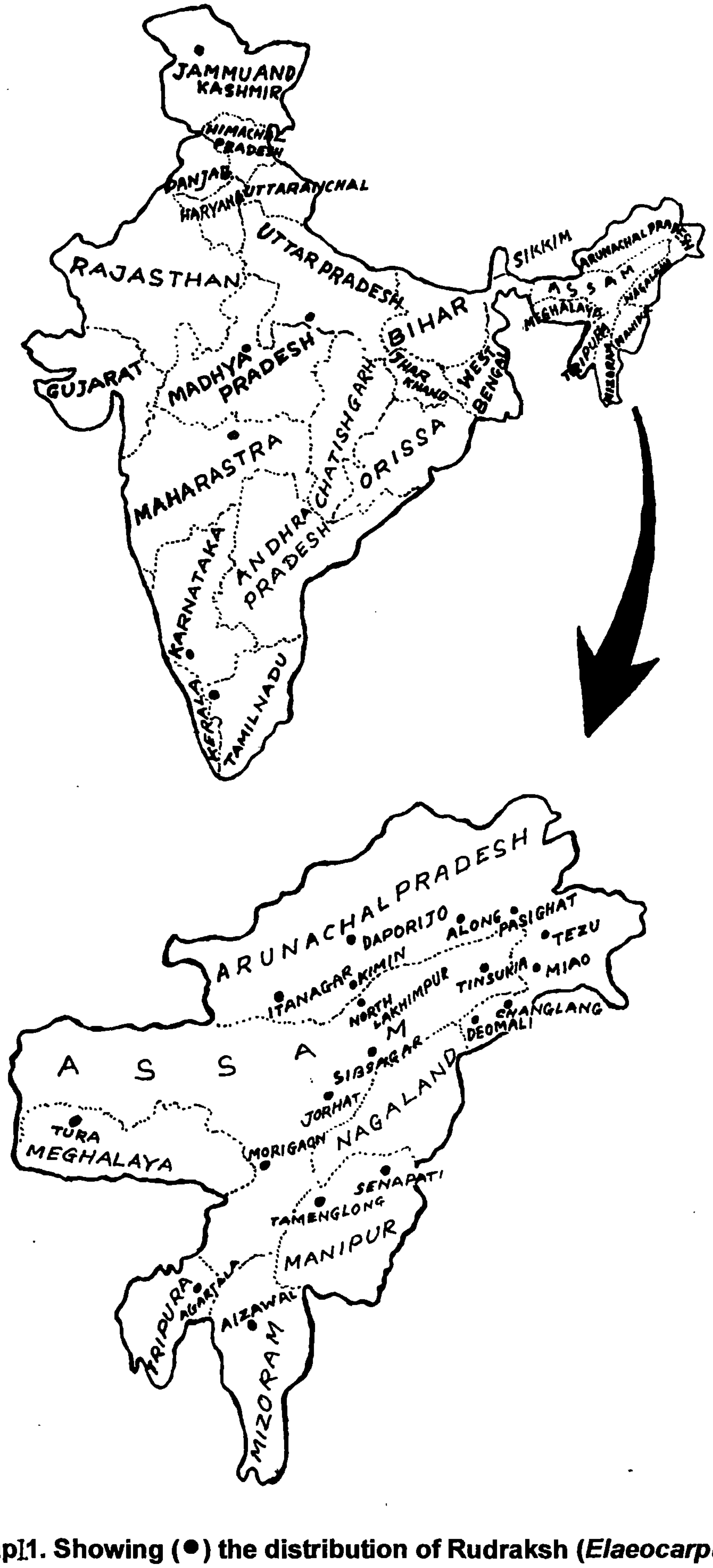
Rudraksh beads can be of the size of small peas or as large as marble. These beads can be worn around the neck, kept in the pocket or purse, in cash box or places of worship or at various points in home. Rudraksh brings good luck, health and many material comforts. When kept under pillow, it induces sound sleep, pleasant dreams, mental stability, better memory and happy feelings, stabilizes the blood pressure etc. (Hazarika 2001). Rudraksh should be worn after being fortified by specific mantras, which make it more effective. The Shiva Purana says that the Rudraksh protects a person from premature death, fulfill desire and bestows worldly pleasure and salvation forever. The Rudraksh improves health, protects from misfortune and planetary afflictions, brings purity and tranquility of mind; it also helps to relieve pain and is especially effective in high blood pressure, heart problems, epilepsy, cough, mental and gynaecological problems. Ghosts and evil spirits cannot withstand the power of the Rudraksh.

As per modern psychology, mind in many ways is governed by the brain, its neurons, neurotransmitters, endocrine glands etc. For example, low level of serotinin causes depression, worry, lack of energy, low self esteem and higher level of it causes happiness, energy, higher level of confidence and self esteem etc. Dopamine causes over-activity of neurons resulting in mental agitation, restlessness, tension, fear, lack of control etc. Conversely, decreased level of dopamine results in peace, tranquility, stability etc. Psycho-pharmacological drugs like tranquilizers and antidepressants etc. control the activities of neurotransmitters to effectively soothe mental disturbances. According to Suhas Roy (unpublished), Rudraksh beads have certain electromagnetic and inductive properties and when worn over the heart, they send out corresponding signals differing for different 'mukhis' to the brain, acting or controlling certain brain chemicals and neurotransmitters, thereby influencing the status of mind. For example, the mental agitation and dopamine level of those who wore 5 mukhi Rudraksh was found to be less and the serotinin level of those who wore 1 mukhi and 12 mukhi Rudraksh beads was found to be high. The activity of neurons in the right part of the brain was found to be high among the wearers of 14 mukhi Rudraksh beads (right part of the brain controls abstract and lateral thinking as against logical and structural thinking controlled by left part of brain). This perhaps, is the reason behind the change in personality and attitude of the wearers of different types of Rudraksh beads. When the person gets a positive confidant frame of mind, the impact goes deep into his subconscious mind sending out powerful vibrations thereby changing the way of nature and others reaction to him. He also takes quick decisions and frequently finds himself in right place at the right time. This is perhaps called 'luck'. What have been said in Vedic scriptures is increasingly being proved almost with 100% precision scientifically (from unpublished literature).

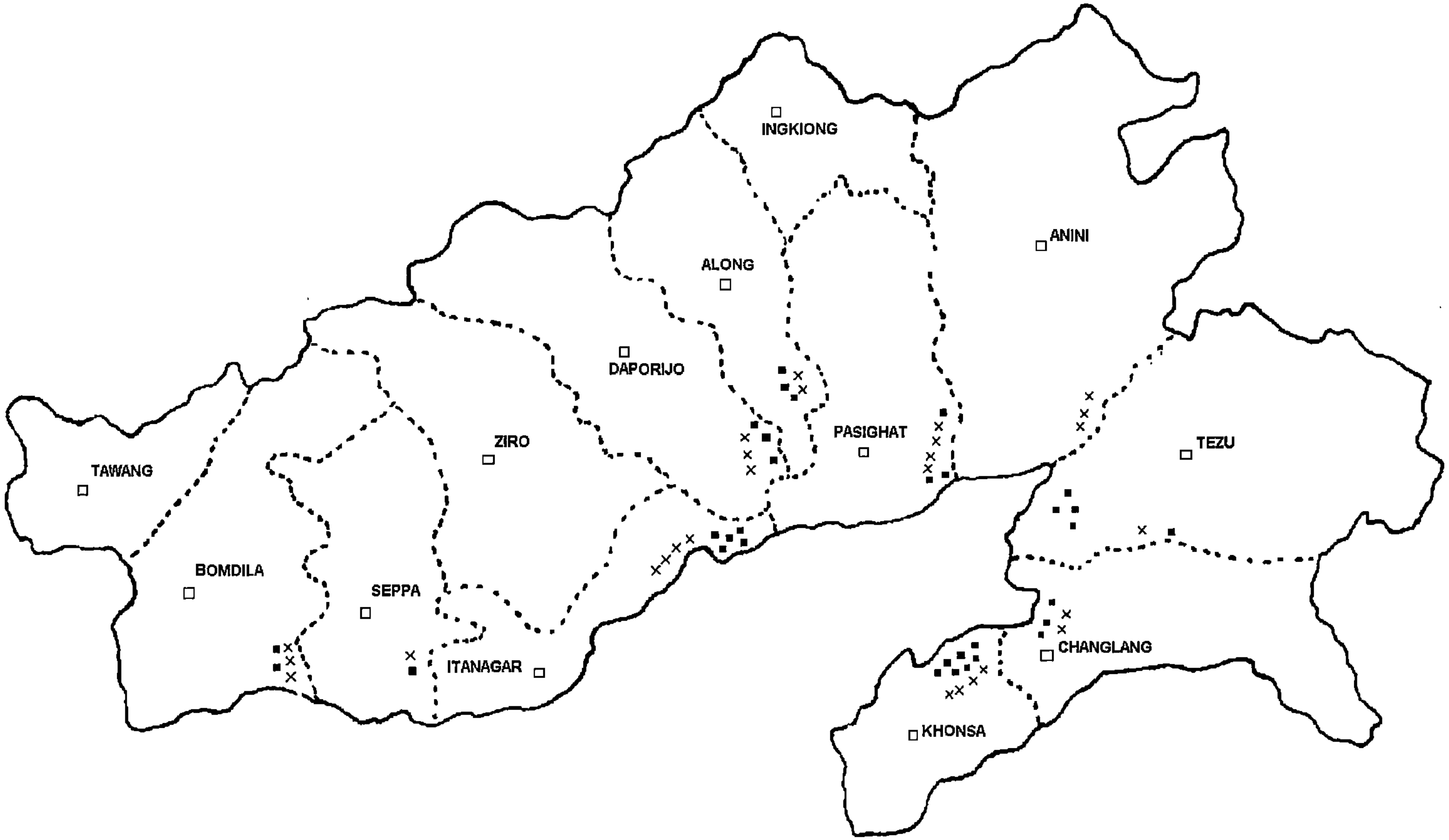
Elaeocarpus, a genus with about 360 species of Elaeocarpaceae family, contains hard and highly ornamental stony endocarp commonly known as 'Rudraksh'. Stony endocarp (nut) is used as religious jewellery in the form of beads throughout India and Southeast Asia (plate1.1). The sculpturing of the stony endocarp surface appears as faces, commonly known as 'mukhi', associated with the locules of the ovary, normally five in number. Nuts with fewer or more locules are due to abnormalities. Each locule houses a seed. Out of about 120 species of *Elaeocarpus* reported from different parts of Asia including Nepal, Bhutan, Sikkim, Tibbet, Java, Indonesia, foot hill of Himalayas and various parts of India, 25 species are found in different parts of India, such as Uttar Pradesh, Maharastra, Bihar, Madhya Pradesh, Assam, Arunachal Pradesh, Meghalaya etc (Map1.1). The Rudraksh tree occurs sporadically in all districts of Assam but is more frequent in Arunachal Pradesh. In Assam, Rudraksh is found in places like Charaideu, Digboi, Margherita, Dibrugarh, Jorhat, Golaghat etc. In Arunachal Pradesh it is common along the foothill of all districts except Tawang and Upper Subansiri and some other high altitude areas (Map1.2).

Kaul & Haridasan (1987) have classified the forest vegetation of Arunachal Pradesh into five broad types. Rudraksh is found in tropical evergreen forest which is characterized by three-tier forest structure. The emergent top canopy trees are straight boled with an average girth of 2-5 m and height of 40-50 m. They do not form continuous close canopy. Second story is composed of

Plate 1.1. Nuts of Rudraksh collected from the forests being sold in market (A, B & C) in different forms, and the beads are worn as sacred jewellery (D).



Map I.1. Showing (●) the distribution of Rudraksh (*Elaeocarpus ganitrus*) in India and North Eastern Region.



Map 2. Showing the distribution of natural (■) and planted (×) populations of Rudraksh (*Elaeocarpus ganitrus*) in Arunachal Pradesh.

other tree species, which occur gregariously to form a closed canopy ranging in height between 20-30 m. Rudraksh is usually present in this story. A few thin boled tree species occupy the lower level of the canopy as well.

However, tropical forests of Arunachal Pradesh are being modified and degraded due to increased anthropogenic pressure. The age-old practice of shifting agriculture is one of the potent factors changing the forest microenvironment and reducing the forest cover (Mishra & Ramakrishnan 1981, Ramakrishnan *et al.* 1981, Kushwaha & Ramakrishnan 1987). The 'jhum' cycle has been shortened as a result of population pressure, diversification and consequent shrinkage in available land area for agriculture due to logging activities (Ramakrishnan 1985). Accelerated search for new timber resource for industrial purposes is another cause of forest exploitation. Improved technology, pattern of forest resource use and infrastructure development have widely increased the effective wood harvesting and land clearing activities. It is believed that if the present trends continue and effective conservation measures are not implemented, most of the still existing forests will be destroyed or replaced by degraded communities (Thapliyal 1991, Beniwal & Haridasan 1992a, b, Menon *et al.* 2001). Rudraksh population in the natural as well as planted forest stands has been decreasing day by day due to household and other industrial uses. Moreover, nut collection for beads has caused the shrinkage of the seed bank in the soil, which has adversely affected the regeneration of the species. Thus the species is being pushed to the threatened category (Rao & Haridasan 1983). The species flowers during May to June and fruits ripe during November to December. The ripe fruits are blue in color. The fruits are consumed and dispersed by large birds. The fruits are consumed as a whole and the endocarp is passed through the digestive tract. Sometimes small birds partly stripe the fleshy exocarp. The exocarp is rich in carbohydrates and proteins and provides nutritious reward to consumers (Lee 1998). The species bears very low regeneration power and mainly reproduces through seeds.

Rudraksh is a fast growing species and has been included under the social forestry programme of Arunachal Pradesh and has been planted along roadside, in institutional premises, as small forest pockets etc. Many pockets of Rudraksh plantation can be noticed in various parts of the state. Many forest nurseries are engaged in raising the seedlings of this species to meet the requirement of various types. However, the germination of Rudraksh is very poor and erratic, and so it is a difficult task to raise the seedlings in nursery.

Although certain aspects of Rudraksh such as its biology (Lee 1998), chemical properties of nuts (Dutta & Mathur 1992), taxonomy of the species (Mitra *et al.* 1992), medicinal and aesthetic values (Sayani 1999, Hazarika 2001), and biochemical properties (Das *et al.* 2000) have been studied to some extent, there is a conspicuous lack of studies on fruit/nut production, dispersal and regeneration of the species. Thus a study on regeneration of Rudraksh (*Elaeocarpus ganitrus* Roxb.) was undertaken.

The present study focusing on the regeneration of Rudraksh (*Elaeocarpus ganitrus*) covers the following aspects:

1. Quantification of the population stock of Rudraksh in different forests of Arunachal Pradesh.

2. Study of the phenological events of Rudraksh in fragmented and undisturbed forests.

3. Investigations relating to the natural dispersal mechanism of Rudraksh (*Elaeocarpus ganitrus*) in fragmented and undisturbed forests and to find out as to how this dispersal mechanism has been changed/modified in response to human induced disturbances such as deforestation and harvest of nuts.

4. The determination of the nut bank in fragmented and undisturbed forests.

5. Evaluating the fitness components of the species (e.g. seed germination, seedling growth, seedling establishment and vegetative propagation etc.).

The '***General Introduction***' which sets out the objectives of the thesis is followed by the '***Review of Literature***' ***(Chapter I)***, which is followed by ***Chapter II*** on the climate, soil and vegetation of the study sites. The experimental data on various aspects mentioned above have been presented in ***Chapters III –VIII***. Each chapter has been provided with a separate discussion. In addition to this, the results contained in various chapters have been discussed in an integrated manner under '***General Discussion***'.

CHAPTER I

Review of Literature

Forest resources are renewable only because they do regenerate. The pace at which older trees are replaced by younger ones is very much important in this respect. Regeneration dynamics, therefore, is one of the thrust areas of study in the management of natural forests. The very birth of the science of forestry owes to the interest in regeneration studies. The colonial powers in India were very much in need of teak for shipbuilding. Shortage of teak and the need for its continuous supply led to the raising of first teak plantations in India and Burma (Stebbing 1922). This tradition of artificial regeneration and domestication of forest trees is well established as plantation forestry. Literature on this subject is enormous and has been precisely reviewed by Libby (1973) and Seymour *et al.* (1986).

While plantation forestry is an alternative measure to increase the turn-over of yield of desired species, it has the demerits of monocultures. Epidemic diseases and outbreak of pests are always associated with it. Moreover, plantations modify the natural vegetation completely. This led to the concept of managing the natural forests, keeping their original structure and diversity intact using the techniques of natural regeneration. The recent trend in forest management research centers around the concept of sustainable management of multiple resources conserving the rich natural diversity (Bawa & Krugman 1986). Precise knowledge of the intrinsic structure of the dynamics of ecosystems is a *sine qua non* in developing practical methods for sustainable management. Thus, research with the aim of acquiring basic information on ecosystem dynamics has been conducted in various parts of the world (Bawa 1974, Frankie *et al.* 1974a, 1974b, Janzen 1978, Bawa 1979, Chan 1981, Leigh *et al.* 1982, Bawa 1983, Sutton *et al.* 1983, Johnkers & Schmidt 1984, Bawa *et al.* 1985a, 1985b) and the process is continuing. Regeneration is the process of sylvigenesis (=forest building; cf. Halle *et al.* 1978) by which trees and forests survive over time. Unlike homogeneous artificial plantations, management of natural forests relies largely on natural regeneration. Successful management therefore depends on good natural regeneration of valuable species. The final goal of these research programmes on regeneration dynamics of forest should be to evolve methods to harmonize the rates of exploitation and regeneration. The practice of natural regeneration over many decades has contributed a vast store of know-how of silvicultural practices in forest management (Nair 1961, Nair 1986). Many international forums are making efforts to develop suitable methods for practicing the concept of sustained yield in forestry (UNESCO 1975) and the subject of natural regeneration is receiving increasing attention. In fact artificial regeneration, natural regeneration, and the sustained yield concept are three phases of development in the history of forestry.

Both foresters and ecologists have contributed to the knowledge of regeneration dynamics of natural forests. Regeneration dynamics have been studied in both unmodified and modified forests of different latitudinal, longitudinal, altitudinal and typological specifications (Brooks 1941, Ayliffee 1952, Holmes 1956, Webb *et al.* 1972, Murray 1981, Kahn 1982, Heuveldop & Neumann 1983, Burschel *et al.* 1985, Venning 1985, Veblen 1989, Oliver & Larson 1990, Harmer 1994, Restrepo 2001, Ganesan *et al.* 2001, Chazdon 2001, Peart *et al.* 2001, Pinard & Swaine 2001, Davies *et al.* 2001, Ratsirarson *et al.* 2001, Connell & Green 2000, 2001, Rocha *et al.* 2001, Boraiah *et al.* 2001, Shukla & Pandey 2001). Regeneration studies on selected species and specific categories of taxa are also numerous (Watt 1919, 1923, Khoon 1981, Newbold *et al.* 1981, Chaconsotelo 1983, Dimitrov 1984, Daly & Shankman 1985, Drapier 1985, Melnik 1985, Morin 1986, Szappanos 1986, Bernier 1987, Everard 1987, Sinha & Bawa 2001, Graham *et al.* 2001). Nair (1961) has brought out a detailed review of the literature concerning the various aspects of natural regeneration. Nair (1986) has given a concise account of the silvicultural systems associated with natural regeneration. Fox (1976) has made a categorical review of constraints of natural regeneration. The vast store of literature on natural regeneration differs markedly in its content as are the forest types themselves, and the factors and the processes involved in regeneration. Effects of disturbance levels on regeneration of trees have been studied at stand (Enright 1978, Khan *et al.* 1987, Woods 1989, Clark 1990, Guariguata 1990, Brokaw & Walker 1991, Boucher *et al.* 1994, Soerianegara 1994, Kneeshaw & Bergeron 1996, Barik *et al.* 1996, Carlton & Bazzaz 1998, Miller & Halpern 1998, Uma Shankar *et al.* 1998a, b, Nicotra *et al.* 1999) as well as species (Lavertu *et al.* 1994, Sato *et al.* 1994, Herranz *et al.* 1997, Rikhari *et al.* 2000) level. A few studies have been carried out to understand the effects of fragmentation on regeneration of tree communities (Laurance 1991, Sizer 1992, Eseen 1994, Murcia 1995, Ferreira & Laurance 1997, Laurance 1997, Laurance *et al.* 1997, Viana *et al.* 1997, Bruna 1999). Gap-phase regeneration has been studied by Barden (1979, 1980, 1981), Runkle (1981), Brokaw (1985a, b, 1987, 1998), Lawton & Putz (1988), Lorimer *et al.* (1988), Canham *et al.* (1990), Phillips & Shure (1990), Clinton *et al.* (1993, 1994), Rao *et al.* (1997), Fraver *et al.* (1998). Brokaw & Busing (2000) reviewed the gap dynamics and stated that a few studies which were unprecedented in scale, detail or approach showed that niche partitioning contributed less, and chance events were more important than expected to maintain tree species richness via gap dynamics in tropical and temperate forests. Some tree species are differentially adapted for regeneration in different gap microenvironments. The stochastic availability of gaps, and limited recruitment of juveniles indicate that gaps are filled mostly by chance occupants rather than by best-adapted species. Such chance survival can show competitive exclusion and maintain tree diversity. Gap dynamics do not explain the latitudinal gradient in tree richness. Forest management modifies, directly or indirectly, the physical environment, affecting regeneration (McCarthy & Facelli 1990, Smith & Vankat 1991, Wagner & Zasada 1991). Gobbi (1999) analyzed the impact of different forest management treatments on regeneration of *Austrocedrus chilensis*, an endemic conifer from South America.

All populations are under the flux of two vital, but opposite processes, viz. growth and death. Regeneration leads to increase in population number (Krebs 1972). Different kinds of organisms have different kinds of regenerative strategies (Grime 1979). Of these, forest trees by and large have seed-based regenerative strategies (i.e. by genets) although some species also show a certain degree of vegetative regeneration (i.e. by ramets). The establishment of a young forest stand by means of natural regeneration involves a chain of biological processes occurring over several years, all of which are affected by environmental conditions to various degrees. This has been summarized schematically in Figure I.1.

Climatic conditions together with stand characteristics and site fertility play an important role in influencing the processes of initiation of flowers, flowering, fertilization, seed and fruit ripening and seed dispersal involved in the regeneration of forest trees. There are several biological constraints on seed production that vary between years and sites (Owens 1995). Once the seeds are dispersed, conditions in the soil and on the ground surface, in combination with climate, will largely determine the subsequent development of seeds, seed germination and seedling growth. Booth (1984) emphasized the importance of the combined effect of many environmental factors and considered the sufficient seed supply, a suitable seedbed, favourable climatic conditions and protection from damaging agents to be the basic prerequisites for successful natural regeneration. Important aspects related to processes and phases of natural regeneration are reviewed hereunder. A number of reviews on the subject are already available (Nair 1961, UNESCO 1978a, b).

Adequate seed supply, effective dispersal, good viability and longevity of seeds, successful establishment of seedlings and good conversion to mature trees are all neccessary for a sustainable forest regeneration. All these attributes are influenced by the environmental conditions. The characteristic regeneration pattern of individual tree species and forest types are therefore, the compromises between

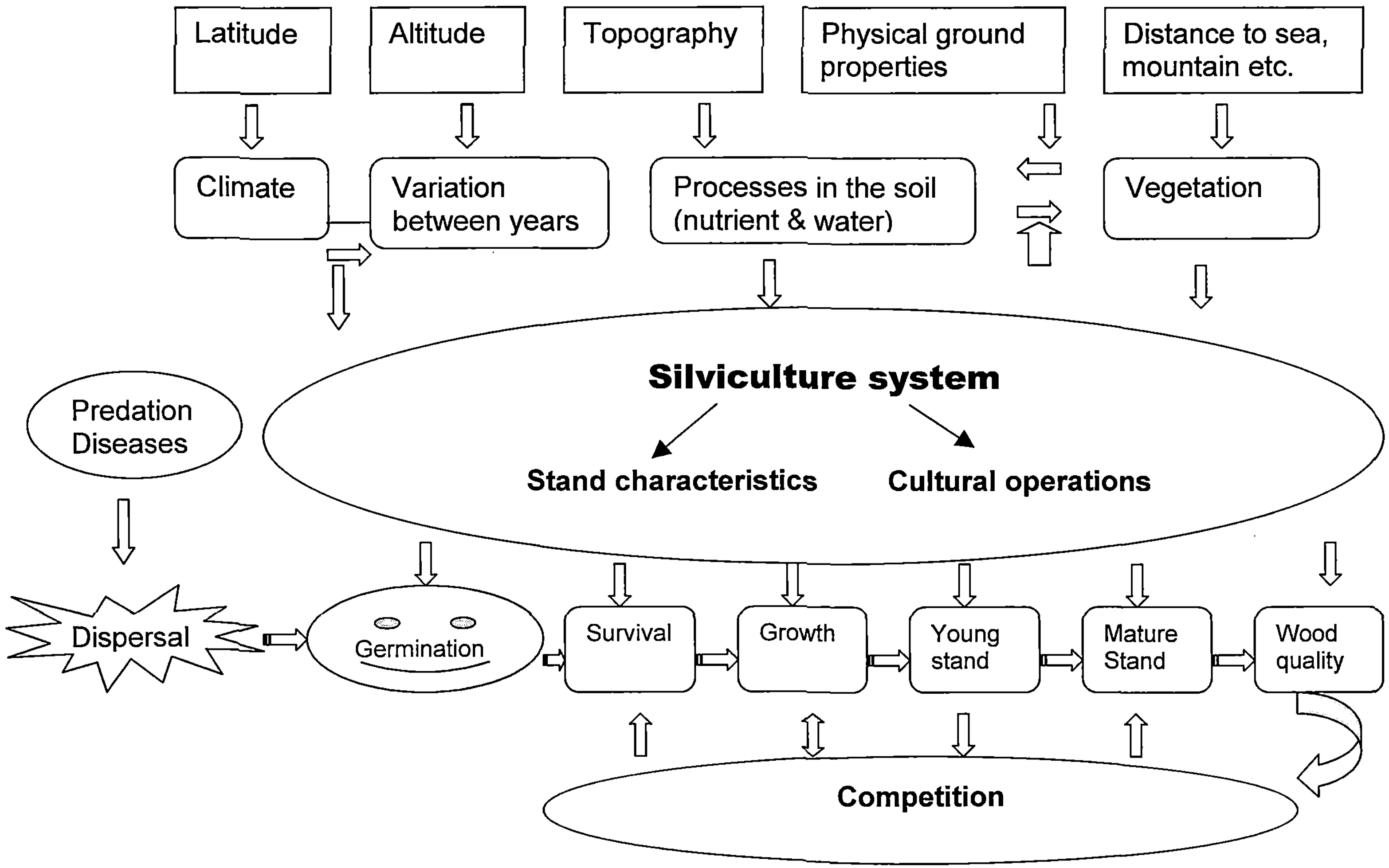


Figure I. 1. Summary of environmental influences on the establishment of naturally regenerated forests.

the real regeneration potential and the pressure offered by the environmental constraints (Fox 1976).

Trees are perennials with long life span extending over hundreds of years. The long-term studies relating to the population behaviour of tree species by following the life history of individuals in a given population of any given species or forest type are totally lacking. The tree size reflects its age and therefore, size structure of population proxies the dynamics of size conversions in the past. To certain extent it also tells about the future of the stands (Buell 1945, also cf. Harper 1977). Oliver and Larson (1990) have reviewed the subject of forest stand dynamics thoroughly. Seth (1974) has refined the mathematical tools for the study of forest stand dynamics. Distribution of diameter classes is the most studied parameter. Nevertheless comparison of data is very much difficult owing to differences in the lower size limit, the class intervals and units of measurement (UNESCO 1978a) or because of limiting measurements to certain classes. Size (diameter) class distributions were studied in most forest types, viz., lowland and montane evergreen forests, semi deciduous forests, dry deciduous forests, mangrove and swamp forests (Beard 1946, Rollet 1952, 1962, 1974, Dawkins 1958, Anderson 1961 etc., cf. UNESCO 1978a). Each forest type shows wide variability in stand structure. Some forest types are richer in large stems (>60 cm dbh) than others (Rollet 1962, Nicholson 1965, 1988, Pierlot 1966), owing to the behaviour of certain species and partly due to the history of stands. In some gregarious Dipterocarp forests this may be due to mast seed years.

Forest structure always tends to be exponential especially in a semi-logarithmic graph (UNESCO 1978a). When the limit of size class goes further and further down, the graph develops a concavity thus diverging from the exponential model. According to the exponential model the sum of stems larger than a given diameter is equal to the number of stems in the immediate lower class. If the survival probability is greater than 0.5, the conversion from one class to another increases (Wyatt-Smith 1963). Meyer (1952) theorizes that structure of forests over any large area approaches a balanced condition where the quotient of population size in two successive size classes approaches a constant value. This ideal state is never observed although stands tend towards it (Harper 1977). Moreover the situation can be very much worsened by disturbance, which results in broken lines in graphs (UNESCO 1978a). Population structure of most tree species shows strongly skewed L-shaped graphs while others show an exponential model. Some erratic species show normal distribution. Semi-logarithmic graphs show upward or downward concavity indicating sharp decrease in the survival probability of lowermost or uppermost classes (Krebs 1972, UNESCO 1978a). Yoda *et al.* (1963) have proposed the self thinning rule for even-aged single-species populations. According to this rule, individuals get eliminated owing to limitations of space and mass, due to overcrowding (Westoby 1984). Bazzaz and Harper's (1976) arguments extend the applicability of the rule to mixed-aged and mixed species stands. White (1974, 1975, 1980) has extended the rule to forest stands, explaining mortality and population structure.

Many workers have suggested the predictive regeneration models to predict the future size distribution of trees, growth and yield of forest stands. Dey *et al.* (1996) described a method for modeling the regeneration of even-aged oak stands. Their approach was based on a growth model that was applicable to both oak sprouts and advance reproduction and a method for probabilistically estimating future size distribution of trees. Regeneration status of trees can be predicted by the age structure of their populations (Saxena & Singh 1982, Saxena *et al.* 1984, Khan *et al.* 1987). The population of seedlings and young trees in a given population indicates the status of regeneration. Age structure and regeneration of trees in forest ecosystems are strongly influenced by burning, clear felling, logging and grazing. Khan *et al.* (1987) reported that population structure in the undisturbed stand (sacred grove) was an inverted pyramid (i.e. large diameter individuals were greater in number than small diameter individuals) while in the disturbed stand population structure was upright pyramidal. Maram & Khan (1998) have investigated the regeneration status of various categories of forests by studying the population structure of trees. Nautiyal *et al.* (1997) analyzed the vegetation pattern in alpine zone of the north-west Himalayas and reported that the species distribution among different stands was contagious and random. Bhandari *et al.* (1997) analyzed the forest community structure in the Garhwal Himalayas and reported that *Pinus roxburghii* was the dominant species on different slopes. Johnston & Gillman (1995) studied tree population in low diversity forests of Guyana and discussed the mechanisms of competitive interactions associated with species dominance in relation to mycorrhizae and persistence of species dominance.

Sundriyal *et al.* (1994) studied tree structure, regeneration and woody biomass removal in subtropical forest of Mamlay watershed in Sikkim Himalayas and observed good regeneration potential with 5474 seedlings/ha and 1774 saplings/ha but the population structure revealed a marked reduction in population of trees of higher diameter classes. Sundriyal & Sharma (1996) further studied the effect of anthropogenic pressure on tree population structure and regeneration in temperate forest of Mamlay watershed and reported high diversity of tree species. However, out of 81 tree species growing in Mamlay watershed, only 39 were found regenerating and most of the canopy species showed poor regeneration. Many studies have been carried out to study the tree composition, population dynamics and regeneration status in different types of forest ecosystems (Rao & Singh 1986, Ashton & Hall 1992, Singh *et al.* 1994, Halpern & Spice 1995, Cao *et al.* 1996, Brokaw *et al.* 1997, Parthasarathy & Karthikeyan 1997a, Kammesheidt 1998, Uma Shankar *et al.* 1998a, b), Parthasarathy 1999, Pandey & Shukla 1999, 2001, Bhuyan *et al.* 2001, Boraiah *et al.* 2001, Baker 2001, Gunatilleke *et al.* 2001). Species-specific studies on population structure and regeneration status have also been carried out. Beniwal and Haridasan (1992b) investigated the natural distribution, regeneration and growth statistics of poplars in Arunachal Pradesh and reported that natural regeneration in poplar species is very good in subtropical and temperate forests. Regeneration is good on exposed freshly turned soils, land slips, etc. Beniwal and Haridasan (1992a) have also studied the natural distribution and regeneration status of gymnosperms in Arunachal Pradesh. Parthasarathy & Karthikeyan (1997b) compared the population structure of *Grewia pandaica*, a rare and endemic tree species, in two forest stands of south-west India, and reported that population structure was discontinuous with several empty size classes. Mean density of adult trees in the study sites was 3 individuals per hectare. Ajit & Parthasarathy (1998) have made a comparative study of the populations of *Cinnamomum malabatrum* in two Shola forests of Southern India. Regeneration of sal (*Shorea robusta*) in relation to disturbance magnitude has been studied by Pande (1999) in some sal forests. Nagarajan *et al.* (2001) have studied the ecological adaptations and population structure in teak (*Tectona grandis*). Many other studies have been carried out on the population structure and regeneration status of individual species in relation to biotic and abiotic factors (Hett & Loukes 1976, Solbrig 1981, Clark & Clark 1987, Itow & Mueller-Dombois 1988, Primack & Lee 1991, Fensham & Bowman 1992, Oyama *et al.* 1992, Forget 1991a, 1992a, 1994, 1997a, Forget 1997b, Forget *et al.* 1999b, 2001a).

Studies on tree phenology abound in the tropical literature, but their application to forest management issues appears to be rare. In the tropics flowering and fruiting of forest trees are quite irregular. It is well known that at the community level, seasonality in flower and fruit production is the rule in most tropical wet and moist forests (Frankie *et al.* 1974a, b, Foster 1982, Carabias-Lillo & Guevara-Sada 1985). At the species level, reproductive phenology varies from continual to supra-annual (Newstrom *et al.* 1994), while at the population level, reproductive output is highly variable due to fluctuations in the density of flowering individuals (Murawski & Hamrik 1991, Hall *et al.* 1996). It is common that a few trees make a disproportionately high contribution of the total seed crop and seedling recruitment in any given year (Schupp 1990, De Steven 1994, Forget 1996, 1997b). These irregularities affect regeneration. Adequate tree dispersion in space appears necessary to ensure seed supply if inter-annual variability in seed production is high for a given species, unless this is partially compensated by logging and/or silviculturally mediated phenological changes. So the logging operations are to be based on the flowering and fruiting behaviour of the important tree species (Nair 1961, Borchert 1980, Dhamanijayakul 1981, Guariguata & Pinard 1998, Jayappa & Kumar 2001). Bawa (1983) has made a brief review on flowering phenology of tropical plants. Flowering phenology of many forest trees, especially the evergreen forest, has been studied in the tropics (Holttum 1931, Holmes 1942a,b, Koelmeyer 1959, Pinto 1970, Medway 1972, Ng & Loh 1974, Cockburn 1975, Ng 1977, 1981, Brokaw 1998, Davies & Ashton 1999, Cunningham 1994, 1997a, 2000a). Flowering phenology of a few ecosystems in toto had also been studied (Lee 1971, Frankie *et al.* 1974a,b, Augspurger 1983a, Van Schaik *et al.* 1993, Bochert 1994, Stranghetti & Ranga 1997, Datta & Rawat 2001, Ssnchez-Azofeifa & Kalacska 2001, Somanathan *et al.* 2001). Flowering includes floral bud initiation, development, blooming and floral persistence (Bochert 1983, Rathcke & Lacey 1985). In a broader sense it also includes the study of breeding systems including floral biology. Of these, bud initiation, development and blooming are subjects of interest to physiologists and except for a few crop trees, forest trees have not been studied in this respect. All the trees do not flower and fruit in the same manner. Variation exists in frequency, time and duration of flowering and fruiting. It also varies with species, populations and ecosystems, and according to the climatic conditions

(Bawa 1983, Primack 1985). The Costa Rican forests show a bimodal distribution of flowering frequencies (Baker *et al.* 1983). Flowering patterns have been studied by Reich & Bochert (1984), Kress & Beach (1994), Newstrom *et al.* (1994) etc. The South East Asian Dipterocarps flower synchronously once in 5-13 years. This phenomenon is commonly termed as gregarious flowering (Medway 1972, Janzen 1974a). In most other trees annual flowering is common. Periodicities between these extremes are also known.. Flowering phenology in Dipterocarp forests has been studied by many workers (Ashton *et al.* 1988, Momose *et al.* 1998, Sakai *et al.* 1999).

One of the principal characteristics of flowering phenology in tropical forests may be the high diversity partly due to weaker physical constraints on the schedules of biological activities. Gentry (1974) was among the first to indicate the existence of high diversity in phenology among species within a tropical forest, and to discuss its significance in relation to pollination systems. Recently, Sakai (in press) also suggested diversity in phenology among tropical forest communities. Since favourable flowering patterns for pollinators are different depending on pollinator groups, flowering phenology and pollination systems are thought to be correlated with each other (Sakai 2001). These phenological patterns are very much related to competition of pollinators, pollinator activities and selection for life history traits (Bawa 1983, Primack 1985, Cunningham 1991, 1995, 1996, 1997b, Gross 2001, Ganesh *et al.* 2001, Frankie & Vinson 2001).

Rapid human modification of landscapes may disrupt the loose mutualistic relationships between plants and their pollinators and may cause declines in plant reproduction (Kearns & Inouye 1997, Kearns *et al.* 1998, Murcia 1996, Rathcke & Jules 1993, Quesada *et al.* 2001). This concern has led to warnings of an impending scenario of crop failures and species extinctions (Allen-Wardell *et al.* 1998, Buchmann & Nabhan 1996). The pollinator crisis scenario warns that habitat destruction is reducing the abundance of pollinators, causing a decline in the rate plants are pollinated in fragmented sites that will, in turn, lead to lower fruit or seed production. Recent research on fragmented plant populations has demonstrated that this process does indeed pose a plausible threat (Steffan-Dewenter & Tscharntke 1999, Cunningham 2000 b, c, Ghazoul *et al.* 1998).

Fruit set includes fruit initiation, growth, ripening, fruit fall and the availability of fruits/seeds to dispersers (Rathcke & Lacey 1985). Janzen (1978) made a detailed review of seeding patterns for tropical trees. Generally flowering periodicities are reflected in fruiting. But, a tree flowering profusely need not always fruit. Size of the seed crops of any given individual for any two years need not be the same (De Viana 1999, Khan *et al.* 1999, Khan & Uma Shankar 2001). In *Hymmenaea courbanil* (Fabaceae) although flowering takes place annually, fruiting is abundant only once in five years (Swarupanandan & Sasidharan 1992). Abortion of flowers and immature fruits ranging between 1 to 100 percent has been recorded (Bawa *et al.* 1985a, b). In the West African *Parkia capertoniana*, out of approximately 2000 fertile flowers only 4-5 develop into fruits (Baker and Harris 1957). The number and quality of the seeds produced may be limited by external or internal plant factors, which may vary over space and time. Plants may adjust resource allocation to seed production by altering the number of flowers, the number of ovules per flower, the number of aborted fruits and seeds, and the mass of the mature seeds (Lee 1988, Stephenson 1981, 1984, 1992, Cunningham 1996). Both the magnitude and pattern of these traits is known to vary in response to environmental conditions (Silvertown 1989, Stephenson 1992, Felfili *et al.* 1999). Intrinsic factors such as age, vigour of the tree and its genetic constitution (Winn & Werner 1987, Brokaw 1998) may also significantly affect fruit production. The fruit production may differ among populations of the same species on spatial and temporal scale and again individual trees within a population may also vary in fruit set (Howe 1982, Grubb 1977, Schupp 1990, Barik *et al.* 1996, Khan *et al.* 1999). Grubb (1977), Clark & Clark (1987), Barik *et al.* (1996), Khan *et al.* (1999) in shade-tolerant species and Milton *et al.* (1982), De Viana (1999) in light-demanding pioneer species have recorded such variations in fruit production. Most hypotheses suggest that resource limitation is the main cause of yearly variation in fruit production in trees (Mouselise & Goldschmidt 1982, Fenner 1991). Mathews (1963) and Wright *et al.* (1999) argued that elevated fruit production consumes reserves and limits future production in many fruit and timber trees. A few environmental attributes like prolonged depression of minimum night temperature, increasing length of dry season and a dry sunny year following a wet year may induce heavy fruiting in many tropical tree species (Ashton *et al.* 1988, Van Schaik *et al.* 1993, Wright *et al.* 1999). Further, extrinsic factors such as rainfall, hailstorm and wind speed, particularly during flowering season, may significantly affect fruit production (Felfili *et al.* 1999, Khan *et al.* 1999). The fruit production is also known to be influenced by forest fragmentation (Barik *et al.* 1996, Ghazoul *et al.* 1998, Guariguata & Pinard 1998, Cunningham 2000b, c, Hamrick 2001). The predator-seed crop relation has been studied in some detail (Cunningham 1997b, 2000a, Curran & Leighton 2000a, b). Janzen (1974a, b) argued that mast seeding in Dipterocarps is a result of predator satiation achieved by individual trees. The time taken by fruits and seeds to mature varies from few weeks to several months (Ng & Loh 1974). Time of ripening of fruits and seeds are correlated with the zoochorous dispersal in some trees (Smythe 1970).

Indian literature on forest tree phenology is extremely sparse. Nevertheless a few studies are available on the subject (Krishnaswamy & Mathuada 1960, Kaul & Raina 1980, Boojh & Ramakrishnan 1981a, Khosla *et al.* 1982a, Shukla & Ramakrishnan 1982a, Shrivastava 1982, Ralhan *et al.* 1985, Prasad & Hegde 1986, Basha 1987, Swarupanandan & Sasidharan 1992, Murali & Sukumar 1993, Barik *et al.* 1996, Khan *et al.* 1999, 2002, Datta & Rawat 2001, Jayappa & Kumar 2001).

Dispersal of seeds from the parent to the ground surface is an important stage in the life history of a plant which influences not only the recruitment patterns on a spatial and temporal scale but also the structure and dynamics of a plant community (Sinha & Davidar 1992). Seed dispersal is advantageous to plants in many ways. Seeds must move away from the parent plant to reduce mortality by predation, attack by pathogens, and seedling competition for resources (escape hypothesis; Janzen 1970). The place of production of seeds does not have the carrying capacity to grow and sustain all of them (Gadgil 1971). Thus, dispersing seeds even at the danger of causalities avoid competition. Further, considering that habitats are bound to change in time, the plants need to disseminate their seeds widely enabling them to colonize new sites resulting from habitat disturbances/forest fragmentation (colonization hypothesis; Howe & Smallwood 1982). A number of investigations have shown that the distance from source populations is important in determining the establishment and persistence of a species (see Quinn *et al.* 1994). In wet forests seeds of more than 50 percent of the trees are dispersed by sarcochorous means (eaten by animals, Danserau & Lems 1957), while, the dry forests show a greater percentage of wind dispersal (Baker *et al.* 1983). It has been suggested that the dispersal ability is one of the main factors in preventing angiosperms from modifying their distributions in response to climate change (Primack & Miao 1992). The dispersal agents and fruit characteristics determine patterns of fruit dispersal. Janzen (1970) and Connell (1971) were the first to propose that as seed density decreases with distance from the parent plant, seed survival increases and this may lead to higher recruitment at some distance from the plant. However, Hubbell (1980) argued that recruitment could be higher close to the parent because of considerably greater seed abundance there, despite very low seed survival. Seed dispersal away from the parent may not only reduce density and distance-dependent mortality near the adult (Janzen1970), but may also help in colonizing the clearing and gaps (Hamilton & May 1977, Augspurger 1983b, c). Many studies reveal a variety of ways in which fruit color, nutritional content, pulpiness, aroma, or presentation attract dispersal agents (Herrera 1981, Snow 1981, Janson 1983, Gautier-Hion *et al.* 1985, Howe 1985, Howe *et al.* 1985). Rapid disappearance of fruits of many tree species has been reported (Smith & Reichman 1984, Jensen 1985, Kikizawa 1988, Darley-Hill & Johnson 1981, Fox 1982, Kawamichi 1980) through the transportation and storage in caches by several animals e.g. blue jays, squirrels, chipmunks, mice, voles and rodents. Differences in seed dispersal patterns within the species might also result from variations in fecundity and morphological characters of fruit and seeds. Seed weight, seed surface area, morphology, rate of descent, and wing loading in wind-dispersed species can influence the pattern of seed fall around the parent tree and the density of dispersed seeds (Augspurger & Hogon 1983). Aerodynamic properties of wind-dispersed seeds may contribute significantly to dispersal distances and thereby may enhance survival of seedlings (Augspurger 1986, Morse & Schmitt 1985, Ganeshaiah & Uma Shaanker 1991, Sinha & Davidar 1992, Murali 1994). Further, the height of tree, wind speed and direction (Mair 1973), the surrounding topography and vegetation (Cremer 1965) and humidity (McEvoy & Cox 1987) may also influence dispersal. There are reports that light seeds maximize their dispersal efficiency by increasing wing loading in wind- and water-dispersed species (Augsperger & Hogan 1983, Ganeshaiah & Uma Shaanker 1988, 1991, Uma Shaanker & Ganeshaiah 1988, Uma Shaanker *et al.* 1988, Muralikrishna & Chandrashekar 1997) or pulp to fruit ratio in animal dispersed species (Howe & Vande Kerchkhove 1981, Uma Shaanker *et al.* 1988, Hedge *et al.* 1991).

Evolutionary plants have an obligate relationship with vertebrate animals, which eat their fruits, and either digest or disperse the seeds (Howe 1986). Moll & Jansen (1995) proposed that herbivorous turtles play an important role in dispersal and germination enhancement of endangered tambalacoque tree, *Sideroxylon* of Mauritius Island. Kubitzki & Ziberski (1994) stated that turtles, birds and monkeys played a secondary role to fish in seed dispersal. The role of elephants in seed dispersal of plants has been reported by many workers (e.g., Alexandre 1978, Brahamachary 1980, Gautier-Hion *et al.* 1980, Lieberman *et al.* 1987, White *et al.* 1993). Gautier-Hion *et al.* (1985) distinguished the fruit/seed characteristics as ruminant-rodent-elephant syndrome, and a bird-monkey syndrome, in fruits obtained from a tropical rain forest in Gabon. Yumoto *et al.* (1994) analysed the dung and feeding behaviour of apes and other mammals in Zaire and reported that there were several plants in eastern Zaire, which were dispersed only by elephants. Janzen (1970) reported that large seeds germinate into large seedlings with greater shade-tolerance and elephant creates suitable place for the germination of seeds and successful growth of seedling by disturbing the dense cover of vegetation. Howe & Primack (1975) found far higher densities of bird-dispersed *Caseria corymbosa* seeds under than away from two fruiting trees in Costa Rican rain forest. Salmonson (1978) and Clark & Clark (1984) reported that dispersal of seeds by birds for only a few meters resulted in drastic enhancement of seedling survival of *Juniperus monosperma* and *Bursera graveolens*. Hedge *et al.* (1991) reported that *Solanum pubesence* is dispersed by red-vented bulbuls and thus help in harvesting the seeds. Howe *et al.* (1985) found a decisive more than forty fold advantage to seed dispersal away from *Virola surinamensis* trees. Uma Shaanker *et al.* (1988) studied dispersal mechanism of *Croton bonplandianum* and reported that ants dispersed the species due to nectar gland activity. Horvitz (2001) studied six bird-dispersed species and one ant-dispersed species in the family Marantaceae in two wet tropical forests, in the Atlantic and Pacific lowlands of Costa Rica. He investigated four features of seed dispersal and seed ecology comparatively across plant species and sites: (1) the attractiveness of seeds to ants and birds, (2) the distance of dispersal, (3) disperser assemblages, and (4) the effects of gaps on seeds and seedlings. Ganesh *et al.* (2001) have studied the fruit dispersal in the wet forests of the southern Western Ghats of India and observed that six species of birds and 5 species of mammals were involved in dispersal or predation of seeds. Bird-dispersed species were the most common ones (60%) and 9 % were dispersed exclusively by large birds followed by mammal-dispersed species (26%); primates were less important than bats and civets. Fifteen per cent of the species had no apparent adaptation for biotic dispersal. Frugivory is a key process in the ecology of tropical forests. Fruits support a high proportion of the vertebrate biomass and the majority of woody plant species are dispersed by animals (Levey *et al.* 1994). Howe & Smallwood (1982) and Howe (1986) has made an elaborate review on ecology of seed dispersal and dispersal by fruit-eating birds and mammals. Corlett & Lucas (1990), and Corlett (1996, 1998a, 2001) has studied the seed dispersal by birds and vertebrate in the forest trees of Hong Kong. He has also reviewed the frugivory and seed dispersal by vertebrates in the Oriental (Indomalayan) region (Corlett 1998b). Many other studies (Wenny 2000, Fragoso *et al.* 2001, King 2001, McConkey 2000, 2001, McConkey & Drake 2001, Prasad *et al.* 2001) have been made on seed dispersal in different tropical forest ecosystems. Many workers (Roberts & Heithaus 1986, Kaufmann *et al.* 1991, Kaspari 1993, Levey & Byrne 1993, Chambers & MacMahon 1994, Bohning-Gaese *et al.* 1999) have emphasized the importance of secondary seed dispersal.

Sontos & Telleria (1994) have investigated the effect of forest fragmentation and argued that fragmentation decreases the dispersal agents, increase the seed consumption and result in reduction in dispersal and establishment. Vertebrates that depend on fruit for a significant part of their diet may, in turn, be vulnerable to changes in fruit supply resulting from deforestation and logging (Leighton & Leighton 1983). Wright *et al.* (2000) evaluated the hypothesis that poachers reduce the abundance of herbivorous mammals, and that this, in turn, alters seed dispersal, seed predation, and seedling recruitment for two palms (*Astrocaryum standleyanum, Attalea butyraceae*). However, Forget (1991b) and Ratiarison & Forget (2001) in their study on impact of forest fragmentation on frugivory and primary seed dispersal in French Guiana, have reported that there was no significant effect of forest fragmentation on seed dispersal and predation rates. They argued that the continuous area within the fragmented landscape that was used as a control could also have been disturbed, especially by hunting activity during the time of study.

Predation is an important factor controlling the viable seed population. After dispersal, seed predation is often extensive for tropical trees (DeSteven & Putz 1984, Howe *et al.* 1985, Chapman 1989, Hammond 1995, Cintra & Horna 1997, Peres *et al.* 1997, Wenny 2000). Predators can affect the seed population by feeding on photosynthetic tissues, flowers and directly on fruits and seeds. Both pre-dispersal and post-dispersal predation occurs. There are instances of up to 40% seed predation by rodents (Synnott 1973). In *Shorea ovalis* greater than 90% seed predation due to insects has been recorded (UNESCO 1978b). Generally predation decreases with distance from seed tree or with poor seed density. Janzen (1971a, b) suggested a 'predator escape hypothesis' according to which plants escape predation by satiating them (Howe & Smallwood 1982). Janzen (1970) and Connell (1971) were the first to propose that as seed density decreases with distance from the parent plant, seed survival increases and this may lead to higher recruitment at some distance from the plant. Seed populations may exceed the level of predator interest sufficiently to allow germination and establishment under the parent. This may be at the cost of producing large quantity of fruit crops to satiate the predators (Janzen 1971a, b, 1978). The seeds may escape predator threat by immediately germinating and building up a seedling bank (Grime 1979). Wright *et al.* (2000) have studied the impact of poaching of mammals on seed predation. Schupp (1988) studied the seed predation in the forest understory and treefall gaps. Curran and Webb (2000) coducted the experimental tests of the spatio-temporal scale of seed predation in mast-fruiting dipterocarpaceae. Predation in relation to seed size has been discussed by Foster (1986). Defense mechanisms in seeds against the predation have been discussed by many workers (Janzen 1969, 1971a, b, Bell 1984, Kiltie 1981, 1982, Shazali 1987, Kinzey & Norconk 1990, Smith 1990, Lucas *et al.* 1994). Seed collection from natural stands for various purposes also reduces the seed population from forest floor.

Seed dynamics play an important role in structuring and maintaining plant communities. Seeds sustain populations during temporarily unfavourable conditions, allow establishment in new areas, and can introduce novel genotypes to populations (Cavers 1983, Fenner 1985). All the seeds do not germinate as soon as they are dispersed. A good proportion of seeds are buried into the soil a few centimeters down. These form a 'seed bank'. Seed banks, in particular, are important in maintaining species and genetic diversity in communities and in allowing species to persist through disturbance or adverse conditions (Thompson 1992, Rees 1996). The existence of soil seed banks has been documented in many different plant communities (Fenner 1985, Leck *et al.* 1989, Thompson 1992, Thompson *et al.* 1997, 1998, Baskin & Baskin 1998, Halpern *et al.* 1999, Pugnaire & Lazaro 2000). According to whether or not viable seeds persist for more than a year, the seed bank of any plant species is classifed as 'transient' or 'persistent' (Thompson & Grime 1979). Persistent seed banks play a predominant role in habitats where disturbances such as fire, are frequent and unpredictable. Most studies of seed banks have concerned arable lands and sucessional fields (Thompson *et al.* 1997, Bekker *et al.* 2000 and references therein) where seed bank composition reflects historical land use and includes many weedy invaders and colonizers (Thompson & Grime 1979, Thompson 1992). While fewer investigations of forest seed banks have been made, it is clear that seed banks are important in forest regeneration and recovery after disturbance (Nakagoshi 1985, Pickett & McDonnell 1989, Mladenoff 1990, Hughes & Fahey 1991, Houle 1994, Peterson & Pickett 1995, Peterson & Carson 1996, Jankowska-Blaszczuk & Grubb 1997, Jankowska-Blaszczuk *et al.* 1998). Keay (1960), Roberts (1981) and Cavers (1983) have given the reviews of forest seed banks. Whitmore (1983) has discussed the secondary succession of seeds in tropical rain forests. There are few studies on seed banks of tropics (Symington 1933, Liew 1973, Hall & Swaine 1980) and of higher latitudes (Kellman 1970, Johnson 1975). Many studies indicate that seeds of dominant trees of the communities are either totally absent (Thompson & Grime 1979) in the soil or they are poorly represented (Karpov 1960). Generally the seed banks contain seeds of pioneer species. This non-correspondence of seed flora to the dominant tree flora is thought to be due to 1) immigration of seeds by bird dispersal, and 2) quick loss of viability of dominant trees (Roberts 1981). A few investigations of seed banks in forests of Pascific northwest have been made in older stands and recently clearcut sites (Kellman 1970, 1974, Archibold 1989, Ingersoll & Wilson 1989, Clark 1991, Mcgee & Feller 1993, Harmon & Franklin 1995). A few studies have been published on forest soil seed banks of broadleaved and pine forests in the Mediterranean basin (Trabaud 1994, 2000a, 2000b, Valbuena & Trabaud 1995, Ferrandis *et al.* 1999a, b, Nathan & Ne'eman 2000, Izhaki & Ne'eman 2000). Seed bank formation has been studied in some of the early successional (Hyatt & Casper 2000 and references therein) and old growth (Leckie *et al.* 2000 and references therein) in temperate deciduous forests.

Dispersed seeds generally show a period of rest termed 'dormancy' (cf. Harper 1977). To remain dormant for long period is the ability of seed to escape from unpredictable environment and climate (Fenner 1985, Tybirk 1991, Gutterman 1993). Further, hard seed coat has several other advantages that allows endozoic dispersal, recolonization after fire and helps the seeds to withstand unfavourable condition such as heat, drought, digestive juice as well as mechanical damage (Tybirk 1991). This also helps seed to remain viable for a long period in the soil waiting for the favourable conditions for germination (Coe & Coe 1987, Sabiiti &

Wein 1987, Tybirk 1991, Tybirk *et al.* 1994). Seeds of trees of mature phase in wet forest are generally not dormant (Tang & Tamari 1973) while those of other species extend from two weeks to 3 years (Mensbruge 1966). Most species of semi-evergreen forests lack seed dormancy (Hoi 1972). Seed dormancy is by far the chief factor determining the time of germination. Even in forests where there are two peak seasons of seed dispersal there is only one peak season for seed germination (Garwood 1983a), the peak being within the first two months of the rainy (wet) season. In tropical seasonal forests canopy species, lianas and the pioneer species show a unimodal pattern of germination. On the contrary, in case of understorey and shadetolerant species germination occurs throughout the rainy season, without a peak in any of the months (Garwood 1983b). Seedling emergence in canopy gaps peaks 1-6 weeks prior to that in shaded understories (Garwood 1983a). The conditions for germination and establishment of mature phase tree species are very much specialized (Gomez-Pompa *et al.* 1972). In the life history of a plant highest mortality rates operate between flowering and seedling establishment (Wyatt-Smith 1963). Mortality due to vagaries of rainfall, intense drought, herbivore predation and self-thinning are recorded (UNESCO 1978b). Seeds of many tree species do not germinate due to seed coat impermeability to water. Seeds of such species require some pretreatment to make the coat permeable and to enable them to germinate. Negi & Todaria (1995) reported that *Terminalia tomentosa* germinate quickly in naked endospermic condition. Todaria and coworkers have conducted several studies on pretreatments of seeds of tree species (e.g., Todaria & Negi 1992, Negi

& Todaria 1993, Todaria & Negi 1995, Negi & Todaria 1995, Negi *et al.* 1995, Chuahan *et al.* 1996).

It has been demonstrated by several workers that mechanical treatment and boiling/hot water treatment improve the germination in many tree species (Khan & Tripathi 1987b, Todaria & Negi 1992, Sneh Lata & Verma 1993, Negi & Todaria 1995, Ali *et al.* 1997, Demel Taketay 1997 and references therein). Hard seed coat impermeability which is a characteristic feature of many leguminous and non-leguminous species, may be viewed as a delaying mechanism that prevents germination under condition which might prove unsuitable for establishment (Ballard 1973, Rolson 1978, Cavanagh 1980, Tran & Cavangh 1984, Cavangh 1987, Baskin & Baskin 1989, Egley 1989, Tybirk 1991, Bist & Ahlawat 1999, Bisht *et al.* 2000). The critical objective in hard seeded species is to make the coat permeable to water by breaking dormancy and induce the germination. There are reports that acting only at specific weak areas rather than the whole seed coat can break dormancy. Structural and chemical factors responsible for water impermeability in seed are not well studied. However, most of the evidences indicate the continuous layer of tightly packed palisade cells in the nut/seed coat acting as the major barrier to water entry into the seed (Tran & Cavangh 1984, Cavangh 1987, Egley 1989). If structural weakness can be disrupted either naturally or by several specific treatments, seed coat becomes permeable to water. As soon as seed coatimposed dormancy is broken, seeds start absorbing water quickly indicating their adaptation to rapid intake of moisture after the rains (Jensen 1996, 1997, Demel Teketay 1997, Derkx & Joustra 1997, Jones *et al.* 1997a, b, 1998).

Survival and growth of tree seedlings are determined by the interactive influence of biotic and abiotic factors of the forest environment (Whitemore 1975, Gause & Stone 1979, Augspurger 1984a, b). The effects of certain factors such as light intensity (Whitemore 1975, Fetcher *et al.* 1983, Burton & Muller- Dombois 1984, Vance & Running 1985, Clark *et al.* 1996), soil moisture (Muller- Dombois *et al.* 1980, Lawrence & Ochel 1983), soil temperature (Wyant *et al.* 1983), soil nutrient (Van Den Driessche 1982, 1984), pathogen (Muller-Dombois *et al.* 1983, Augsperger 1984a, b, c, Augsperger & Kelly 1984) and burning (Abbott & Loneragum 1984, O'Dowd & Gill 1984) have been studied on seedlings in natural and controlled conditions. There is considerable difference in the responses of tropical forest tree species to irradiance, particularly in photosynthetic responses (Oberbauer & Strain 1984, 1986, Oberbauer 1985, Pearcy 1987, Turnbull 1991, Kitajima 1994, Chazdon *et al.* 1996, Press *et al.* 1996, Zipper & Press 1996) and relative growth rate (Coombe & Hadfield 1962, Okali 1972, Whitemore & Gong 1983, Pompa & Bongers 1991, Kitajima 1994, Agyeman *et al.*1999). In tropical rain forest, generally 1-2% of the radiation above the canopy reaches the forest floor (Chazdon 1988, Clark *et al.* 1996). Accordingly, growth rates of seedlings in the understory vary with availability of light. Khan and Uma Shankar (2001) have reported better growth and survival of seedlings of *Quercus semiserrata* in medium light conditions. However, many studies have shown better growth and survival of seedlings in sunny areas (Longman & Jenik 1974, Whitemore 1975, Hartshorn 1978, Lee 1978). Studies conducted by Augsperger (1984b) on tropical trees, Khan *et al.* (1986) and Rao *et al.* (1997) on subtropical trees, Sasaki & Mori (1981) on some Dipterocarpus seedlings have reported better growth and survival in sunny areas. Veenendaal *et al.* (1996) compared the growth of seedlings of 15 West African tree species at various light levels and reported that shadetolerant species showed higher relative growth rate at 16 to 27% of the light intensity, above which the growth rate declined. For pioneer species optimum growth observed between 26 and 100% light intensity in the field was the result of two components: (1) biomass production through growth and (2) biomass losses due to herbivory, mechanical disturbance and shading (Givnish 1988, Kitajima 1996). Coley *et al.* (1985) argued that the relative importance of these components differs between resource rich and resource poor habitats. In low light environment the second component is thought to be of overriding importance. Biomass loss is minimized by low leaf turnover (King 1994) and by allocating resource to the storage and defense. Trees, which are less prone to herbivory, are characterized by high leaf toughness and low inherent growth rate (Cornelissen *et al.*1998). Shade plants and shade tolerant plants allocate more resource to leaf production, giving rise to higher leaf area ratio, and lower root to shoot ratio or relative root mass. They may show greater activity in the apical meristem, leading to reduced branching and more slender stems (Poorter 1999). A recent review of variation in photosynthetic characteristics among tropical trees revealed considerable variation in photosynthetic capacity within early- and late- successional species groups (Strauss-Debenedtti & Bazzaz 1996). Growth traits of many tropical tree seedlings have been studied by Kitajima (1994), Meguro & Miyawaki (1997), Davies (1998), Agyeman *et al.* (1999), Poorter (1999) and several other workers. Guariguata

(2000) studied the seedling ecology of tree species in neotropical secondary forests and discussed the management implications. Toley & Shadangi (1993), Prasad & Mishra (1984) and Prasad *et al.* (1985) have studied the effect of nitrogen and phosphorus fertilization on growth and survival of tree seedlings and saplings in nursery and plantations.

The performance of seedlings of tropical forest tree species is influenced by a range of resources as well as physical aspects of establishment microsites (Brokaw 1987, Clark & Clark 1992, Rao *et al.* 1997, Becker *et al.* 1998). Maguire & Forman (1983) studied the effect of herb cover on the pattern of seedlings in a mature Hemlock-hardwood forest. Kitajima & Augspurger (1989) reported that the proportion of seedlings of *Tachigalia versicolor* killed by damping off disease was significantly higher near the parent trees. Davies (2001) investigated the mortality and growth in 11 sympatric *Macaranga* species in Borneo. Damage to seedlings by insect herbivory in forest stand is the result of complex interactions between the direct and indirect responses of both plants and herbivores to shading and other micro-environmental conditions. Coley (1983) and Coley *et al.* (1985) reported that insects preferred young leaves due to lack of toughness, and higher level of water and nitrogen.

Reproduction of forest tree species by vegetative means is very useful for the multipication of the species especially in the case of species with irregular seeding or producing stone fruits. Such fruits show erratic germination, which may cause the uncertainity in the production of seedlings in nursery for plantation. Stem or shoot portions are generally very good material for vegetative propagation because they usually have undifferentiated tissues, which may permit initiation of root primordia and also have buds already formed. Considerable attention has been paid by many workers in understanding the physiological mechanisms responsible for root formation in cuttings (Hill & Libby 1970). Various studies aimed at improving rooting techniques have involved the physiology of rooting with particular reference to auxins and nutritional relationship (Bhatnagar *et al.* 1968, Bhatnagar & Joshi 1972, Nanda *et al.* 1968, 1970, Nanda 1975). In recent years many studies have been taken up on vegetative propagation of Indian forest tree species (Bhatt 1991, Bhatt & Todaria 1990a, b, 1993a, b, Gupta *et al.* 1993, Chauhan 1994, Chauhan *et al.* 1993, 1997, Kathiresan & Moorthy 1994, Reddy *et al.* 1994, Gauttam & Negi 1997a, b).

The major causes and consequences (on ecological timescales) of patterns, which affect different processes of regeneration of trees as reviewed above, may be summarised (adopted from Nathan Muller-Landau 2000 and modified) in the following schematic diagram (Figure I.2).

Indian literature on the regeneration dynamics of the forest trees are widely segmented. A brief review may be found in Champion and Seth's (1968a) monograph of Indian Silviculture. Chengappa (1937, 1944) has made detailed studies on the regeneration of Andaman forests. Brief notes on phenology, visual estimates of regeneration status, seedling establishment etc. of individual species were compiled by Troup (1921). Highly fragmented but very valuable informations on the silviculture and various aspects of regeneration of the moist deciduous forests are found distributed in the issues of two serial publications: i) Forest

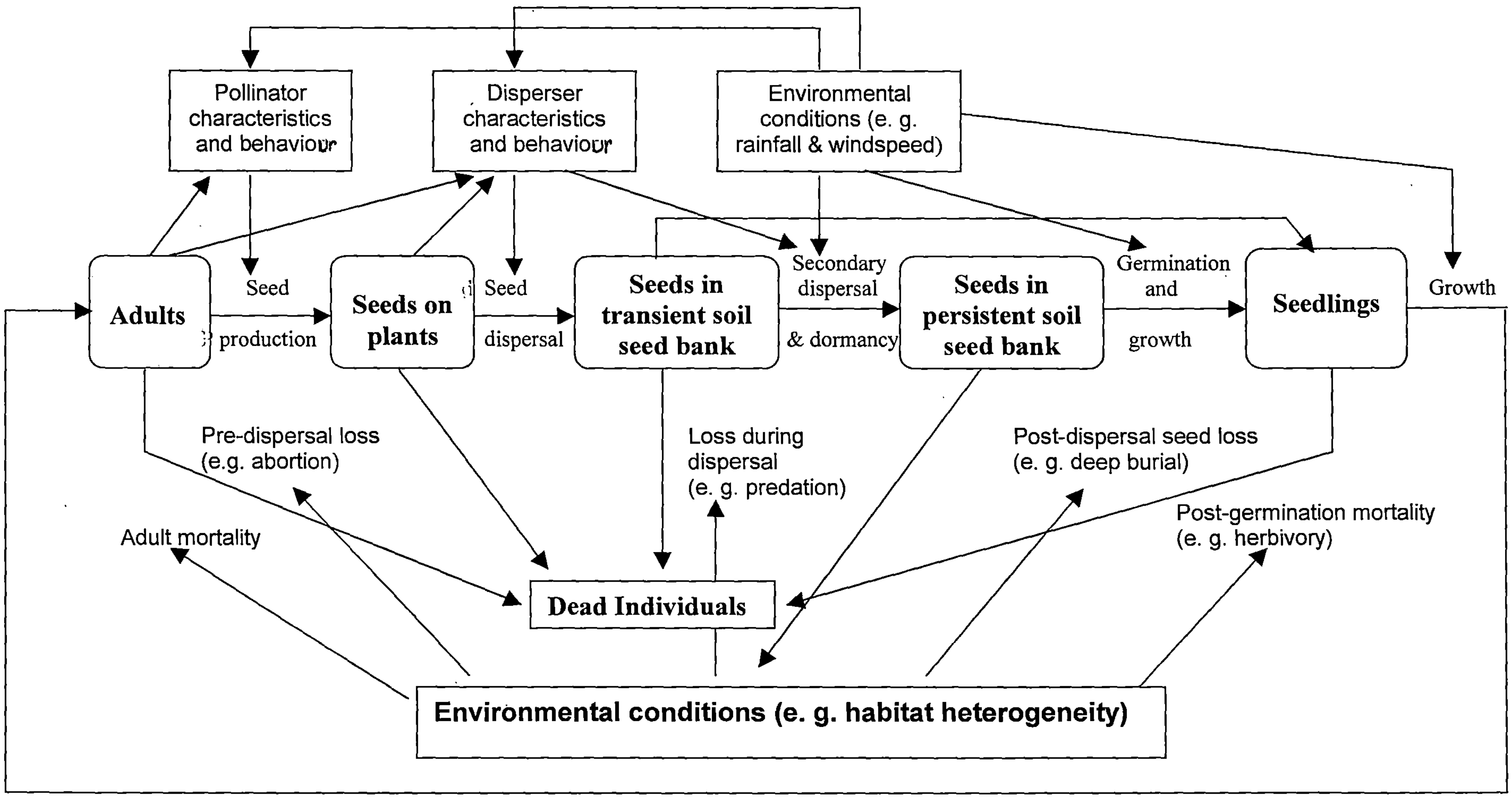


Figure I.2. The major causes and consequences of patterns of natural regeneration of forest trees.

Research in India, Part I and II (1923-1961), published by the Government of India, and ii) The Annual Research Report of the Silviculture Division, Kerala Forest Department. Swarupanandan and Sasidharan (1992) have studied the regeneration of some important tree species in moist deciduous forest ecosystem of Kerala. Regeneration of rosewood (*Dalbergia latifolia*; Balasundaram *et al.* 1979, Deshmukh 1985), *Dipterocarpus* spp. (Thangam 1982), Sal (*Shorea robusta*; Bor 1930, Champion 1933, Chakravarthi 1948, Chaudhuri 1960, Bhatnagar 1961, Sharma *et al.* 1985), teak (*Tectona grandis*; Kadambi 1957), Irul (*Xylia xylocarpa*; Arora 1960) has received much attention. Further details and specifics on the various aspects of regeneration of various tree species are scattered in the various Forest Working Plans and published literature on phytosociological studies of forest ecosystem.

Regeneration status of a few forest types and tree species of north-eastern region of India has been studied by Tripathi and his co-workers (Khan 1986, Khan *et al.* 1986, 1987, Khan & Tripathi 1987a, b, 1989a, b, c, 1991, Maram & Khan 1998, Khan *et al.* 1999, 2002, Khan & Uma Shankar 2001, Tripathi & Khan 1990, 1992, Rao *et al.* 1990, 1997, Rao 1992, Barik 1992, Barik *et al.* 1992, Barik *et al.* 1996, Arunachalam *et al.* 1997) and also by some other workers (Boojh & Ramakrishnan 1981a, b, c, 1982, Shukla & Ramakrishnan 1981, 1982a, b, Beniwal & Haridasan 1992a, b, Shukla *et al.* 1994, Kikim & Yadav 1998, Arunachalam 1998, Bisht & Ahlawat 1999, Singh 1999, Bisht *et al.* 2000, Arunachalam & Arunachalam 2000, Arunachalam *et al.* 2000). However, regeneration of Rudraksh (*Elaeocarpus ganitrus* Roxb.) has not been studied. Rudraksh finds an important place in Hindu religion. Hindu mystics and fakirs wear the nuts. The amulets made from Rudraksh are considered useful to guard against evil spirits and ill omens. The species is believed to possess special merits and therefore sells at much higher price. Preliminary observations suggest that the seeds of Rudraksh germinate with great difficulty. Moreover, collection of nuts every year from the forest at large scale to sell them in the market has caused a real threat to natural regeneration of this species. The population of Rudraksh is fast depleting in the natural forests due to developmental activities and practice of 'jhum' cultivation by the local people. In fact Rudraksh has become an endangered species in nature, though it is not included in Red Data Book of Indian flora. Thus, the study on fruit production, dispersal mechanism, germination and seedling fitness of Rudraksh has been taken up with a view to augment its regeneration which would contribute to its conservation in nature.

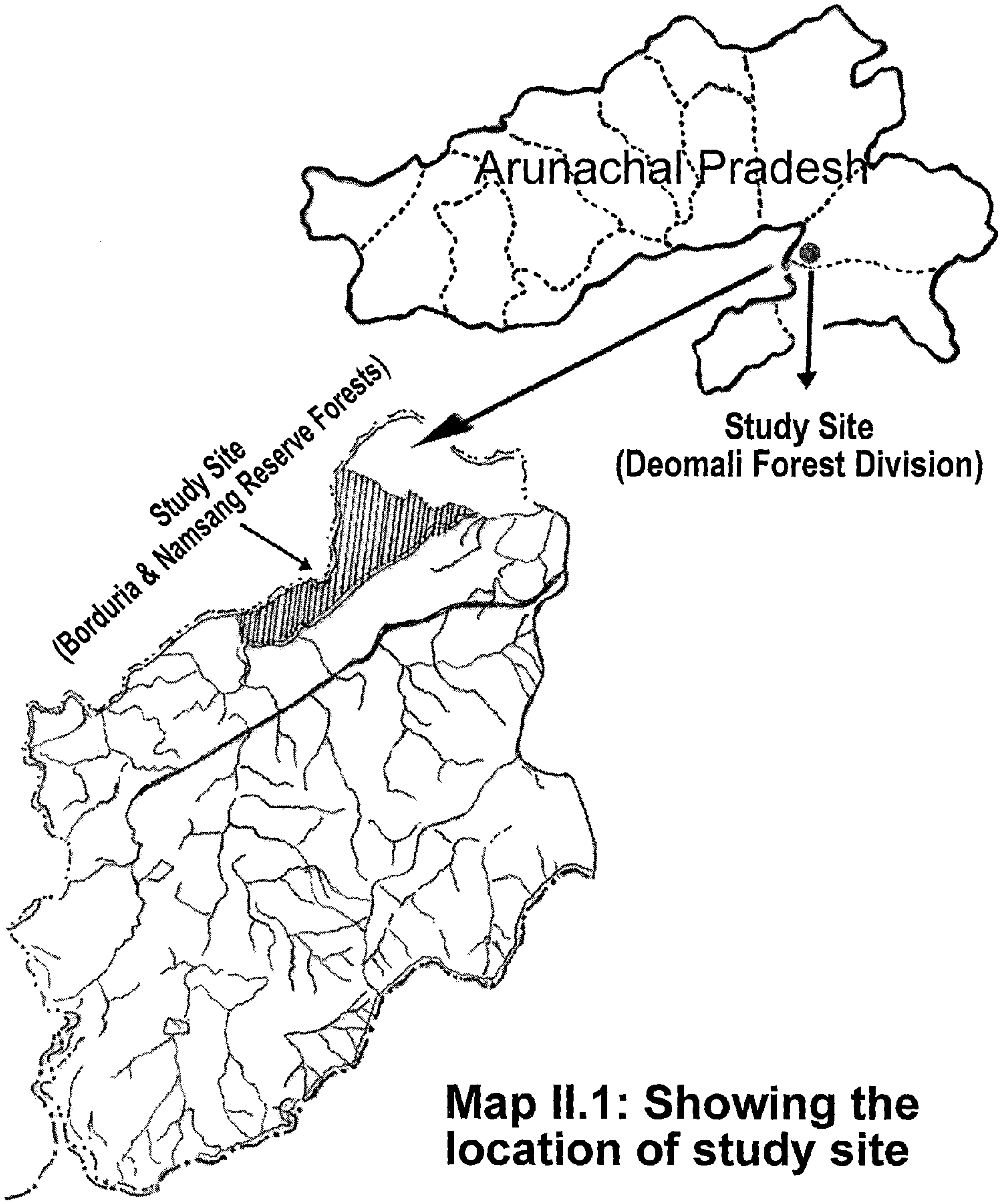
CHAPTER II

The Study Sites: Climate, Soil and Vegetation

Field Studies:

Four forest stands growing in Deomali Forest Division (27° 3′ and 27° 13′ N 95° 22′ and 95° 37′ E; altitude 200 m) in Arunachal Pradesh, north eastern region of India were selected for study. All the four forest stands are classified as wet evergreen *Dipterocarpus* forests (Kaul & Haridasan 1987) and correspond to Champion and Seth's (1968b) IB/CI Assam Valley tropical evergreen forests. All the stands are situated within a circle of 5 km radius (mapII.1, plate II.1).

These forest stands are exposed to various kinds of disturbances such as tree felling, occasional burning and grazing. Commercial crops e.g. coffee, tea, piper etc. are also cultivated within these forest stands. For the purpose of the present study the four forest stands were classified on the basis of a disturbance index (the basal area of the cut trees measured at ground level expressed as a fraction of the total basal area of all trees including felled ones (Rao *et al.* 1990) into highly disturbed (disturbance index 70%), moderately disturbed (disturbance index 40%), mildly disturbed (disturbance index 20%) and undisturbed (disturbance index 0%) categories.



Map II.1: Showing the location of study site

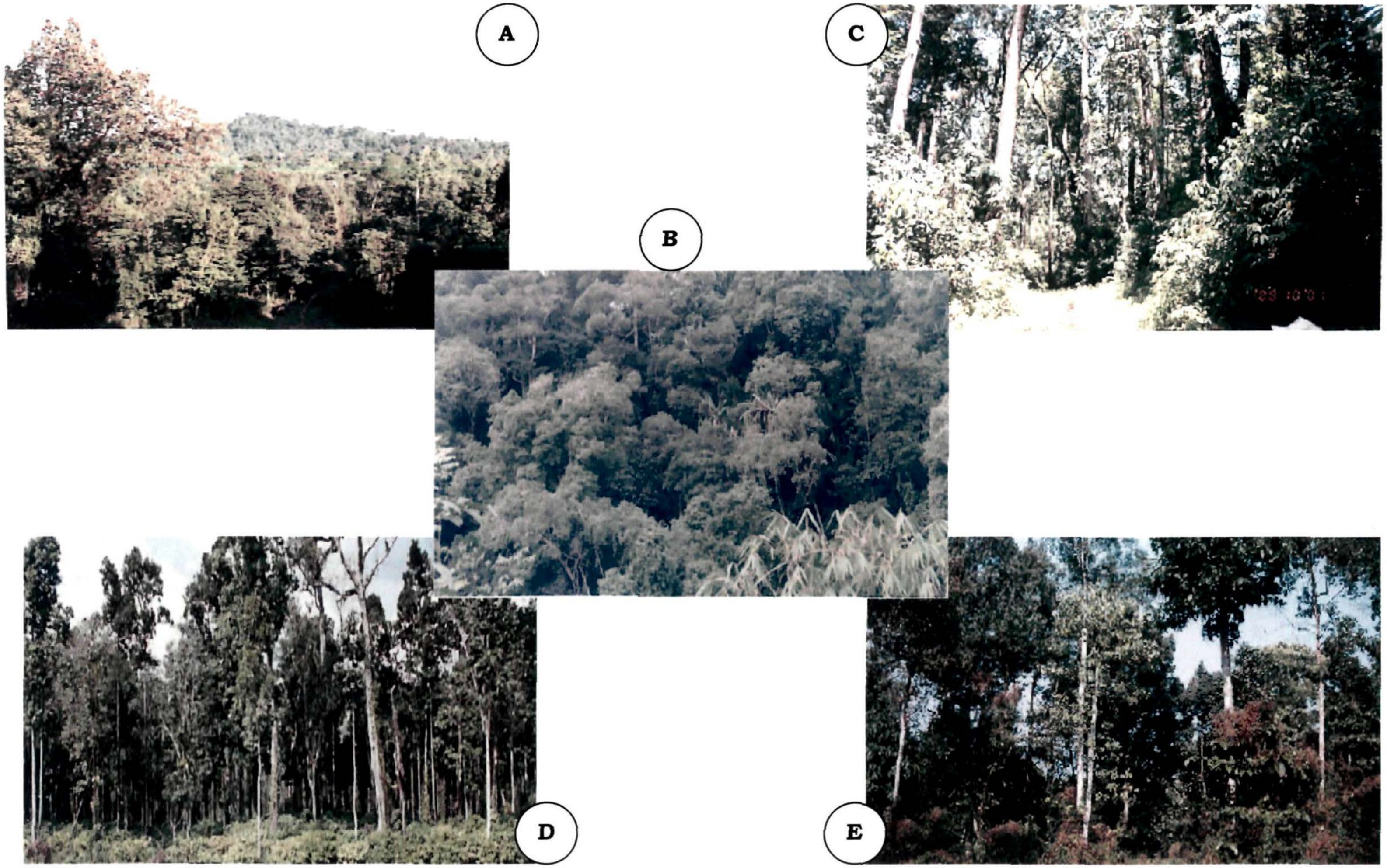


Plate II.1. View of the forest stands exposed to various degrees of disturbances. (A) – An overview of a part of the undisturbed stand, (B) – Close up of a small patch of the same forest, (C) – Mildly disturbed stand, (D) – Moderately disturbed stand, (E) – Highly disturbed stand.

Pot experiments:

The pot experiments were conducted on the campus of North Eastern Regional Institute of Science & Technology, Nirjuli (27° 07' N latitude, 93° 22' E longitude, 100 m altitude) under the greenhouse conditions (over the season: R.H.=60-85%; air temperature, 28-36 ^{0}C max., 15-22 ^{0}C min.; light intensity 290-30000 lux.).

Climate:

The study area falls within the tropical climate and is typically monsoonal with distinct cool (December to February) and wet (May to September) seasons. The periods from October to November and from March to April represent autumn and spring seasons, respectively. Winter months are comparatively cool and dry, and the temperature may drop to 6°C. The average rainfall, temperature and relative humidity data are given in Fig. II.1. The climate is quite wet (annual rainfall, 2500-3000 mm). During pre-monsoon period from March onward occasional showers are of common occurrence. About 85% of the annual rainfall is received during the wet season. During this period humidity is very high (80-95%) and heat prevails for some time when it is not raining. Most of the annual precipitation is received during the rainy season and there is hardly a complete dry month in the year. Rains are received by the southwest as well as northeast monsoon. But maximum rainfall is received from southwest monsoon, which starts from April and continues up to October. During winter rainfall is received from north -east monsoon. The hottest months are July-August (36 °C max. temperature).

Soil:

The soil can be classified into two classes: old alluvial and new alluvial. The old alluvial soil occurs along the river Dihing. The new alluvial soil which is of recent origin also occurs along the bank of Dihing river and it covers the older rock formation along the Namsang valley. The texture of the soil in different parts of the study site varies from sandy loam to clay with 1-5% of its volume occupied by stone. The pH of the soil ranges from 5.5 to 7.5 (Table II.1).

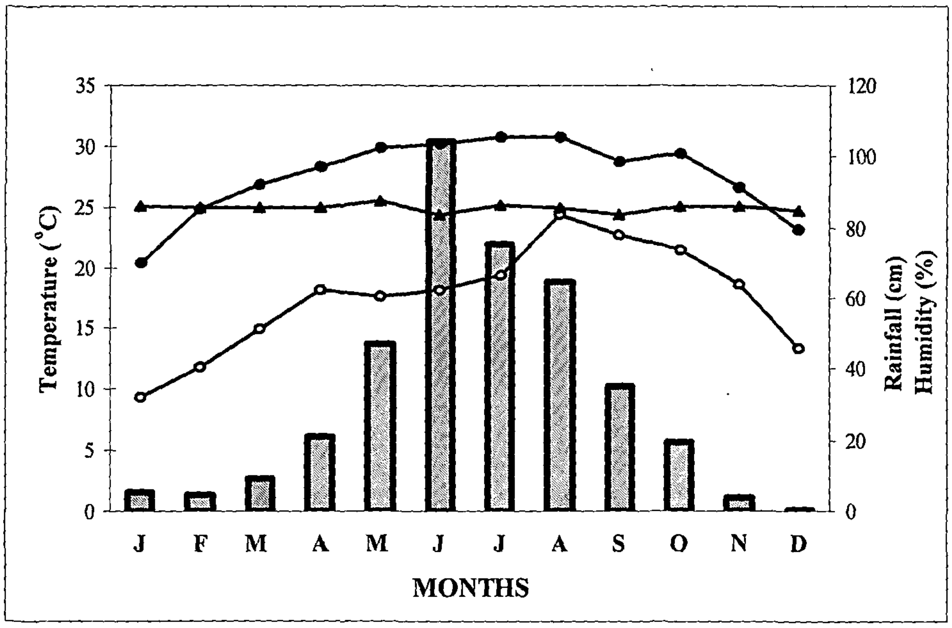


Figure II.1. Rainfall, relative humidity and temperature data for the study area during January to December (mean of years 1997, 1998, 1999 & 2000); ■, average rainfall; ▲, relative humidity; • mean maximum temperature; ○, mean minimum temperature.

Table II.1. Light intensity and soil characteristics of the study sites.

Forest stands	Light intensity (x 10 lux)	Soil texture	Soil pH	Organic matter (%)	Nitrogen (%)
Undisturbed stand	1704	Sandy loam	5.5	6.2	0.3
Mildly disturbed	1960	Sandy loam	6.2	4.7	0.2
Moderately disturbed	2307	Sandy loam	6.3	4.2	0.2
Highly disturbed	3045	Loamy sand	6.5	3.1	0.1

Vegetation:

Vegetation is dominated by *Dipterocarpus macrocarpus*, *Shorea assamica, Terminalia myriocarpa* and *Altingia excelsa*. The forests exhibit a multi-tiered stratification with a canopy layer occupied by the above species along with *Ailanthus grandis* and *Tetrameles nudiflora*. The subcanopy contains *Mesua ferrea, Elaeocarpus ganitrus, E. rugosus, E. aristatus, Bischofia javanica, Turpinia nepalensis, Terminalia citrina, Endospermum chinensis, Aesculus assamcus, Trema cannabina, Talauma hodgsonii, Sapium baccatum, Chisocheton paniculata, Vatica lancifolia, Syzygium* sp. *Mangifera sylvatica, Chionanthes macrophylla,* and *Kydia glabrescence.* The shrub layer is often gregarious and consists of *Blastus cochinchinensis, Boehmaria glomerulata, Phlogacanthus thyrsiflorus, P. tubiflorus, Leea indica, Maesa indica, Calamus* sp., *Clerodendrum* sp. and *Laportea* sp. The herb layer has *Phrynium pubinerve, Musa* sp., *Impatiens* sp., and *Phegopteris* sp. The epiphytic flora is mainly composed of orchids such as *Dendrobium* spp., *Papilionanthe* sp., *Rhynchostylis* sp., *Agapetes* sp., *Hoya* spp., and *Dischidia* sp. A rare epiphytic pitcher plant, *Hoya rafflesiana* is also found in these forests. A detailed description of vegetation is given in ***Chapter III***.

Tree Diversity and Population Structure in Undisturbed and Human-Impacted Forest Stands

Introduction

The world vegetation cover under natural forests has been depleting fast and a significant portion of such areas is being converted to man-made plantation forest, mainly of timber trees (Pandey & Shukla 1999) to meet the growing need of the ever increasing human population. We now largely depend on managed forest for wild plant resources as we donot have much natural forest left. The current pressure on the forest communities for large-scale collection of fuelwood and minor forest products as well as the practice of grazing and trampling may alter the habitats of many species. As a result, there is a lot of spatial and temporal variation in species richness, composition and productivity. A thorough understanding of the dynamics of the forest can help increase the productivity, maintain species composition, limit financial inputs and develop prescription for silvicultural operations (Oliver & Larson 1990, Bhat *et al.* 2000) and conserve the plant diversity (Murali *et al.* 1996).

Tree regeneration can be predicted by the structure of their populations (Marks 1974, Veblen *et al.*1979, Pritts & Hancick 1983, Saxena & Singh 1984, Saxena *et al.* 1984, Khan *et al.* 1987). The presence of sufficient number of seedlings, saplings and young trees in a given population indicates a successful regeneration (Saxena & Singh 1984). A sustained regeneration and growth of all species in the presence of older plants is required for better growth of any plant community (Ramakrishnan *et al.* 1981, Taylor & Zisheng 1988). Information on forest composition, effects of biotic and abiotic pressure, type of species surviving and the extent of biomass removal can help rejuvenate depleting forest through silvicultural practices and community involvement (Ramakrishnan & Toky 1981, Singh & Singh 1987, Sundriyal *et al.* 1994, Murali & Setty 2001).

The present chapter focuses on the tree diversity, population status and community attributes of the forest stands and population structure of tree species in different forests experiencing various degrees of disturbance.

Methods

Phytosociological studies were carried out during 1998-1999 using quadrat method (30 m ×30 m for trees and saplings, 10 m ×10 m for seedlings and shrubs and 1 m ×1 m for herbs within the same 30 m × 30 m quadrat). Ten quadrats were laid randomly in each forest stand for trees, saplings and seedlings. Tree species occurring in each of the quadrats were listed and their circumference was measured. The individuals in the case of tree species were separated into three categories i.e. (a) seedlings (≤10 cm collar circumference at the base), (b) saplings (10≤20 cm collar circumference at the base) and (c) trees (>20 cm circumference at breast height i.e.1.37 m). Density (trees ha^{-1}) and basal area values were calculated for each species. The importance value index for each species was computed by summing up the relative density, relative frequency and relative dominance. Individuals with 10≥20 cm collar circumference at the base were considered regenerating plants (Saxena *et al.* 1984, Khan *et al.* 1987, Sundriyal *et al.* 1994). Regeneration was recorded for each stand to estimate the species status in different stands.

Similarity index (community coefficient) among different stands was calculated as per Jaccard (1912) as given below:

$$Cj = j/(a+b-j)$$

Where 'j' is the number of species common to both stands. 'a' is the number of species in stand A and 'b' is the number of species in stand B.

Shannon–Wiener diversity index (Shannon-Wiener 1963) was calculated from the IVI values using the formula given by Magurran (1988).

$$H = -\sum_{i=1}^{s} pi \ln pi$$

Where 'pi' is the proportion of the ith species and number of individuals of all the species (ni/N).

Simpson's Index (Simpson 1949) which measures concentration of dominance (cd) was calculated as follows:

$$Cd = -\sum_{i=1}^{s} (pi)^2$$

Where pi is the same as for Shannon-Wiener information function.

Results

Species richness, species diversity, concentration of dominance, similarity index and basal area

Species richness varied according to disturbance gradient in different stands. The mildly disturbed stand showed the highest species richness (54 of 51 genera). The species richness was the lowest (16 of 16 genera) in the highly disturbed stand. In the undisturbed stand 47 species of 42 genera were recorded while in the moderately disturbed stand 42 species of 36 genera were found. Tree species diversity index ranged from 0.7 to 2.02 in all stands. The highest species diversity was recorded in the undisturbed stand and the lowest in the highly disturbed stand. The values for concentration of dominance were recorded to be similar in the undisturbed, mildly disturbed and moderately disturbed stands whereas it was the lowest in the highly disturbed stand. The similarity index value was maximum in the undisturbed stand and minimum in the highly disturbed stand.

The forest stand density was recorded highest (5452 stems/ha) in the undisturbed stand and lowest (338 stems/ha) in the highly disturbed stand. The basal area was recorded highest in undisturbed stand ($104.60 m^2 ha^{-1}$) and lowest in moderately-disturbed stand ($18.60\ m^2 ha^{-1}$) (Table III.1). The presence of large number of buttressed trees in the undisturbed, mildly disturbed and highly disturbed stands has contributed to the high basal area.

Plant families, genera and species

Enumeration of plant families, genera and species in different stands showed the presence of 28 families with 42 genera in the undisturbed stand, 31 with 51 genera in the mildly disturbed stand, 27 with 36 genera in the moderately disturbed stand and 14 with 16 genera in the highly disturbed stand (Table III.1). Out of 28 families in the undisturbed stand, 8 were represented by more than one genus and 20 by single genus. Out of the 28 families in the undisturbed stand, 17 families consisted of single species whereas 11 families were found to have more than one species. Only four genera contained more than one species. Dipterocarpaceae, Clusiaceae, Theaceae and Combretaceae contributed more than 90% to the total stand density. In the mildly disturbed stand, out of 31 families, 13 were represented by more than one species and 18 had single species. Only 3 genera contained more than one species. In the moderately disturbed stand, out of 27 families 11 were represented by more than one species where species of Dispterocarpaceae and Clusiaceae families were dominant. In the highly disturbed stand, out of 14 families only 2 were represented by more than one species. In this stand Dipterocarpaceae and Leguminaceae dominated over the other families (Table III.2).

Table III.1. Consolidated details of families, genera, species, diversity index, concentration of dominance, stand density and basal area in four forest stands experiencing different degree of disturbance.

Parameters	Forest stands			
	Undisturbed	Mildly disturbed	Moderately disturbed	Highly disturbed
Species richness	47	54	42	16
No. of families	28	31	27	14
No of genera	42	51	36	16
Diversity index (H)	2.02	1.93	1.99	0.7
Concentration of dominance	0.06	0.06	0.06	0.04
Similarity index	0.46	0.40	0.43	0.07
Stand density (stems/ha) (tree + sapling + seedling)	5452	5014	3656	338
Basal area (m^2ha^{-1})	104.60	51.75	18.60	43.23

Table III. 2. Tree families, genera, species richness and density (no. of trees ha^{-1})in four forest stands experiencing different degrees of disturbance.

Families	Undisturbed stand			Mildly disturbed stand			Moderately disturbed stand			Highly disturbed stand		
	Genera	Species	Density	Genera	Species	Density	Genera	Species	Density	Genera	Species	Density
Anacardiaceae	1	1	6	1	1	77	1	1	7	-	-	-
Apocynaceae	1	1	2	1	1	15	1	1	2	1	1	15
Araliaceae	1	1	102	2	2	7	-	-	-	-	-	-
Burseraceae	1	1	224	1	1	145	1	1	151	1	1	11
Chailetiaceae	1	1	4	-	-	-	-	-	-	-	-	-
Clusiaceae	2	2	745	2	2	784	2	2	421	1	1	20
Combretaceae	1	1	312	1	3	236	1	2	165	1	1	11
Dasticaceae	1	1	5	-	-	-	-	-	-	-	-	-
Dilleniaceae	1	1	2	-	-	-	1	1	7	-	-	-
Dipterocarpaceae	3	3	1760	3	3	1485	3	3	974	2	2	135
Elaeocarpaceae	1	2	110	1	2	48	1	1	57	1	1	7
Euphorbiaceae	3	3	93	3	3	243	3	4	241	-	-	-
Fabaceae	-	-	-	2	2	4	-	-	-	-	-	-
Fagaceae	1	1	386	1	1	332	1	1	164	-	-	-
Flacourtiaceae	-	-	-	1	1	12	-	-	-	1	1	9
Hamemeliaceae	1	1	2	1	1	9	1	1	153	-	-	-
Lauraceae	5	5	131	3	3	132	3	4	336	-	-	-
Leguminosae	-	-	-	2	2	2	1	1	64	2	2	75
Loranthaceae	1	1	2	-	-	-	-	-	-	-	-	-
Lythraceae	1	1	53	1	1	74	2	2	40	1	1	11
Magnoliaceae	3	3	285	3	4	303	1	2	186	1	1	4
Melastomataceae	1	1	4	1	1	4	-	-	-	-	-	-
Malvaceae	1	2	2	1	1	4	-	-	-	-	-	-
Meliaceae	2	3	324	3	3	453	1	2	283	1	1	13
Moraceae	-	-	-	2	2	5	1	1	4	1	1	7
Myrtaceae	1	1	73	1	1	39	1	2	3	-	-	-
Rosaceae	-	-	-	1	1	100	-	-	-	-	-	-
Rubiaceae	2	2	30	1	1	24	1	1	21	-	-	-
Sapindaceae	-	-	-	1	1	24	-	-	-	-	-	-
Sapotaceae	2	2	77	1	1	63	1	1	74	-	-	-
Simarubaceae	1	1	140	1	1	39	1	1	18	1	1	13
Sterculiaceae	1	1	7	1	1	7	1	2	100	1	1	7
Theaceae	1	1	461	1	1	122	1	1	152	-	-	-
Thymelaceae	1	1	100	1	1	5	1	1	2	-	-	-
Unknown	-	-	-	1	1	91	1	1	4	-	-	-
Urticaceae	-	-	-	-	-	-	1	1	4	-	-	-
Verbenaceae	-	-	-	3	3	126	2	2	23	-	-	-
Total	**42**	**47**	**5452**	**51**	**54**	**5014**	**36**	**42**	**3656**	**16**	**16**	**338**

Dominance and rarity

Dominance calculated as IVI of different species varied greatly in different stands. *Shorea assamica, Dipterocarpus macrocarpus, Mesua ferrea, Castanopsis indica, Terminalia chebula, Vatica lancefolia* were dominant in all stands except the highly disturbed one. The canopy layer of the strata was occupied by *Shorea assamica, Dipterocarpus macrocarpus* and *Terminalia chebula* in all the stands (Table III. 3). Species represented by a few individuals were considered rare. Rudraksh (*Elaeocarpus ganitrus*) which was found sporadically in the forest stands, belongs to the category of rare species.

Girth class wise tree density and species richness

Stand densities and species richness consistently decreased with increasing girth class of tree species from 20 to > 200 cm girth (Fig III.1, III. 2). The highest species density and species richness were recorded in the medium girth class (51-110) in all stands. In the undisturbed stand the highest stand density was found in 111-140 cm girth class, while in the mildly disturbed stand 51-80 cm girth range recorded the highest stand density. In the highly disturbed stand no tree was recorded in >140 cm girth range. The highest contribution of stand density per girth class to the total density in the undisturbed, mildly disturbed and moderately disturbed stands was recorded in the 51-80 cm girth class (47%, 31% & 28%) while in the highly disturbed stand it was maximum (54%) in the 81-110 cm girth class. *Dipterocarpus macrocarpus, Shorea assamica, Mesua ferrea, Castanopsis indica,* Canarium

Table III. 3. Importance value index of tree species in four forest stands experiencing different degrees of disturbance.

Species	Undisturbed stand	Mildly disturbed stand	Moderately disturbed stand	Highly disturbed stand
	I.V.I	I.V.I	I.V.I	I.V.I
Ailanthus excelsa Linn.	-	3.34	-	-
Ailanthus grandis Prain.	6.11	5.12	9.83	8
Albizia lucida Benth.	-	1.98	-	-
Albizia procera Benth.	-	-	-	19.44
Alstonia scholaris Brown	1.26	-	-	-
Altingia exelsa Noronha.	1.15	4.42	12.03	-
Amoora wallichii King	-	3.62	-	-
Artocarpus heterophyllus Lamk	-	2.8	-	-
Barceaura sapida Murll.	4.11	6.76	9.57	9.41
Bischofia javanica Bl.	3.17	5.91	10.72	-
Bombax ceiba Linn.	.99	2.81	-	-
Camellia chinensis Linn.	22.45	10.53	4.92	-
Canarium resiniferum Linn.	11.91	8.74	14.30	19.43
Castanopsis indica D. C.	18.65	16.31	18.37	-
Chickrassia tabularis Andr. Juss	1.4	-	1.67	-
Chrysophyllum roxburghii G.Don.	.97	-	-	-
Cinamommum tamala Nees.	3.03	8.63	2.38	-
Cryptocarya amygdalina Nees	-	2.28	-	-
Dalbergia assamica Benth.	-	2.5	-	-
Dalbergia sissoo Roxb. Ex DC	-	6.06	-	-
Dillenia indica Linn.	1.13	3.43	5.4	-
Dipterocarpus macrocarpus Veque	52.3	41.96	47.34	34.54
Duabanga grandiflora Roxb. ex DC	-	10.41	4	9.63
Dysoxyllum binectariferum HK	3.35	8.41	8.53	8.53
Dysoxyllum procera Hiern.	8	8	10	-
Elaeocarpus floribundus Roxb.	.97	2.77	5.05	-
Elaeocarpus ganitrus Roxb.	4.75	4.38	6	-
Elaeocarpus robustus Roxb.	5.17	-	-	-
Eugenia praceox Roxb.	1.56	-	-	-
Ficus sp.	-	2.74	-	5.22
Flacourtia cataphracta Roxb.	-	5.56	-	-
Garcinia sp.	7.54	7.91	5.10	-

contd.

Glochidion arboreascens Bl.	1.59	4.13	2.64	-
Gmelina arborea Roxb.	-	5.19	3.32	-
Gynocardea odorata R. Br.	-	-	-	7.43
Heteropanax fragrans (D. Don). Seem	1.59	-	3.48	-
Hodgsonia macrocarpa (Bl.)	-	3	7.42	-
Kydia calycina Roxb. Cogn	1.59	1.79	-	-
Lagerstroemia parviflora Roxb.	1.38	-	-	-
Lagerstroemia speciosa Roxb.	1.60	3.46	3.6	-
Litchi chinensis Sonnor	-	2.82	-	-
Litsea monopetela King.	1.68	5.13	3.95	-
Litsea salicifolia (Roxb.) ex Nees	2.19	-	-	-
Macropanax undulatus Seem.	1.92	-	-	-
Magnifera sylvatica Roxb.	2.59	2.10	4.04	-
Magnolia sp. Hk.	8.93	3.59	-	-
Melastoma malabathricum Linn.	8.02	2	-	-
Mesua ferrea Linn.	26.96	37.39	31.11	13.63
Michalia oblonga Wall. Ex HK	-	3.52	-	-
Mimusops elengi Linn.	2.14	4.84	6.25	-
Persea bombycina Koster	3.33	-	3.14	-
Peterospermum aecrifolium wild	2.27	2.40	5.15	6.91
Phobe goalparensis Hutch.	4.28	-	8.79	-
Premna bangalensis Clarke.	-	2.28	7.18	-
Sapium baccatum Roxb.	4.33	-	-	-
Shorea assamica Dyer.	33.68	43.64	39.46	18.45
*Skamoila**	4.09	11.15	9.62	-
Spondias mangifera Willd.	-	6.06	-	17.22
Syzygium cumini Linn.	2.46	4.07	2.47	10.72
Symplocos spicata Roxb.	9	5.38	8.73	-
Talauma hodgsonii Hk. f. & Thoms.	9.82	10.78	15.14	4.41
Talauma procera King.	9.63	8.95	-	-
Terminalia chebula Retz.	12.69	10.69	10.04	9.63
Terminalia myriocarpa Muell.	3.76	4.3	2.99	-
Tetramelos nudiflora R.Br.	3.90	-	-	-
Toona ciliata Roxb.	3.24	-	-	-
Vatica lancaefoedia Bl.	15.58	10.45	8.73	-
Vangueria spinosa Roxb.	1.13	4.9	7.69	-
Ziziphus apetala Hk. f.	2.16	-	-	-

* local name

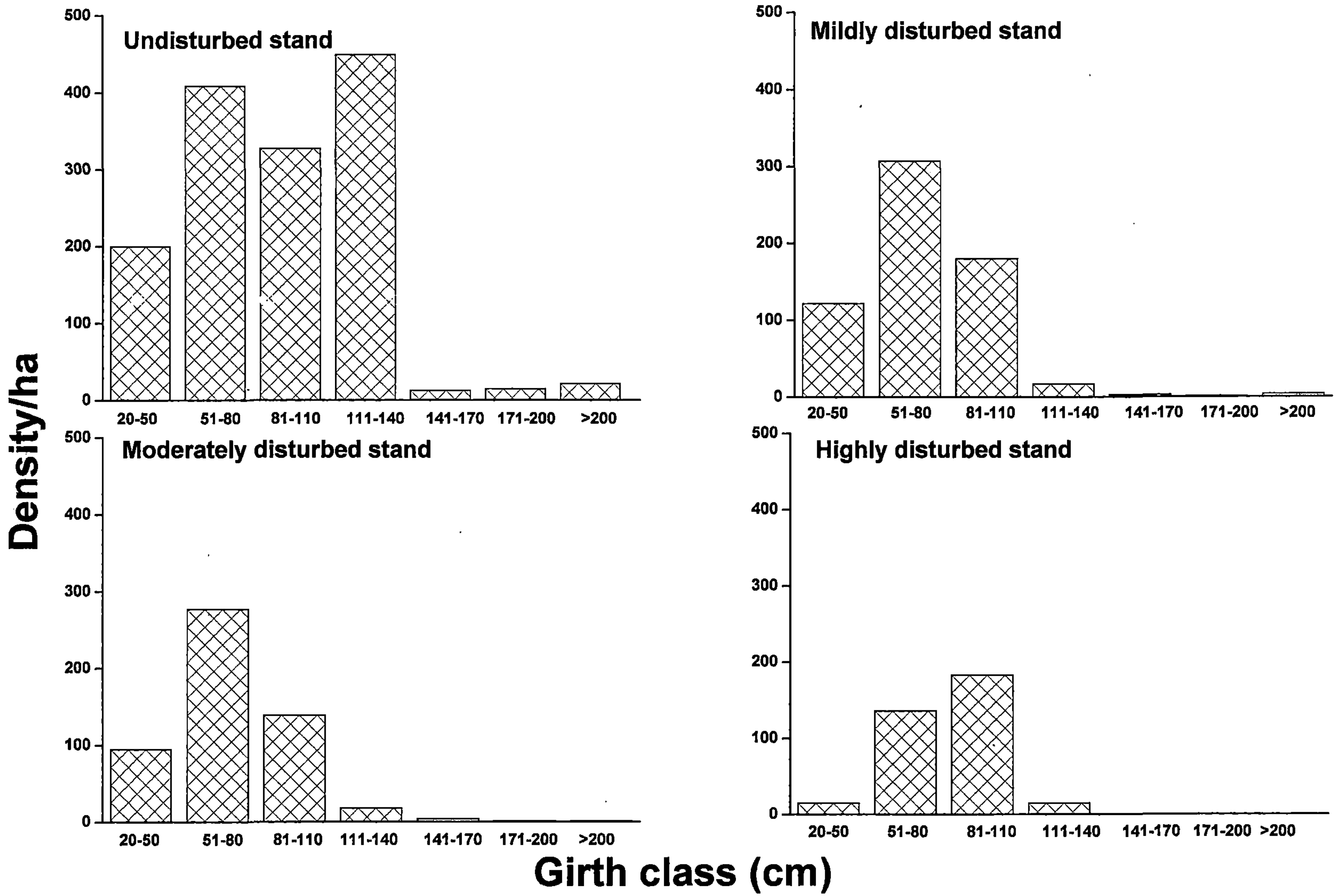


Figure III.1. Density of tree species in various girth classes in four forest stands.

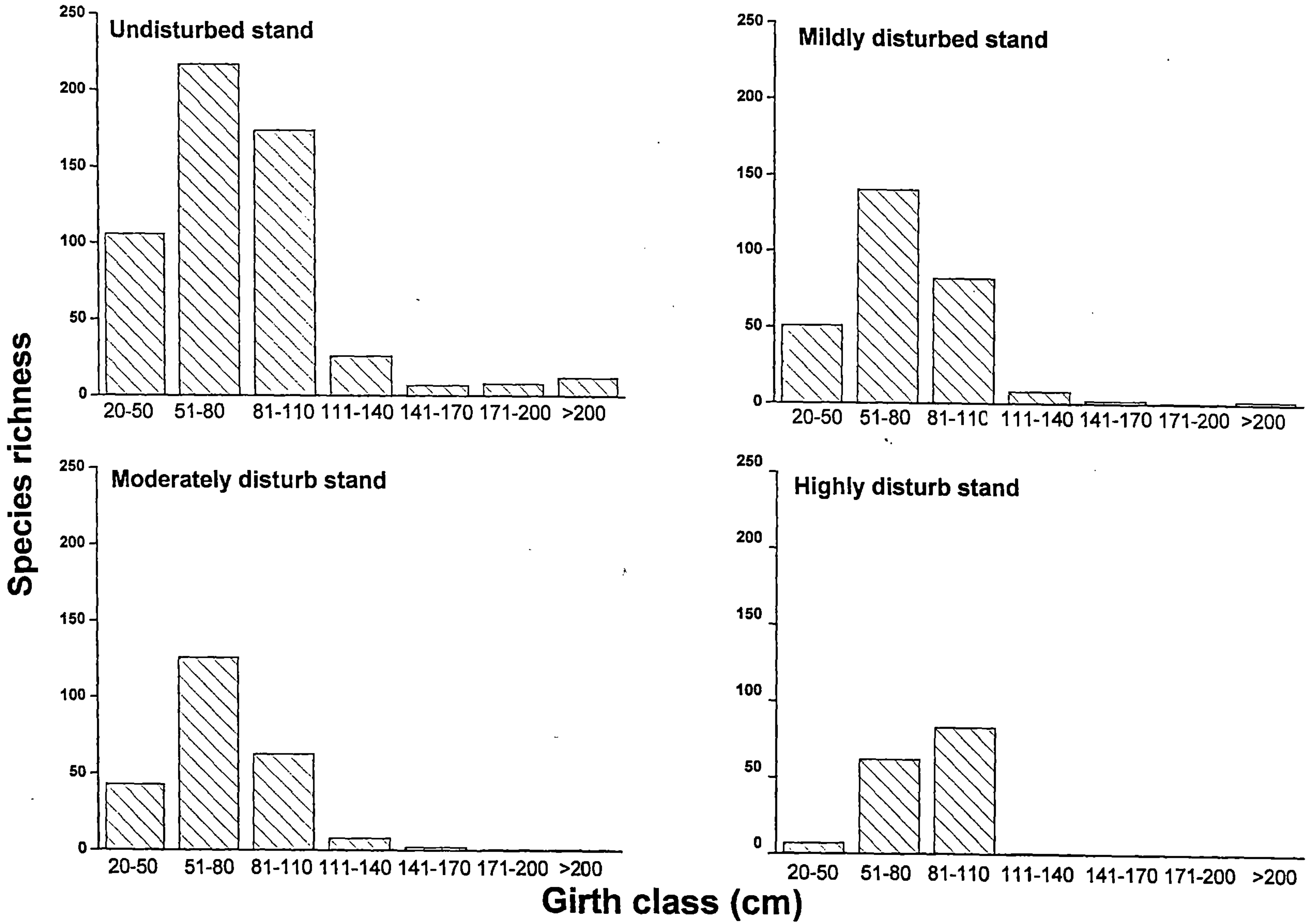


Figure III.2. Species richness of tree species among various girth classes in Four forest stands experiencing different degrees of disturbance.

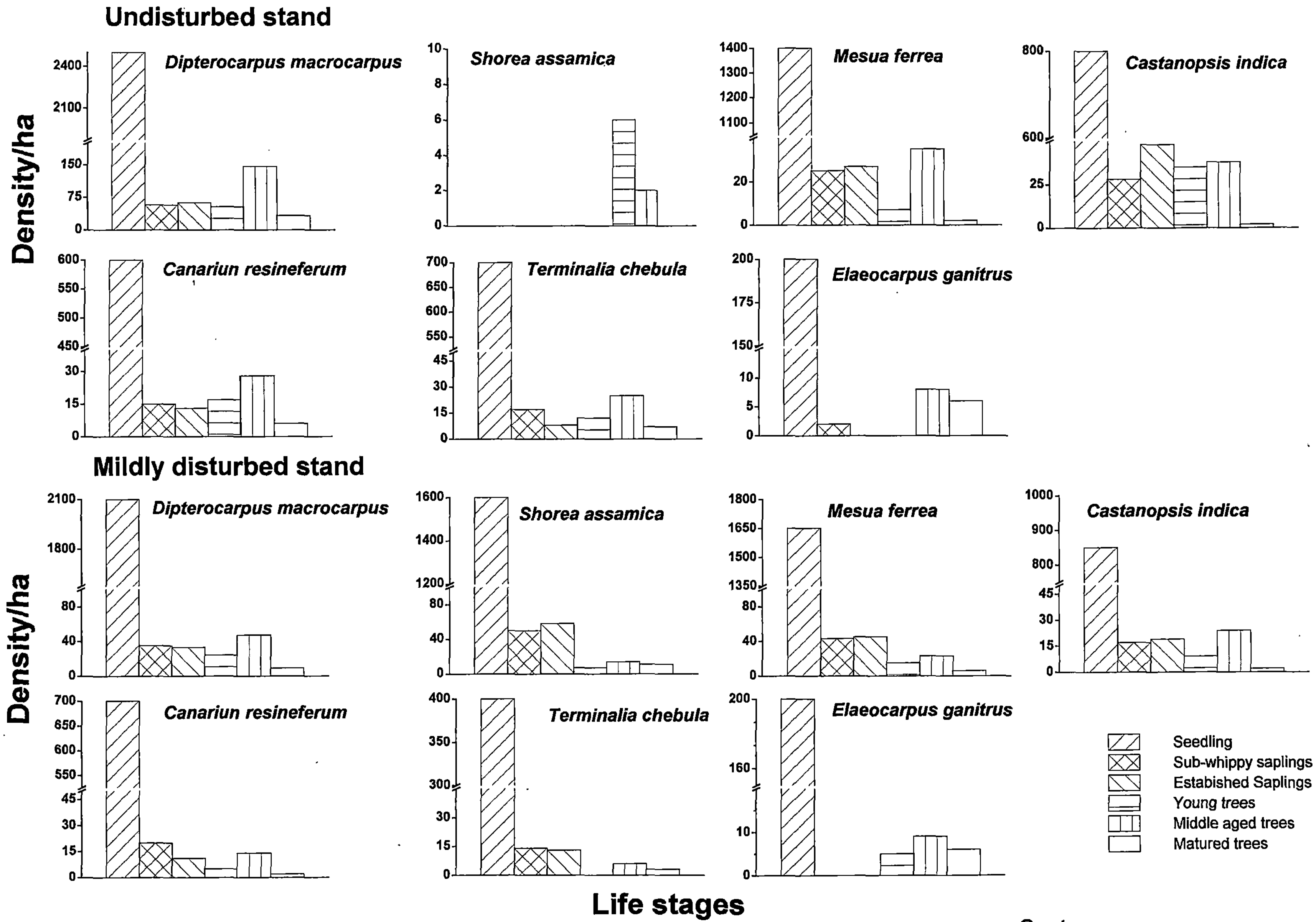
resiniferum and *Terminalia chebula* are the dominant species and these are uniformly distributed in all the forest stands. However, the distribution of these species was greatest in the 60-100 cm girth class in all the stands (Fig. III.3). Moreover, some individuals in the girth range >100 cm were also seen in the undisturbed, mildly disturbed and moderatly disturbed stands and these belonged mostly to *Dipterocarpus macrocarpus*, *Shorea assamica* and *Terminalia chebula*.

Regeneration status

Out of the 47 species in the undisturbed stand, only 26 were found to be regenerating. Twenty species showed good regeneration (predominance of saplings + seedlings), 1 species had fair regeneration and 5 species showed poor regeneration. No regeneration was recorded for other species. In the mildly disturbed stand, out of 54 species, 36 were found regenerating of which 23 species had good regeneration, 9 showed fair regeneration and 4 had poor regeneration. Out of 42 species in the moderately disturbed stand, 22 were found regenerating and good regeneration was recorded in 11 species, 7 species showed fair regeneration and 4 species had poor regeneration. No regeneration was recorded in the highly disturbed stand (Table III. 4).

Density of shrubs and herbs

Shrub and herb density are presented in tables III.5 and III.6. The highest shrub density was recorded in the undisturbed stand but the shrub species richness was maximum in the mildly disturbed stand. In all the stands



Undisturbed stand
Mildly disturbed stand
Dipterocarpus macrocarpus
Shorea assamica
Mesua ferrea
Castanopsis indica
Canariun resineferum
Terminalia chebula
Elaeocarpus ganitrus
Density/ha
Life stages
Seedling
Sub-whippy saplings
Estabished Saplings
Young trees
Middle aged trees
Matured trees

Cont...

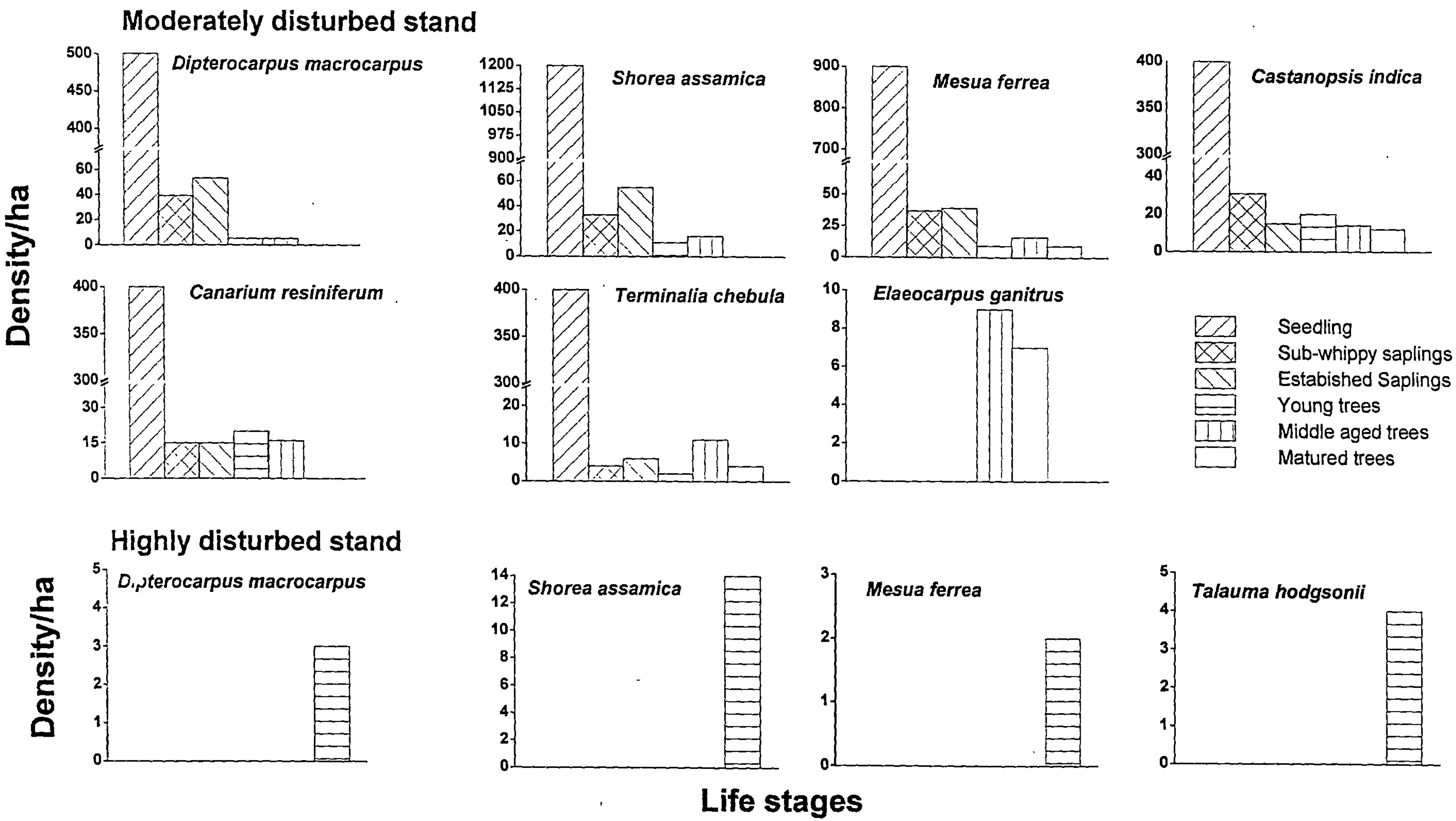


Figure III.3. Population structure of some important trees growing with *Elaeocarpus ganitrus.*

Table III. 4. Regeneration status of tree species in four forest stands experiencing different degrees of disturbance.

Species	Undisturbed stand				Mildly disturbed stand				Moderately disturbed stand				Highly disturbed stand			
	SE (ha^{-1})	SA (ha^{-1})	Prop.(%)*	Status	SE (ha^{-1})	SA (ha^{-1})	Prop.(%)*	Status	SE (ha^{-1})	SA (ha^{-1})	Prop (%)*	Status	SE (ha^{-1})	SA (ha^{-1})	Prop (%)*	Status
Ailanthus grandis Prain.	400	9	95	GR	100	6	91	GR	300	115	94	GR	-	-	-	-
Albizia lucida Benth.	-	-	-	-	-	2	#	FR	-	-	-	-	-	-	-	-
Alstonia scholaris Brown.	-	2	50	PR	-	-	-	-	-	-	-	-	-	-	-	-
Altingia exelsa *Noronha*	-	-	-	-	-	2	77	PR	-	-	-	-	-	-	-	-
Artocarpus heterophyllus Lamk..	-	-	-	GR	200	4	#	FR	-	-	-	-	-	-	-	-
Barseaura sapida Murll.	200	9	#	-	250	18	90	GR	-	-	-	-	-	-	-	-
Bischofia javanica Bl.	-	-	-	GR	-	7	31	PR	500	-	4	FR	-	-	-	-
Camellia chinensis Linn.	0	120	95	GR	600	33	57	GR	400	-	-	-	-	-	-	-
Canarium resiniferum Linn.	600	29	93	GR	700	115	96	GR	400	31	94	GR	--	--	--	-
Castanopsis indica Spach	800	78	92	FR	750	41	71	GR	100	49	91	GR	-	-	-	-
Cinnamomum tamala Nees.	-	15	78	-	100	9	85	GR	-	-	98	PR	-	-	-	-
Cryptocarya amygdalina Nees	-	-	-	-	-	4	#	FR	-	-	-	-	-	-	-	-
Dalbergia sisso. Hk.	-	-	-	-	100	-	#	PR	-	-	-	-	-	-	-	-
Dillenia indica Linn.	-	-	-	GR	-.	-	-	-	-	9	68	FR	-	-	-	-
Dipterocarpus macrocarpus Vesque	2500	120	91	GR	2500	70	96	GR	1400	93	96	GR	-	-	-	-
Dysoxylum procerum Hiern	-	-	-	-	-	-	-	-	200	-	95	PR	-	-	-	-
Elaeocarpus floribundus Bl.	-	-	-	-	-	7	#	FR	-	-	-	-	-	-	-	-
Elaeocarpus ganitrus Roxb.	200	2	92	GR	-	-	-	-	-	-	-	-	-	-	-	-
Elaeocarpus robustrus Roxb.	-	35	#	GR	-	-	-	-	-	-	-	-	-	-	-	-
Ficus sp.	-	-	-	-	-	9	#	PR	-	-	-	-	-	-	-	-
Garcinia species Linn.	600	11	95	GR	300	9	90	GR	200	4	96	FR	-	-	-	-
Glochidion multiloculare Muell.	-	-	-	-	250	4	#	FR	-	7	#	PR	-	-	-	-
Gmelina arborea Linn.	-	-	-	-	-	8	88	FR	-	20	60	GR	-	-	-	-
Heteropanax fragrans D Don	100	-	98	PR	-	-	-	-	-	-	-	-	-	-	-	-
Kydia calycina Roxb.	200	2	99	GR	-	-	-	-	-	-	-	-	-	-	-	-
Lagerstroemia speciosa (L.) pers	-	-	-	-	-	100	96	GR	-	4	30	FR	-	-	-	-

contd.

Litchi chinensis Sonnor	-	-	-	-	-	100	96	GR	-	-	-	-	-	-	-	-
Litsea lacta Benth.	-	2	28	PR	-	-	-	-	-	-	-	-	-	-	-	-
Litsea monopetala (Roxb.)	-	-	-	-	200	100	#	GR		-	-	-	-	-	-	-
Litsea salicifolia (Roxb.) ex Nees	100	20	#	GR				GR	13	#	FR	FR	-	-	-	-
Magnolia sp.	100	-	77	PR	100	4	96	GR	-	-	-	-	-	-	-	-
Melastoma malabathricum Linn.	500	42	31	GR	-	-	-	-	-	-	-	-	-	-	-	-
Mesua ferrea Linn.	1400	115	94	GR	1650	91	97	GR	900	78	92	GR	-	-	-	-
Michelia oblonga Wall. ex Hk	-	-	-	-	-	100	98	GR	-	-	-	-	-	-	-	-
Mimusops elengi Roxb.	100	2	93	GR	200	15	98	GR	-	15	68	GR	-	-	-	-
Premna bengalensis Cl.	-	-	-	-	-	11	#	FR	-	15	#	FR	-	-	-	-
Pterospermum acerifolium Willd.	-	-	-	-	-	9	#	FR	-	7	#	FR	-	-	-	-
Shorea assamica Dyer.	1000	153	93	GR	1600	135	84	GR	1200	89	93	GR	-	-	-	-
Sikamiola*	100	20	96	GR	200	46	90	GR	-	-	-	-	-	-	-	-
Sizygium cumuni Linn.	200	-	99	PR	150	5	94	GR	-	2	33	PR	-	-	-	-
Spondias magnifera Willd.	-	-	-	-	-	11	#	GR	-	-	-	-	-	-	-	-
Talauma hodgsonii Hk.	700	35	73	GR	600	21	96	GR	500	27	96	GR	-	-	-	-
Terminalia belerica Retz.	200	29	88	GR	-	-	-	-	-	-	-	-	-	-	-	-
Terminalia chebula Retz.	700	35	94	GR	250	18	90	GR	400	11	94	GR	-	-	-	-
Terminalia myriocarpa Heurck	-	-	-	-	100	7	#	FR	-	-	-	-	-	-	-	-
Vatica lanceaefolia Bl.	1100	51	96	GR	500	29	90	GR	200	11	95	GR	-	-	-	-

* local name
*Proportion (%) of seedlings and saplings in total density of a particular tree species. SE- Seedlings, SA- Saplings, GR- Good regeneration, FR- Fair regeneration, PR- Poor regeneration.
#- No mature tree present.
- Absence of saplings of a given species was taken as an indication of poor regeneration irrespective of presence of any number of seedlings of that species.
- Number of saplings was given more weightage while assigning the status of regeneration of a particular species.

Table III. 5. Density (no. of individuals 10 m^{-2}) of shrubs in four forest stands experiencing different degree of disturbances, ± SD values.

Species	Undisturbed stand	Mildly disturbed stand	Moderately disturbed stand	Highly disturbed stand
Abroma augusta Linn.	-	0.6 ± 08	0.2 ± 0.4	-
Baliospermum micranthum Muell.Arg.	-	0.2 ± 0.4	-	-
Begonia roxburghii (Miq) DC	-	0.2 ± 0.4	-	-
Beilschmiedia assamica Meissn.	-	0.2 ± 0.4	0.2 ± 0.4	-
Blastus cochichinensis Lour.	6.6 ± 2.6	3.8 ± 1.7	2 ± 0.4	-
Chasalia assamica Thw.	-	3.2± 1.1	-	-
Cinnamomum bejolghota Buch.Ham.	-	0.2 ± 0.4	1 ± 0.6	-
Cinnamomum sp.	0.6 ± 1.2	-	1.6 ± 1.2	
Clerodendrum infortunatum L.	1.2 ± 0.4	-	-	-
Clinogyne dichotoma Salisb.	-	0.2 ± 0.4	-	-
Coffea genkinsii Hk.	1.4 ± 0.4	0.2 ± 0.4	-	-
Datura stramonium Linn.	2 ± 1	-	-	-
Glycosmis pentaphylla Correa	-	0.4 ± 0.4	0.4 ± 0.8	-
Helicia nilagirica Bedd.	-	0.2 ± 0.4	-	-
Hymenodictyon sp	-	0.2 ± 0.4	0.2 ± 0.4	-
Laportea crenulata Gaud.	3.8 ± 1.4	1.4 ± 1.01	-	-
Litsea elongata Wall.	-	0.6 ± 0.4	0.2 ± 0.4	-
Litsea salicifolia Roxb.	4.6 ± 3	4 ± 2.05	1.2 ± 0.4	-
Lycianthes subtruncata Hassl.	0.4 ± 0.4	0.2 ± 0.4	1 ± 0	-
Ophiorrhiza sp.	-	0.2± 0.4	-	-
Randia dumetorum Benth.	-	0.2 ± 0.4	-	-
Saprosma ternatum Hk.	8.8 ± 2.3	3.2 ± 2.6	0.2 ± 0.4	-
Solanum torvum Swartz	0.2 ± 0.4	-	-	-
Solanum spirale Roxb.	1.8 ± 1.7	0.4 ± 0.4	-	-
Sterculia villosa Roxb.	0.2 ± 0.4	-	-	-
Tetracera sarmentosa (Linn) Vahl	4.4 ± 2.6	-	-	-
Viburnum foetidum Wall.	-	0.4 ± 0.4	-	-
Vitis bracteolata Wall.	-	1.6 ± 1.4	1 ± 0.6	-
Wendlandia sp.	1.4 ± 0.3	2.8 ± 1.2	1 ± 0.6	-

Table III. 6. Density (no. of plants m^{-2}) of herbs and vines in four forest stands experiencing different degrees of disturbance, ± SD values.

Species	Undisturbed stand	Mildly disturbed stand	Moderately disturbed stand	Highly disturbed stand
Borreria articularis Linn.	4.4± 2.5	1.6 ± 0.48	1± 0	-
Buettneria aspera Colebr. ex Wall	1± 0	1.2 ± 0.4	-	1.2 ± 0.4
Cardiospanum halicacabum Linn.	-	2 ± 1.67	1.2 ± 0.4	1.6 ± 0.4
Cerasus jenkinsii Hk.f. & Thoms.	-	0.87 ± 0.5	-	1.6 ± 0.8
Cyanotis cristata Linn.	-	2.4 ± 1.2	-	1 ± 0
Cyathula prostrata Blume.	3.1± 1.2	1.2 ± 0.4	-	-
Cynodon dactylon Pers.	9.4± 2.6	7.8 ± 4.22	2.6 ± 1.62	5.4 ± 3.8
Cyperus rotundus Linn.	4± 2.4	2.2 ± 0.54	-	1 ± 0
Forestia glabrata Linn.	10.6± 2.15	10± 3.78	1.8 ± 0.74	9.4 ± 3.92
Glycosmis sp.	-	0.6 ± 0.48	1.2 ± 0.4	-
Hedyotis scandens Roxb.	-	-	2.6 ± 1.35	-
Hypochaeris radicata Linn.	-	3.4 ± 1.62	-	0.4 ± 0.8
Hyptis sauveolens Poit.	1.2 ± 0.4	1 ± 0.4	-	3.2 ± 1.2
Myxopyrum smilacifolium Bl.	-	0.8± 0.6	1.2 ± 0.4	1.2 ± 0.4
Phrynium sp.	-	-	2.2 ± 0.4	-
Piper sp.	1 ± 0.63	-	7 ± 2.09	-
Pteris sp.	10.2 ± 3.31	4.2 ± 1.57	0.4 ± 0.8	3.4 ± 1.2
Selaginella sp.	3.2 ± 0 .97	-	-	2.4 ± 0.97
Setaria glauca Beauv.	-	-	-	1.2 ± 0.4
Setaria palmifolia Stapf.	1.2 ± 0.7	1.2 ± 0.4	0.8 ± 0.4	-
Tinospora cordifolia Hiers.	-	0.2 ± 0.4	-	1.2 ± 0.82
Trachelopermum lucidum Hk.f	-	-	-	-
Uncaria sessilifructus Roxb.	0.2 ± 0.4	-	-	0.2 ± 0.4

Blastus cochichinensis and *Litsea salicifilia* dominated over other species. No shrub was recorded in the highly disturbed stand due to cultural operations.

Herbs and vines covered the entire ground surface of the forest stands. The undisturbed stand recorded the highest herb and vine density while the lowest density of these plants was recorded in the moderately disturbed stand. Herb and vine species such as *Cyperus rotundus, Forestia glabrata and Pteris quadrissmita were* common to all the stands.

Discussion

The overall structural pattern of the forest community revealed that all the study stands were mainly dominated by *Dipterocarpus macrocarpus, Shorea assamica, Castanopsis indica, Terminalia chebula* and *Vatica lancefolia* with a few exceptions in the highly disturbed stand. Status of regeneration of *Elaeocarpus ganitrus* seems to be very poor in all the stands. All the stands had a highly heterogeneous distribution of trees and can be considered as the highly diverse forests in the Eastern Himalaya (Singh & Singh 1987). The undisturbed stand had a high density of tree species due to restricted access of human being.

The canopy layer is occupied by *Dipterocapus macrocarpus, Shorea assamica, Duabanga grandiflora* and *Terminalia* spp. in all the stands. These dominant species restrict the light availability to the sub-canopy and ground vegetation in the undisturbed and mildly disturbed stands. The presence of seedlings and saplings of these canopy species reveals that they are regenerating adequately in all the stands in spite of competition from the sub-canopy and herbaceous species. The data on regeneration status of tree species indicate that these species show continuous establishment of seedlings and saplings because of their widespread occurrence in the forest. However, in the moderately disturbed stand the additional microsites created due to man- made interference favour the germination of other opportunist species improving their regeneration (Ohsawa *et al.* 1986). The reduced frequency of such opportunist species can be attributed to the occurrence of sporadic periods of environmental conditions favorable for their regeneration (Wilson 1991). If such periods of opportunity were repeatedly available at different times within the landscape, such species may show good germination and may even become dominant (Loucks 1970, Bormann & Likens1979). However, some species still show poor regeneration due to problems in germination of seeds even though favorable condition prevailed in forest. Sporadic regeneration of Rudraksh may be attributed to such problems.

Tropical forest is rich in species density (Richards 1952, Paijamans 1970) and many factors affect its diversity (Janzen 1970, Connell 1971, Hubbell 1979; Parthasarathy 1999). According to Whitmore (1984) in tropical rain forest, tree species number per hectare ranges from 20 to a maximum of 223. Species diversity is often correlated with rainfall, nutrient status (Hartshorn 1980) and disturbance level (Rao *et al.* 1990). Human-induced disturbance (such as mining, timber extraction etc.) and livestock grazing also cause changes in species number, tree density and basal area (Rao *et al.* 1990). Unrestricted and open accessibility may cause enhanced utilization of resource and this may eventually lead to a species-poor state (Vetaas 1993, Murali *et al.* 1996).

Role of gaps in the regeneration of forest trees is well recognized. Tree regeneration in the gaps has been shown to be dependent upon the history of forest community, seed availability and biology of the species (Hubbell & Froster 1992). Reduction of basal area in the mildly, moderately and highly disturbed forest stands could be due to extraction of timber, debarking, rotting of boles etc. Physical processes such as hydration and dehydration affect the basal area, stand quality and species. In spite of high disturbance a greater basal area was observed in the highly disturbed forest. This happened due to the retention of over mature, mature, buttressed and bad-form inferior tree species. Further, many broad-leaved tree species are also good coppicers and coppiced shoots have faster growth (Evans 1992) and such shoots are abundant due to the extraction of trees from the highly disturbed forest stand. Species composition is related to stand productivity and decrease in basal area reported due to deteriorating stand quality (Rai 1983). According to Smiet (1992), basal area values could be related to the stand disturbance index. So, in the heavily disturbed forest stand the basal area is lower than the undisturbed and mildly disturbed stands. In the present study the regeneration of Rudraksh was found to be very poor. Though the adult trees were present in all the study stands, the density of saplings and seedlings was very poor except in the undisturbed and mildly disturbed stands. This could be attributed to the relatively greater disturbance in the other two stands. The undisturbed stand is protected and is not accessible to the wood collectors. Therefore, the seedlings and saplings got the chance to establish and develop. On the other hand, in the mildly disturbed stand the presence of gaps created by human interference facilitated light penetration to the ground. Hence, germination of seeds was facilitated and subsequent development also occurred. Removal of overstory trees might have also favoured germination and seedling establishment through increase in solar radiation on the forest floor and consequent increase in surface temperature and reduced competition from the trees of upper canopy (Koller 1972, Noble & Slatyer 1980, Oliver 1981, Rao *et al.* 1997).

Species composition of forest in the undisturbed stand, mildly disturbed stand and moderately disturbed stand were more or less similar, which may be attributed to the similar topography, soil and climatic conditions of the study sites. However, the highly disturbed stand shows a different species composition especially at lower canopy level, due to *taungya* system of planting. Coffee bushes grew luxuriantly in the sub-canopy layer and no saplings of other species were recorded within the coffee bushes. The canopy layer is covered by *Dipterocarpus macrocarpus, Shorea assamica, Terminalia chebula, Duabanga grandiflora* etc. and regeneration of these species was abundant in the undisturbed, mildly disturbed and moderately disturbed stands. However, regeneration of Rudraksh was seen only in the undisturbed and mildly disturbed stands wherever the small gaps were created in the canopy and the surface was burnt with low intensity of fire.

All the forest stands except the undisturbed one, were under increasing biotic pressure due to firewood, fodder and timber collection and therefore, regeneration suffered most because most of the tree species produced seeds concurrently with the peak period of collection from the forest. Moreover, seeds of most of the forest timber species were susceptible to pests due to their thin seed coat and were viable only for a limited period (Sundriyal *et al.*1994). The outbreak of a few insect pests has been a major cause of poor regeneration. The proportions of seedlings, saplings and mature trees in a given species population may help in predicting its possible future status in the forest. Species with nearly the equal distribution of individuals in the three life stages are expected to remain dominant in the near future. The population size of such species which lack either seedlings or saplings may decline in coming years. The forest stands characterized by the abundance of only adults of the canopy and sub-canopy species and absence or very low populations of seedlings and saplings are expected to face extinction of some species in due course. The increasing biotic pressure may cause a drastic reduction in regeneration of several tree species. Indiscriminate tree cutting by local people, selective felling by forest department, timber trade, use of enormous amount of wood in house construction and plantation of tea and coffee are the major causes of forest destruction in Arunachal Pradesh and adjoining areas. These biotic stresses are also not allowing the degraded forests to regenerate properly.

However, Rudraksh and a few associated species show good regeneration in the mildly disturbed forest stand signifying the role of mild disturbance in tree regeneration. Harris & Far (1974) and Boring *et al.* (1981) have also emphasized the positive role of mild disturbance in increasing the regeneration of trees. Khan *et al.* (1987), Barik *et al.* (1996) and Maram & Khan (1998) have also reported better regeneration of tree species in mildly disturbed forests of north-east India.

CHAPTER IV

Regeneration Status and Population Structure of Rudraksh

Introduction

Regeneration status of tree species can be predicted by the age structure of their populations (Marks 1974, Vablen *et al.* 1979, Pritts & Hancick 1983, Saxena & Singh 1984, Saxena *et al.* 1984, Khan *et al.* 1987). Presence of sufficient number of seedlings and saplings and young trees is greatly influenced by the interaction of biotic and abiotic factors of the environment (Boring *et al.* 1981, Lange & Graham 1983, Aksamit & Irving 1984, Khan *et al.* 1986). These factors may affect the recruitment, survival and growth of tree seedlings and sprouts. Some species cannot grow under shade and hence require gaps for regeneration. During the period following large disturbance such as windstorm, drought and fire, there is sudden appearance of pioneer tree species in areas where direct sunlight reaches the ground (Brokaw 1982, Putz *et al.* 1983, Whitmore 1984, Denslow 1987, Putz & Appanah 1987). Population structure may, however, be greatly influenced by disturbance and the species responses to gaps (Parthasarathy & Karthikeyan 1997b). The study on the regeneration pattern and population structure of Rudraksh in four different forest stands was undertaken to analyze the impact of disturbance on regeneration and population structure of the species.

Methods

Population structure of Rudraksh was studied during 1998-1999 using quadrat method (30 m ×30 m for trees and saplings, 10 m ×10 m for seedlings). For this purpose, ten quadrats were placed randomly at each stand for trees, saplings and seedlings. The individuals of Rudraksh occurring in each of the quadrats were listed and their circumference was measured. These individuals were separated into three categories i.e. (a) seedlings (≤10 cm collar circumference at the base), (b) saplings (10≥20 cm collar circumference at the base) and (c) tree (>20 cm circumference at breast height i.e.1.37 m above ground level - CBH). About 20 seedlings were tagged for growth and survival studies. Cut stump were recorded in each quadrat and sprouts were counted. Density (trees ha^{-1}) and basal area values were calculated.

There were four stands of forest plantation adjacent to the studied area, which gave the opportunity to study the difference in sprouting and regeneration behaviour of planted and natural populations. The stumps were more pronounced in the planted stands due to household uses by neighbouring human settlement. On the other hand, in the undisturbed and highly disturbed stands no cut stump was observed. This might be due to restricted tree felling and other operations in the undisturbed stand and digging out of the stumps in the highly disturbed stand.

Results

Population of Rudraksh varies in different stands (Fig IV. 1). The mean density of adult trees is 21 individuals per hectare in the undisturbed stand, 19 in mildly disturbed stand, 14 in moderately disturbed stand and 12 in highly disturbed stand. The total density and basal area of the species were more in the undisturbed stand as compared to the disturbed stands.

The saplings were recorded in two stands only. Four saplings/ha were recorded in the mildly disturbed stand and 2 saplings in the undisturbed stand. No sapling was recorded in the moderately disturbed and highly disturbed stands.

Seedling population was sporadic and discontinuous. No seedling was recorded in the highly disturbed stand, while 200 seedlings/ha were recorded in the mildly disturbed stand as well as undisturbed stand and 100 seedling/ha were recorded in the moderately disturbed stand (Fig. IV.1). Seedlings were found mostly under the canopy of Rudraksh trees, while one sapling in the undisturbed stand was found outside the canopy of the tree (30 m away from the Rudraksh tree).

Basal area values for trees and saplings of Rudraksh in different stands are given in Table IV.1. Total basal area for the undisturbed stand was 4190

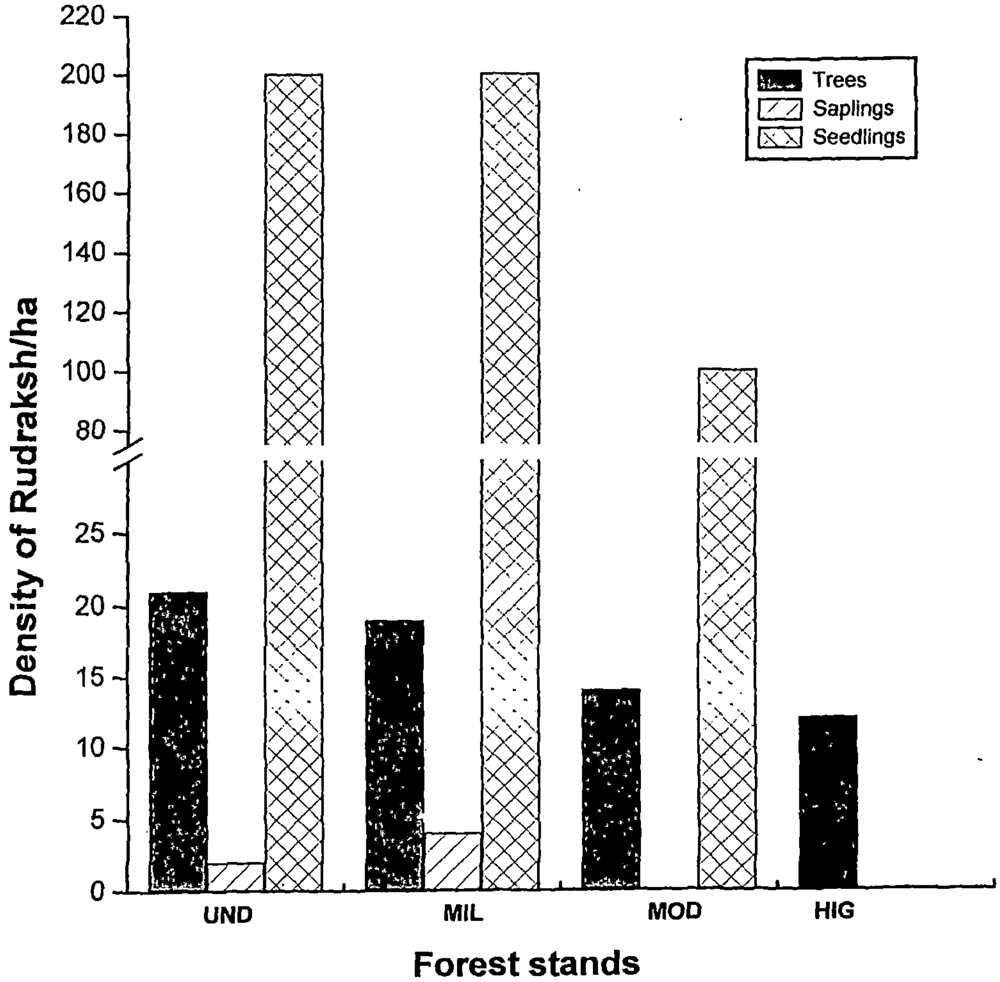


Figure IV.1. Density of tree, sapling and seedling populations of Rudraksh in the four forest stands experiencing different degrees of disturbance.

cm^2/ha while it was 2564, 1875 and 2785 cm^2/ha for the mildly, moderately and highly disturbed forest stands.

Table IV. 1. Basal area of Rudraksh in four forest stands experiencing different degrees of disturbance.

Parameters	Undisturbed stand	Mildly disturbed	Moderately disturbed	Highly disturbed
Basal area (cm^2/ha) (Trees+ saplings)	4190	2564	1878	2785

Survival of seedlings is greatly affected by the ambient environment, biotic factors and abiotic factors. The highest seedling survival (59%) was recorded in the moderately disturbed stand followed by the undisturbed stand (50%) while the lowest seedling survival (31%) was recorded in the mildly disturbed stand. The maximum seedling growth was recorded in the mildly disturbed stand followed by the undisturbed stand (Table IV. 2). Growth rate in terms of seedling height and leaf number was maximum in the undisturbed stand followed by the mildly disturbed stand.

Table IV. 2. Seedling survival and growth rate of seedlings in the four forest stands.

Stands	Tagged seedling population	Seedling survival (%)	Growth Rate	
			Height (cm/month)	Leaf number (no./month)
Undisturbed stand	20	50	2.39	5.57
Mildly disturbed stand	17	31	2.40	4.45
Moderately disturbed stand	17	59	2.14	2.78
Highly disturbed stand	-	-	-	-

The cut stumps were recorded in the two stands only. The moderately disturbed stand recorded 22 stumps per hectare while 8 stumps were recorded in the mildly disturbed stand. No stump was recorded in the undisturbed and highly disturbed stands. Sprouting was observed in 36% of the stumps in the moderately disturbed stand while in the mildly disturbed stand 75% stumps showed sprouting. It was observed that lower diameter cut stumps had the greater ability of sprouting than the stumps having greater diameter classes in both natural and planted stands of Rudraksh in different locations (Fig IV. 2). Sprouting ability of the cut stumps was more in the natural stands as compared to the planted stands (Table IV. 3).

Table IV. 3. Characteristics of four planted stands of Rudraksh nearest to the natural stands.

Location	Number of individuals	Area of the stand (m^2)	Number of cut stumps	Seedling number
Deomali	103	4800	13	Nil
Namchangmukh	47	2048	Nil	Nil
Dirok	35	550	2	Nil
Borduria	17	200	Nil	Nil

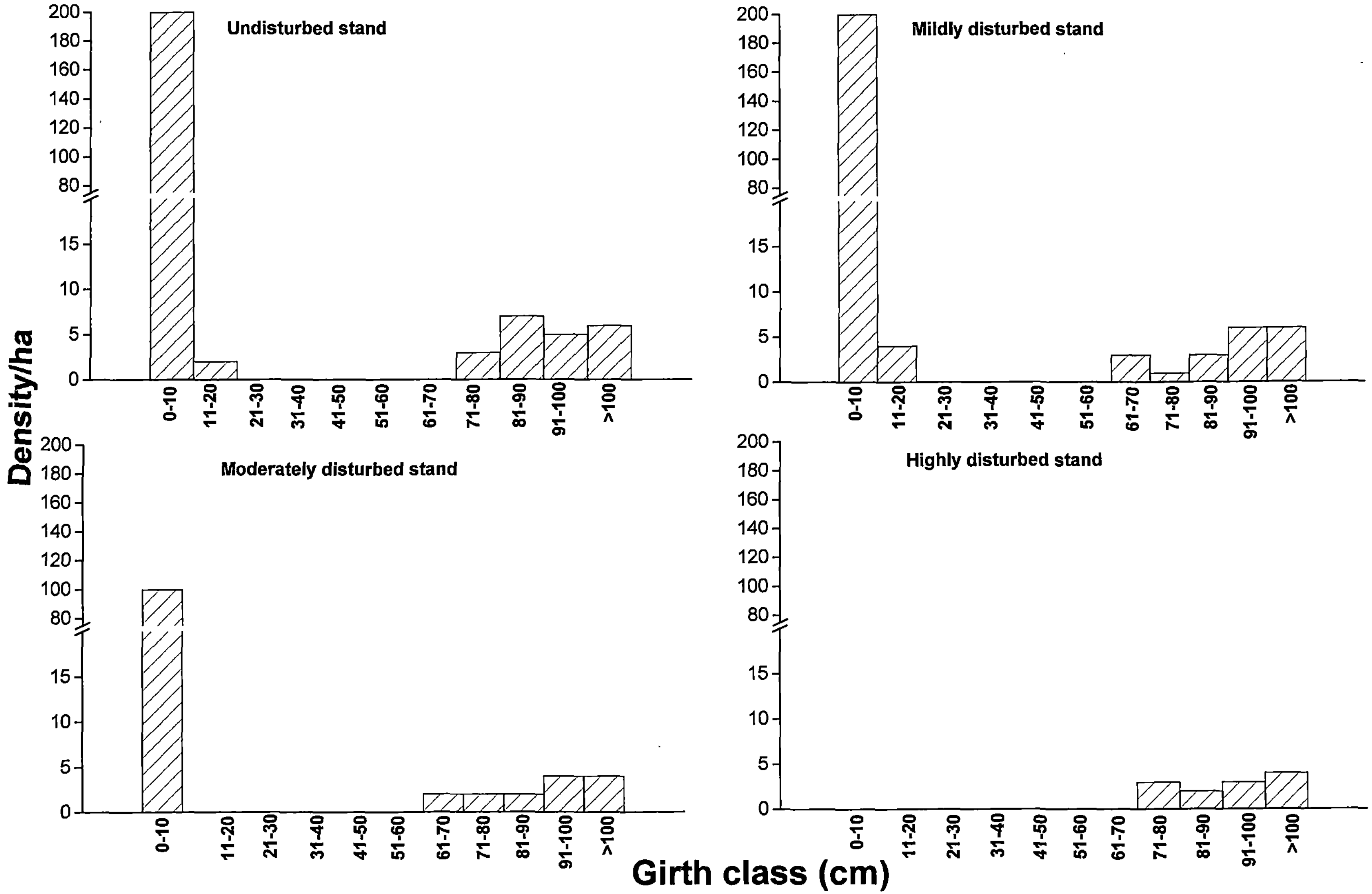


Figure IV. 2. Population structure of Rudraksh in four forest stands.

Discussion

The population of Rudraksh was rather low in the forest stands. The adult individuals were recorded in all the stands, but the absence of seedlings and saplings was evident in most stands. This may be attributed to the canopy condition and human interference in different stands. Restricted access of human beings and control over tree felling and other operations in the undisturbed stand might have favoured the regeneration and thus larger number of seedlings are available in this stand. Clark & Clark (1987) reported an adult density of 2 trees per hectare for the Neotropical emergent tree species *Dipteryx panamensis* in Costa Rica. Pande (1999) reported less tree diversity of *Shorea robusta* in disturbed forest whereas the shrub and herb diversity followed the reverse trend. On the contrary, Tripathi and Khan (1992) reported that survival of tree seedlings is greater in the disturbed forest compared to the protected forest.

The age-structure of Rudraksh indicates that it has a poor regeneration potential. Some girth classes (especially the girth class of 30-60 cm) are not represented in the population. Most of the adult individuals were in the girth range of >60 cm in all the stands (Fig. IV.3). Discontinuous population structure has been reported for a number of other tropical light demanding pioneer species such as *Endospermum medullosum* in Solomon Island (Whitmore 1984), *Trema micrantha* in tropical moist forest on the Barro Colorado Island, Panama (Brokaw 1987), *Scalesia pedunculata* a fast growing pioneer tree in Galapages Island

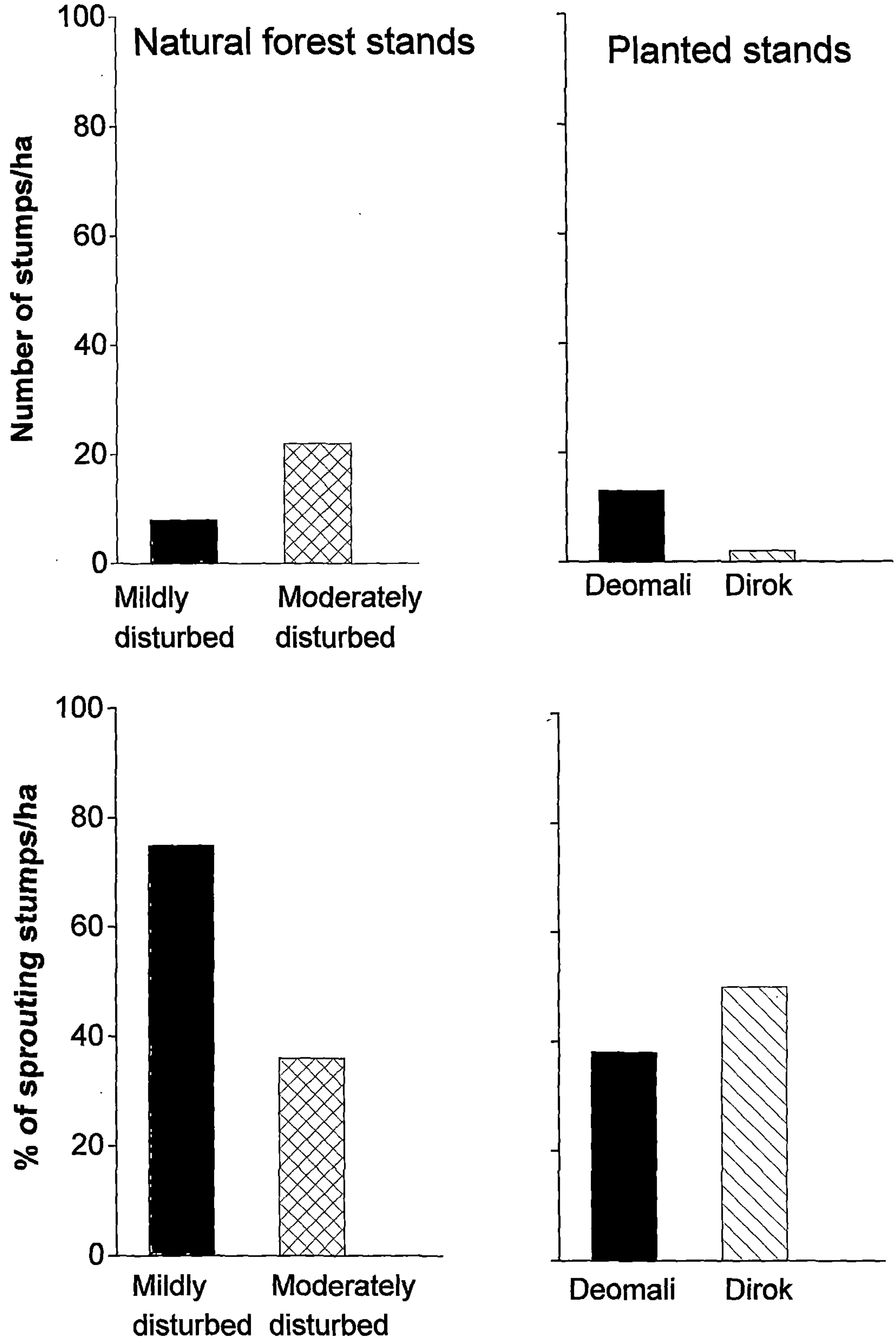


Figure IV. 3. Number of cut stumps and percentage of sprouting stumps in different natural and planted forest stands.

(Itow & Mueller- Dombois 1988), *Grewia pandaica* in Western Ghats (Parthasarathy & Karthikeyan 1997b).

The seedlings were recorded in the three stands only viz. undisturbed stand, mildly disturbed stand and moderately disturbed stand. Seedlings and saplings were seen growing under the canopy cover of the Rudraksh trees and no seedling was recorded outside the canopy of the trees (plate IV.3). Only one sapling was recorded outside the canopy in the undisturbed stand and that may be there due to the bird dispersal of the ripen fruit. The density of the adult trees and disturbance do not appear to show any effect on recruitment.

Folivory by leaf eating caterpillars was observed in the undisturbed stand in seedlings, saplings and trees but the intensity of folivory was more in the seedlings and saplings. Also the young leaves in trees were more vulnerable than the old leaves. Spider webs were also quite commonly seen on Rudraksh plants. Further, the incidence of spider webs was highest in the undisturbed and least in the moderately and highly disturbed stands. The shaded and moist conditions of the forest stands stimulated the herbivory and pathogen attack on leaves. Augspurger (1984b) reported pathogen as the cause for seedling mortality in some tropical tree species under shaded condition. Moreover, competition for resource and production of allelochemicals by ground vegetation may also influence the seedling survival in dense canopy forest stand (Stewart 1975, Horsely 1977).

Plate IV. 1 Debarking in adult Rudraksh trees by wild animals (A); humans for medicinal purposes (B); bark destroyed by termites (C).

Plate IV. 2. An overview of Rudraksh plantations.

Plate IV. 3. Natural regeneration of Rudraksh through seeds.

Plate IV. 4. Cut stumps (A & B) and regeneration through stump sprouting in Rudraksh (C).

Resprouting of cut stumps was observed in both natural and planted populations of Rudraksh. But their resprouting ability varied with stand and stump diameter (plate IV.4). The cut stumps of natural population had greater ability of resprouting than the planted stand. This may be due to less human interference in the natural population. The planted stands being near the roadside were subjected to more frequent human interference for seed collection and other purposes (plate IV.2).

In the present study, regeneration of the species was found very poor. The study reveals that a threatened species such as Rudraksh which has a low population density and exacting habitat preference may not be able to perpetuate itself for long if effective conservation measures are not taken in time.

CHAPTER V

Fruit Set, Dispersal and Nut Bank Dynamics in Rudraksh in Relation to Cultural Disturbances

Introduction

Seed production and their dispersal to favourable microsites, seed germination and establishment of seedlings determine the success of tree regeneration (Barik *et al.* 1996). Extrinsic factors such as resource availability, pollination failure, predation on flowers, fruits and leaves, and climatic conditions particularly during flowering season (Stephenson 1981, Lee 1988, Khan *et al.* 1999, Felfili *et al.* 1999) and intrinsic factors such as age, vigour of the tree and its genetic constitution (Winn & Werner 1987) may significantly affect fruit production. The fruit production may differ among populations of the same species on spatial and temporal scale, and the individual trees within a population may also show variation in fruit set (Howe 1982, Grubb 1977, Schupp 1990, Barik *et al.* 1996, Khan *et al.* 1999).

Fruit dispersal is an important stage in the life history of a plant, which influences not only the recruitment patterns on a spatial and temporal scale but also the structure and dynamics of a plant community (Sinha & Davidar 1992). Within areas delimited by specific environmental requirements, the location and persistence of individual populations may be dictated by their vulnerability to stochastic and deterministic processes. These processes can reduce population of a species to levels at which extinction may become imminent (Gilpin & Soule 1986). Such extinction may be averted by the dispersal of propagules to favorable microsites (Taylor 1990). For this reason, dispersal has been described as the 'glue', which keeps local populations of a species together (Hanson 1991). Several investigations have shown that the distance from source populations is important in determining the establishment and persistence of a species (see Quinn *et al.* 1994). It has been suggested that the dispersal ability is one of the main factors in preventing angiosperms from modifying their distributions in response to climate change (Primack & Miao 1992). The dispersal agents and fruit characteristics determine patterns of fruit dispersal. Janzen (1970) and Connell (1971) were the first to propose that as seed density decreases with distance from the parent plant, seed survival increases and this may lead to higher recruitment at some distance from the plant. However, Hubbell (1980) argued that recruitment could be higher close to the parent because of considerably greater seed abundance there, despite very low seed survival. Seed dispersal away from the parent may not only reduce density and distance-dependent mortality near the adult (Janzen 1983), but may also help in colonizing the clearings and gaps (Hamilton & May 1977, Augspurger 1983b).

The main objective here is to study the spatio-temporal patterns of the processes leading to regeneration of Rudraksh. For this, flower and fruit production, distance - related disappearance of fruits during fruit-fall and post- fall periods, and dynamics of nut population on forest floor were followed over a 3-yr period along a disturbance gradient. Individuals of the study species varied in size, which provided an opportunity to investigate the variations in fruit production of the trees. The study also seeks to analyse the factors causing the poor recruitment of Rudraksh in natural forests.

Methods

Estimation of flower and fruit production

Five fruiting trees of *E. ganitrus* in each of the three CBH classes viz., 60-90 cm (11±1.5 m height, 60±2 m^2 canopy cover), 90-120 cm (18.5±1.8 m height, 85±2 m^2 canopy cover) and 120-150 cm (25±1.8 m height, 120±3.5 m^2 canopy cover) were marked in each stand during May, 1997. The numbers of flowers and fruits produced by these marked trees were estimated for three consecutive years during 1997-99 (plate V.1). Flower bud count was the criterion to estimate the flower production. Appearance of shining bluish colour of the fruit coat was taken as an indication of maturity. The aborted fruits were not considered for determining fruit production. Fruits were counted just before maturation in mid-November. Since dispersal of fruits starts during maturation on the tree itself, fruit production estimates made on the tree in the initial stage of maturation represented the total fruit production including those dispersed during the maturation phase.

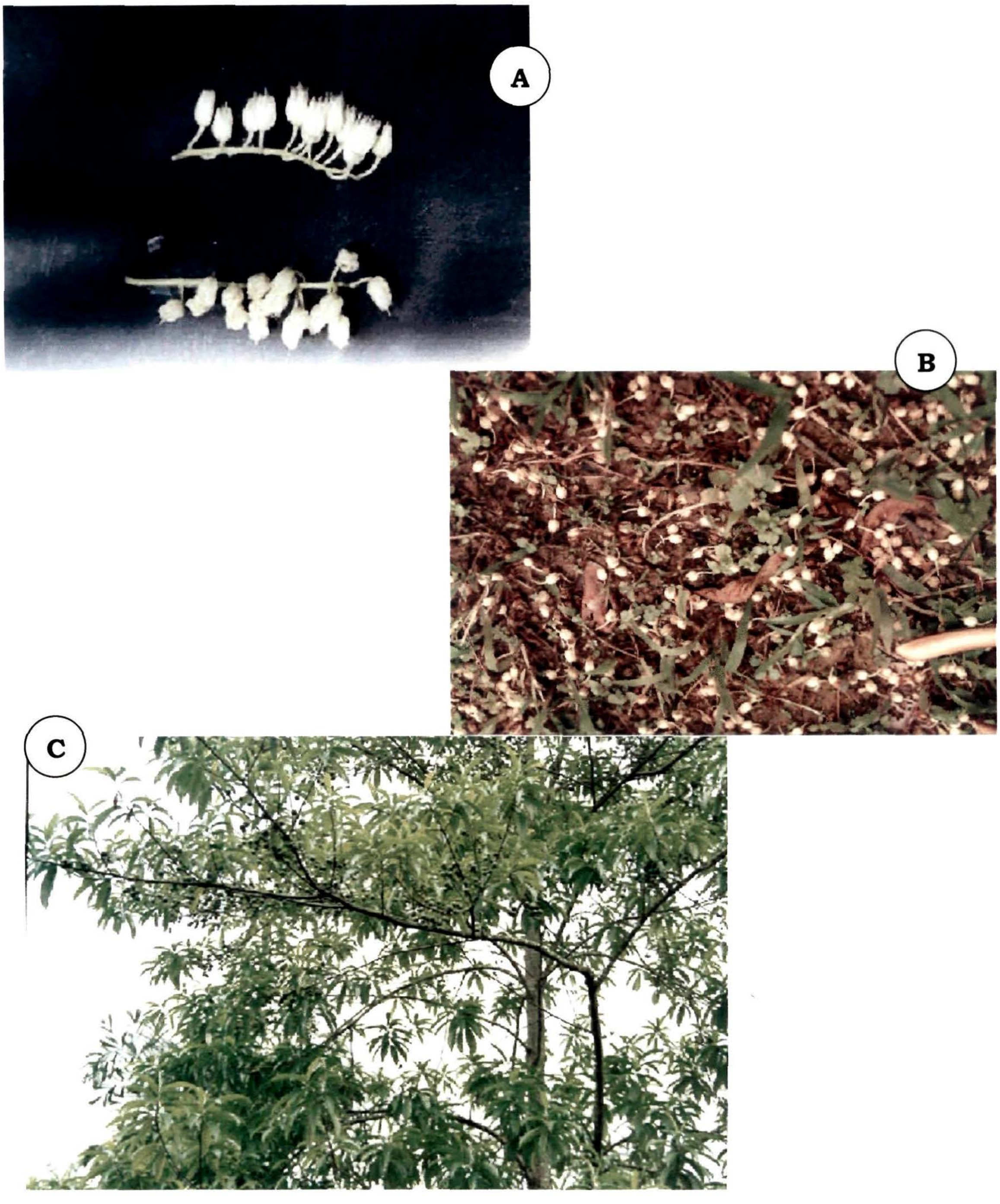


Plate V. 1. (A): Close view of the inflorescence of Rudraksh; (B): Abortion of flowers; (C): Fruits setting.

The flower and fruit production for each tree was estimated as follows: Total flower/fruit production = Total number of branches × mean number of sub-branches per main branch × mean number of inflorescences per sub-branch × mean number of flower buds/fruits per inflorescence (Barik *et al.* 1996).

For each tree, mean number of inflorescence per branch was calculated from a sample of 10 branches and mean number of flower buds/fruits per inflorescence was calculated from a sample of 50 inflorescences. The data were pooled for each CBH class, each stand and each year, and three-way ANOVA (fixed effect-restricted randomization) was performed to test the effect of each of these factors. However, in absence of replication of stands, the inferential statistics for disturbance (i.e. stand factor) was not used for interpreting results and drawing conclusions. To avoid the effect of pseudoreplication, flower and fruit production and flower abortion data have been presented in a tabular form giving standard deviations (see Hurbert 1984). Flower abortion was estimated by subtracting the fruit production from flower production value in each case.

Average fruit weight was determined from a composite sample of 500 fresh fruits collected from each of the marked trees. After fermenting the fruit pulp of the same sample in soil pit for one week, nuts were cleaned in running tap water and their fresh weight was determined.

Dispersal of fruits

Deers (*Cervus unicolor, Axis axis,* and *Muntiacus muntjak*) were seen to eat the ripe fruits that had fallen on the forest floor. Nuts were also found in the dung balls of elephant (*Elephas maximus,* plate V.2). Two species of bats (*Rousettus teschenaulti,* and *Scotophillus heathi*) were seen visiting the Rudraksh trees during night. A few other wild animals e.g. buffalo (*Babulus bubalis*), mithun (*Bos frontalis*), wild pig (*Sus scrofa*) etc. were also sighted near Rudraksh trees during fruiting period. However, rodents viz. *Vandeleuria oleracea*, *Rhizomus pruinosus, Mus musculu, Rattus rattus rufescens* (Gray), *R. rattus brunneusculus* (Hodgson), *Micromys minutus erythrotis* (Blyth), seemed to be the main consumers, dispersers and hoarders of fruits. Hoarded fruits were found in logs (plate V.2). Insect larvae consumed the fruit pulp, but normally, they did not damage the nut. Hornbill (*Anthracoceros malagricus*), flying squirrel (*Belomys pearsoni* and *Petaurista magnificus*), monkey (*Presbytis entellus* and *P. pileatus*) and a few birds were seldom seen eating the ripe fruits during the daytime.

Five sample fruiting trees of *E. ganitrus* were marked in each of the four forest stands for fruit dispersal and predation studies. The trees marked for this study were growing at least 100 m apart and no other tree of this species was present within this distance range. Fruit dispersal was studied in concentric circles around each fruiting tree spaced at 2.5 m radial increments beyond the crown radius. The fruits falling under the tree crown were not taken into account in the fruit dispersal study. The first of the concentric circles had a radius of 5 m

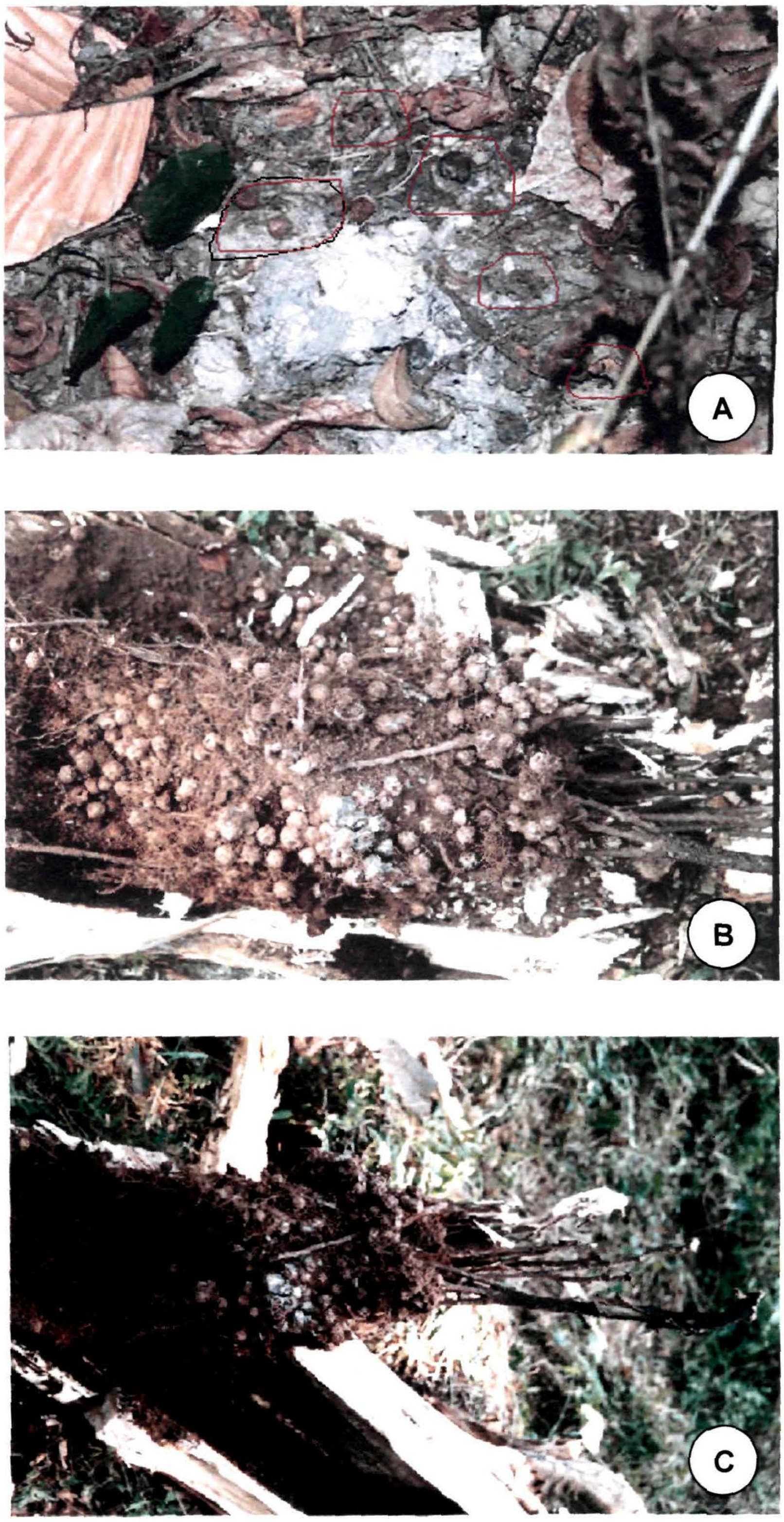


Plate V. 2. Nuts found in elephant droppings (A), hoarded by rodents & stored in rotten logs (B). Stored nuts germinated in rotten logs and, dead seedlings due to over-crowding and physical absence of mineral soil (C).

and the maximum radius considered was 45 m. The circles were visited at alternate day over a period of 20 days during the peak period of fruit-fall. During each visit, fruits in all circles were collected and counted separately. The dispersal was expressed as the number of fruits per 100 m^2. Suitable regression models (Zar 1996) were tested to establish the relationship between dispersal distance and number of fruits dispersed.

The fate of fruit populations

Differentiation between the fractions of fruit population lost to predation and transport is very difficult to assess experimentally (Van Tooren 1988). Thus, the term 'disappearance' used in this paper includes the fruit loss due to predation as well as to transport and dispersal by animals and run-off (Barik *et al.* 1996). Five wooden fruit traps, 100 × 100 cm and 30 cm deep, were laid at random under the tree crown of each of the five marked trees at the beginning of fruit-fall and were visited until the completion of fruit shedding. All the fruits in each trap were counted. The undamaged fruits were separated from those eaten by insects, rodents and birds. The difference between total fruit production and the undamaged fruits that fell beneath the tree crown represented the fraction of fruit populations disappearing during the fruit-fall period.

The fate of undamaged fruits after fruit fall was studied by sowing 30 fruits in each of the five 1 × 1 m plots beneath each sample tree. The plots were visited at 7-day intervals up to 3 months. On each observation date, the numbers of dormant/rotten/germinated fruits and those that had disappeared, were noted. The percentage of fruits in each case was determined and the means (n = 5 trees) for each stand were calculated. The study was repeated during 1998 and 1999 to study the year-wise variation in pattern of fruit loss. The fractions of fruit populations that had disappeared, and those that were dormant/rotten or germinated, were presented as percentages of total fruit production for the three years of study.

Effect of distance from parent trees on fruit disappearance

To study fruit disappearance at different distances from the parent tree, three 1 × 1 m quadrats were randomly placed on each of the concentric circles with radii of 5, 10, 15, 20, 25, 30, 35, 40, 45 m from the base of the fruiting tree. Thirty fruits of Rudraksh were marked with waterproof paint and placed in each quadrat. The fate of fruits was monitored at 3-day intervals for one month and then at weekly intervals over a period of 2 months for determining the disappearance. At the end of 3 months, the numbers of fruits that had disappeared (consumed or transported by herbivores or other agencies) were recorded. This study was carried out during 1997, 1998 and 1999. The data for the three years were pooled and analysis of variance was performed to test the effect of distance from the parent tree on disappearance.

Effect of fruit quality on dispersal/disappearance

To study the preferential effect of fruit quality on dispersal/disappearance, five 1 m × 1 m quadrats, were randomly laid at the centre of the crown of the marked fruiting trees in each forest stand. Thirty fruits of Rudraksh (10 ripe + 10 unripe + 10 fruits without pulp or nuts) were marked with waterproof paint and placed in each quadrat. The fate of fruits was monitored at 3-day intervals over a period of forty-five days for determining the disappearance. At the end of the observation period, the numbers of fruits that had disappeared (consumed or transported by herbivores or other agencies) were recorded. This study was carried out during 1997, 1998 and 1999. The data for the three years were pooled and analysis of variance was performed to test whether dispersal/disappearance were influenced by the fruit quality.

Assessment of nut bank in the soil

To assess the fate of remaining nuts of Rudraksh after the dispersal/ disappearance of fruits during fruit-fall and post-fruit fall period, nut-banks were estimated beneath the five marked trees in each stand just before the next fruit rain in October 1997, 1998, 1999. As the nuts of Rudraksh are usually present on the soil surface, the forest floor beneath the marked trees was swept before the fruit fall period to avoid the addition of nut banks of previous years. To study the nut-bank, five 1 m × 1 m quadrats were randomly laid on each of the concentric circles with radii of 5, 10, 15, 20, 25, 30, 35, 40, 45 m from the base of the fruiting tree. The nuts were collected from each quadrat and total nut bank was computed for each marked tree. The fractions of predated and undamaged nuts were calculated. The study was carried out during 1997, 1998 and 1999. The data for the three years were pooled and analysis of variance was performed to test the year-wise differences in nut bank and the predation of nuts.

Results

Flower and fruit production

Flower production in Rudraksh increased significantly (F= 1582.08, df = 2, $P<0.0$; three-way ANOVA) with the increase in CBH of fruiting trees. The year-wise flower production also varied significantly (F = 286.9, df = 2, $P<0.0$; Table V.1). Production of flowers also differed significantly (F = 87.9, df = 3, $P<0.0$) between the four forest stands experiencing different degrees of disturbance, and was the highest in the moderately disturbed forest and lowest in the undisturbed forest. Flower abortion too varied significantly with years (F = 756.08, df = 2, $P<0.0$) and CBH classes (F = 37.06, df = 2, $P<0.0$). However, the fruit abortion did not differ significantly in different forest stands (Table V.1).

Production of fruits in Rudraksh also increased significantly (F=867.3, df = 2, $P<0.0$) with the increase in CBH of fruiting trees, and the year-wise variation in fruit production was also significant (F = 1106.2, df = 2, $P<0.0$; Table V.1). Fruit production also differed significantly (F = 61.3, df = 3, $P<0.0$) between the forest stands, the highest being in the moderately disturbed forest and lowest in the undisturbed forest.

Table V. 1. Year-wise variation in flower and fruit production and percentage of aborted flowers in trees of different CBH classes of Rudraksh in different forest stands experiencing different degree of disturbance. ± indicates SD values.

	Undisturbed stand			Mildly disturbed stand			Moderately disturbed stand			Highly disturbed stand			
	CBH class (cm)			CBH class (cm)			CBH class (cm)			CBH class (cm)			
	60-90	90-120	120-150	60-90	90-120	120-150	60-90	90-120	120-150	60-90	90-120	120-150	*F* value
Flower production (n=5)													
1997	7951	21216	37609	9948	24905	41932	14459	32547	50145	12439	30401	46005	Stand=87.9; p=0.0
	±1083	±1812	±3174	±939	±2556	±4601	±1424	±2620	±7381	±1452	±2570	±4753	CBH=1582; p=0.0
													Year=286.9; p=0.0
1998	4284	11568	24602	5793	17981	28202	9713	22187	34064	7548	20193	30826	Year ×GBH=27.3; p=0.0
	±1259	±1913	±2625	±1022	±4727	±2793	±1042	±4685	±3000	±1110	±4671	±3212	Year ×stand=0.4; p=0.9
													CBH ×stand=2.8; p=0.01
1999	9598	23047	42190	12777	27464	47820	16813	33244	54998	14722	31390	51213	Year×GBH× stand=0.1; p=0.9
	±1303	±1071	±2562	±1781	±1453	±4518	±1450	±1548	±4175	±1353	±1677	±3821	
Fruit production (n=5)													
1997	904	3028	4664	1150	3655	5474	1579	4656	6590	1397	4365	6449	Stand=61.3; p=0.0
	±307	±130	±797	±317	±249	±764	±442	±881	±911	±382	±749	±939	CBH=867.3; p=0.0
													Year=1106.2; p=0.0
1998	317	478	770	453	611	902	607	812	1096	479	724	1028	Year ×GBH=160.7; p=0.0
	±88	±119	±87	±42	±133	±167	±60	±166	±174	±51	±157	±189	Year × stand=9.06; p=0.0
													CBH× stand=4.5; p=0.0
1999	1056	3785	4855	1284	4456	5830	1891	5607	7593	1554	4839	6600	Year×GBH× stand=1.2; p=0.3
	±200	±413	±494	±265	±549	±336	±265	±398	±353	±231	±514	±190	
Flower abortion (%) (n=5)													
1997	88.87	85.67	87.65	88.48	85.24	86.97	89.22	85.66	86.80	88.91	85.68	86.00	Stand=0.3; p=0.8
	±2.35	±0.93	±1.18	±2.72	±1.23	±0.46	±1.96	±2.67	±1.04	±1.74	±1.62	±0.91	CBH=37.05; p=0.0
													Year=756.08; p=0.0
1998	92.82	95.77	96.86	91.98	93.68	96.8	93.70	96.23	96.78	93.56	96.26	96.66	Year ×GBH=56.7; p=0.0
	±2.47	±1.13	±0.24	±1.56	±6.24	±0.45	±0.75	±0.88	±0.36	±0.94	±1.07	±0.47	Year × stand=1.2; p=0.3
													CBH × stand=1.4; p=0.2
1999	89.01	83.50	88.51	89.96	83.71	87.72	88.76	83.12	86.16	89.45	84.60	87.07	Year×GBH× stand=0.3; p=0.9
	±1.34	±2.20	±0.48	±1.38	±2.34	±1.23	±1.04	±1.03	±0.50	±1.14	±0.92	±0.64	

Mean fruit and nut weight of Rudraksh decreased significantly (F = 7872.4 & 3545.2 respectively; df = 3; *P*<0.0; one way ANOVA) with increasing disturbance (Table V.2).

Table V.2. Mean fruit weight (g ± SD, n=500) of Rudraksh in different forest stands.

	Forest stand					
	Undisturbed	Mildly disturbed	Moderately disturbed	Highly disturbed	F-value	P-level
Fruit with pulp	5.89±0.47	4.55±0.4	3.24±0.3	2.85±0.4	7872.4	00
Fruit without pulp	3.55±0.34	3.00±0.6	1.83±0.3	1.80±0.2	3545.2	00

Fruit dispersal

The number of fruits per unit area of the forest floor decreased significantly (F = 7065.2; df = 16; *P* <0.0) with increase in distance from the parent tree crown in all the four forest stands (Fig. V. 1). Maximum fruits (32-191 fruits per 100 sq. m) were counted within 5 m of the tree. Regression models indicating the relationship between the number of fruits and dispersal distance in the four forest stands experiencing different degree of disturbance are shown in Table V. 3.

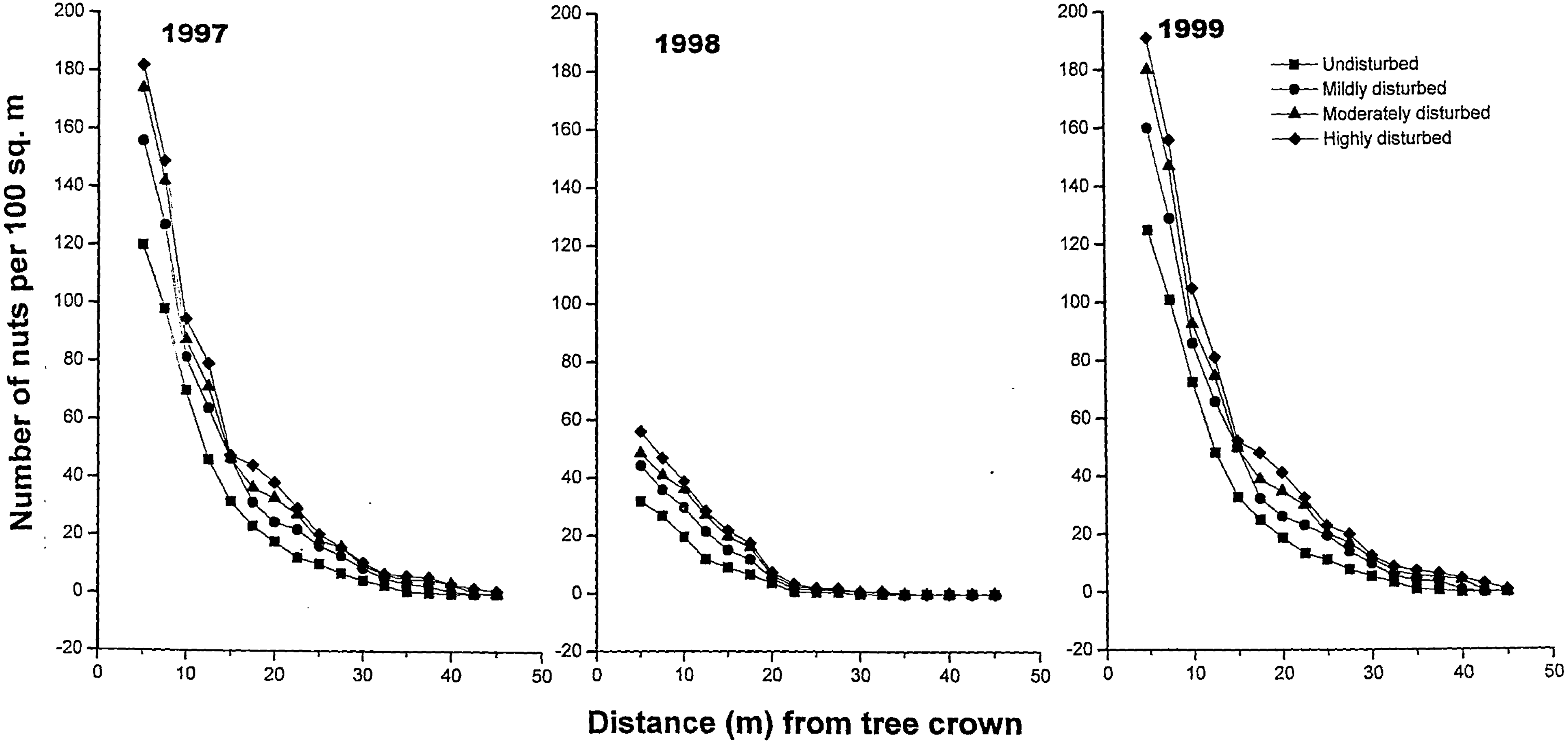


Figure V. 1. Dispersal curves of Rudraksh in different forest stands.

Table V. 3. Relationship between seed density per 100 sq. m (y) and dispersal distance in metres (x) in Rudraksh.

Forest stand	Regression model	r^2	n	Range of values for x
Undisturbed	y = 32.56-0.37x	0.71	17	5-45
Mildly disturbed	y = 33.13-0.30x	0.73	17	5-45
Moderately disturbed	y = 33.62-0.27x	0.74	17	5-45
Highly disturbed	y = 33.81-0.25x	0.75	17	5-45

Fate of fruits

40-70% of the total fruits produced by Rudraksh disappeared during the fruit fall period. Disappearance of the fruits was mainly attributable to the eating of the fruit pulp by birds and other animals, which drop them away from the parent tree, and also to the hoarding by rodents. It was maximum in the undisturbed stand (*ca.* 65%) and minimum in the moderately disturbed forest (*ca.* 45%: Table V.4). The fraction of damaged seeds was lower in good seed years than in the lean year. Though the fraction of the fruit population damaged by the insects was quite low (3.38-17.2%), it was generally greater in the moderately and highly disturbed stands than in the undisturbed stand.

During post-fruit fall period, a large fraction (55-99%) of the remaining fruits disappeared. However, disappearance increased with the increase in disturbance index and was maximum in the highly disturbed stand and minimum

Table V. 4. Fractions (%, ±SD) of dispersed/disappeared, insect-damaged and undamaged fruits in the total fruit population of Rudraksh during the fruit fall period; and of disappeared, dormant/rotten and germinated nuts in the undamaged nut population during the post-fruitfall period in the four forest stands (stands I, II, III, and IV are undisturbed, mildly disturbed, moderately disturbed and highly disturbed forest patches, respectively).

	1997				1998				1999				
	Stands				Stands				Stands				*F* -value
	I	II	III	IV	I	II	III	IV	I	II	III	IV	
Fruit fall period													
Disappeared/dispersed	63.08 ±2.47	56.56 ±0.82	42.38 ±1.21	49.74 ±2.98	70.0 ±3.8	60.6 ±1.9	50.7 ±1.7	48.1 ±2.1	62.9 ±2.9	59.7 ±1.3	40.6 ±0.7	53.4 ±1.9	Stand = 249.6; p = 0.0 Year =19.05; p = 0.0 Year × stand=14.2; p=0.0
Insect-damaged	3.94 ±0.6	6.02 ±0.71	12.1 ±1.43	12.58 ±2.12	7.14 ±0.4	7.42 ±0.7	17.2 ±1.1	13.0 ±2.0	3.38 ±0.7	5.3 ±0.6	10.8 ±1.1	11.6 ±2.1	Stand = 153.8; p = 0.0 Year = 29.6; p = 0.0 Year × stand=6.4; p=0.0
Undamaged	32.98 ±2.4	37.42 ±0.92	45.52 ±2.18	37.68 ±4.68	22.8 ±4.1	32.0 ±2.4	32.1 ±2.4	38.9 ±3.7	33.7 ±2.4	35.0 ±1.6	49.0 ±1.2	35.0 ±3.4	Stand = 54.4; p = 0.0 Year = 33.7; p = 0.0 Year × stand=15.1; p=0.0
Post-fruit fall period													
Disappeared	60.32 ±3.85	76.28 ±3.49	91.08 ±2.58	98.2 ±1.83	67.1 ±2.4	82.0 ±1.9	97.0 ±2.5	99.6 ±0.7	54.6 ±3.2	73.3 ±2.4	89.5 ±2.6	97.0 ±2.3	Stand = 593.3; p = 0.0 Year = 36.5; p = 0.0 Year × stand=3.2; p=0.01
Dormant/rotten	39.68 ±3.85	23.72 ±3.49	8.92 ±2.58	1.8 ±1.83	32.9 ±2.4	18.0 ±1.9	2.98 ±2.5	0.42 ±0.7	45.4 ±3.2	26.7 ±2.4	10.5 ±2.6	3.0 ±2.3	Stand = 593.3; p = 0.0 Year = 36.5; p = 0.0 Year × stand=3.2; p=0.01
Germinated	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	

in the undisturbed stand (Table V.4). During this period not a single nut germinated.

In general, about 80% of the total fruits produced by Rudraksh disappeared from the forest floor including the nuts damaged by insects especially by ants and termites. About 20% of fruits/nuts was dormant. However, the percentage of the rotten nuts was negligible (Table V.5).

Fruit disappearance in relation to distance from parent tree

Fruit disappearance (F=2015.7, df=8, $P<0.0$) decreased with increase in distance from the tree. Disappearance also differed significantly (F=2765.5, df = 3, $P<0.0$) among forest stands and was highest in the highly disturbed stand and lowest in undisturbed stand (Fig. V.2). More than 85% of the sown fruits disappeared within a 5-m circle around the tree, while about 55% of fruits disappeared from the concentric circle at a distance of 45 m from the tree. Remaining fruits lie dormant and none of them germinated during the study period at any concentric circle.

Impact of fruit quality on dispersal/disappearance

Disappearance of fruits significantly (F = 695.5; df = 2; $P=0.0$) depended upon the quality of fruits. The ripe fruits disappeared more than the unripe fruits and the fruits without pulp. Disappearance was maximum (>80%) in the highly disturbed stand and minimum (<60%) in the undisturbed stand (Fig. V.3).

Nut bank in the soil

Table V. 5. Dispersed, disappeared, dormant/rotten and germinated seeds expressed as fraction (%, ±SD) of the total number produced by Rudraksh in four forest stands experiencing different degree of disturbance (stands I, II, III, and IV are undisturbed, mildly disturbed, moderately disturbed and highly disturbed forest patches, respectively).

	1997				1998				1999				
	Stands				Stands				Stand s				F value
	I	II	III	IV	I	II	III	IV	I	II	III	IV	
Dispersed	2.16 ±0.22	3.24 ±0.59	4.68 ±0.39	5.64 ±0.88	4.24 ±0.4	5.0 ±0.5	7.64 ±0.8	8.88 ±1.1	2.28 ±0.4	3.34 ±0.5	4.6 ±0.3	4.88 ±0.2	Stand = 97.8; p = 0.0 Year =117.6; p = 0.0 Year × stand=3.3; p=0.008
Disappeared	66.14 ±1.93	73.58 ±1.93	77.28 ±2.16	80.36 ±3.97	72.9 ±2.2	79.5 ±1.0	83.5 ±2.0	85.7 ±2.3	65.5 ±1.4	72.4 ±2.2	75.9 ±2.0	78.1 ±2.0	Stand = 5.4; p = 0.0 Year = 0.5; p = 0.0 Year × stand=0.9; p=0.5
Dormant/rotten	31.7 ±1.79	23.18 ±2.0	18.04 ±2.37	14.0 ±4.27	22.8 ±2.3	15.5 ±1.1	8.84 ±2.7	5.4 ±2.9	32.2 ±1.3	24.3 ±1.9	19.5 ±2.1	17.0 ±2.0	Stand = 132.4; p = 0.0 Year = 100.8; p = 0.0 Year × stand=0.3; p=0.9
Germinated	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	

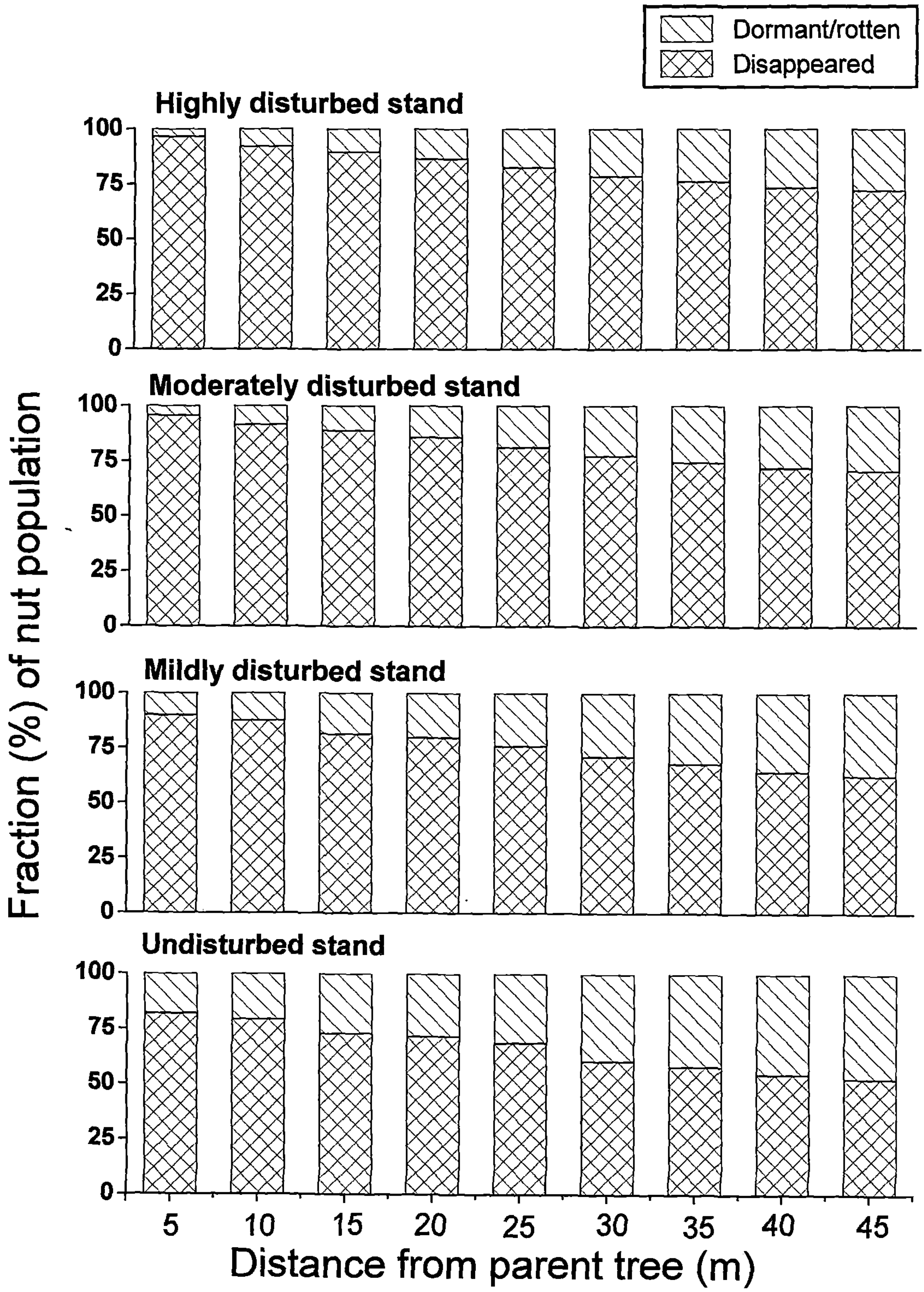


Figure V.2. Percentage of disappearance and dormant/rotten nuts at different distances from parent tree of Rudraksh in different forest stands.

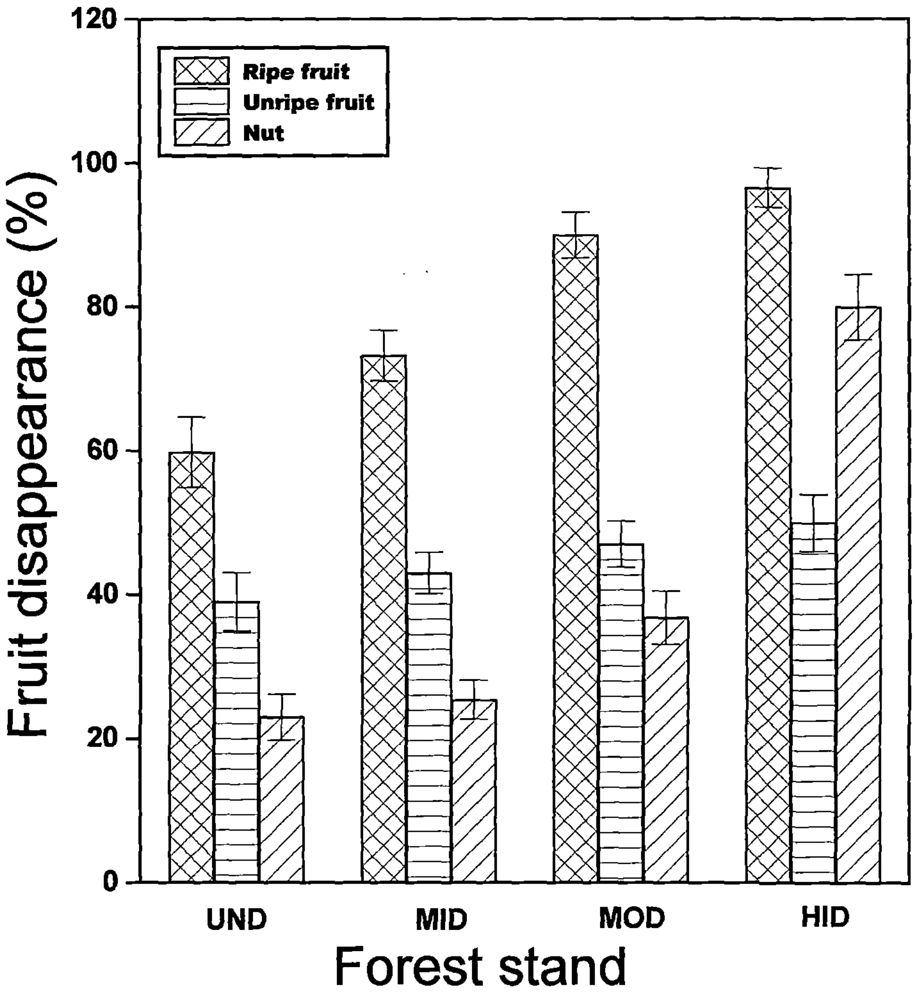


Figure V. 3. Disappearance of fruits of Rudraksh as influenced by their ripeness and pulp in the undisturbed (UND), mildly disturbed (MID), moderately disturbed (MOD) and highly disturbed (HID) forest stands.

Nut bank of Rudraksh in soil decreased significantly (F = 663.4; df = 3; $P<0.0$) with an increase in the disturbance index. Nut bank in soil was maximum in the undisturbed stand and minimum in highly disturbed stand (Table V.6). During the poor fruit production year (1998) soil nut bank was also low. More than 85% nuts of the soil bank was predated. Though the predation was less in the moderately disturbed stand as compared to other stands, differences were not significant.

Different events at a glance

About 89% of flowers aborted and only 11% matured into fruits in all the forest stands irrespective of disturbance intensity. More than 70% fruits disappeared within three months of their fall (Fig. V.4). Disappearance was maximum in the highly disturbed stand. Further, about 45% disappearance of the remaining fruits in soil bank was accomplished during nine months before the next fruit rain. This disappearance was maximum (79.6%) in the highly disturbed stand and minimum in the mildly disturbed and undisturbed stands. Of the remaining population of fruits in soil, about 87% was predated and only about 13% was healthy (Fig. V. 4).

Discussion

Flower and fruit production in Rudraksh varied greatly in time and space. Grubb (1977), Clark & Clark (1987), Barik *et. al.* (1996), Khan *et al.* (1999) in shade-tolerant species and Milton *et al.* (1982) and De Viana (1999) in light-

Table V. 6. Nut bank in the soil (per 100 sq. m.) and fractions (%) of predated and undamaged nuts in the total nut population of Rudraksh before the next fruit-fall crop in the four forest stands (stands I, II, III and IV are undisturbed, mildly disturbed, moderately disturbed and highly disturbed forest patches, respectively).

	1997				1998				1999				
	Stands				Stands				Stands				F value
	I	II	III	IV	I	II	III	IV	I	II	III	IV	
Total nut bank	347 ±23	337 ±21	216 ±15	97.8 ±9.7	257 ±19	225 ±9.7	107 ±7.2	33.4 ±9.3	348 ±26	337 ±23	218 ±14	94.8 ±13	Stand = 663.3; p = 0.0 Year = 202.8; p = 0.0 Year × stand=2.9; p=0.01
Predated (%)	89.7 ±4.1	87.4 ±3.6	79.2 ±6.6	88.4 ±4.9	90.38 ±2.5	86.48 ±2.2	80.44 ±9.9	82.12 ±4.8	90.5 ±4.3	87.6 ±3.6	80.4 ±8.4	89.9 ±6.9	Stand = 8.02; p = 0.00 Year = 0.44; p = 0.7 Year × stand=0.3; p=0.9
Undamaged (%)	10.3 ±4.1	12.6 ±3.6	20.8 ±6.6	11.6 ±4.9	9.62 ±2.5	13.52 ±2.2	19.56 ±9.9	17.88 ±4.8	9.5 ±4.3	12.4 ±3.6	19.6 ±8.4	10.1 ±6.9	Stand = 8.7; p = 0.00 Year = 0.8; p = 0.5 Year × stand=0.7; p=0.7

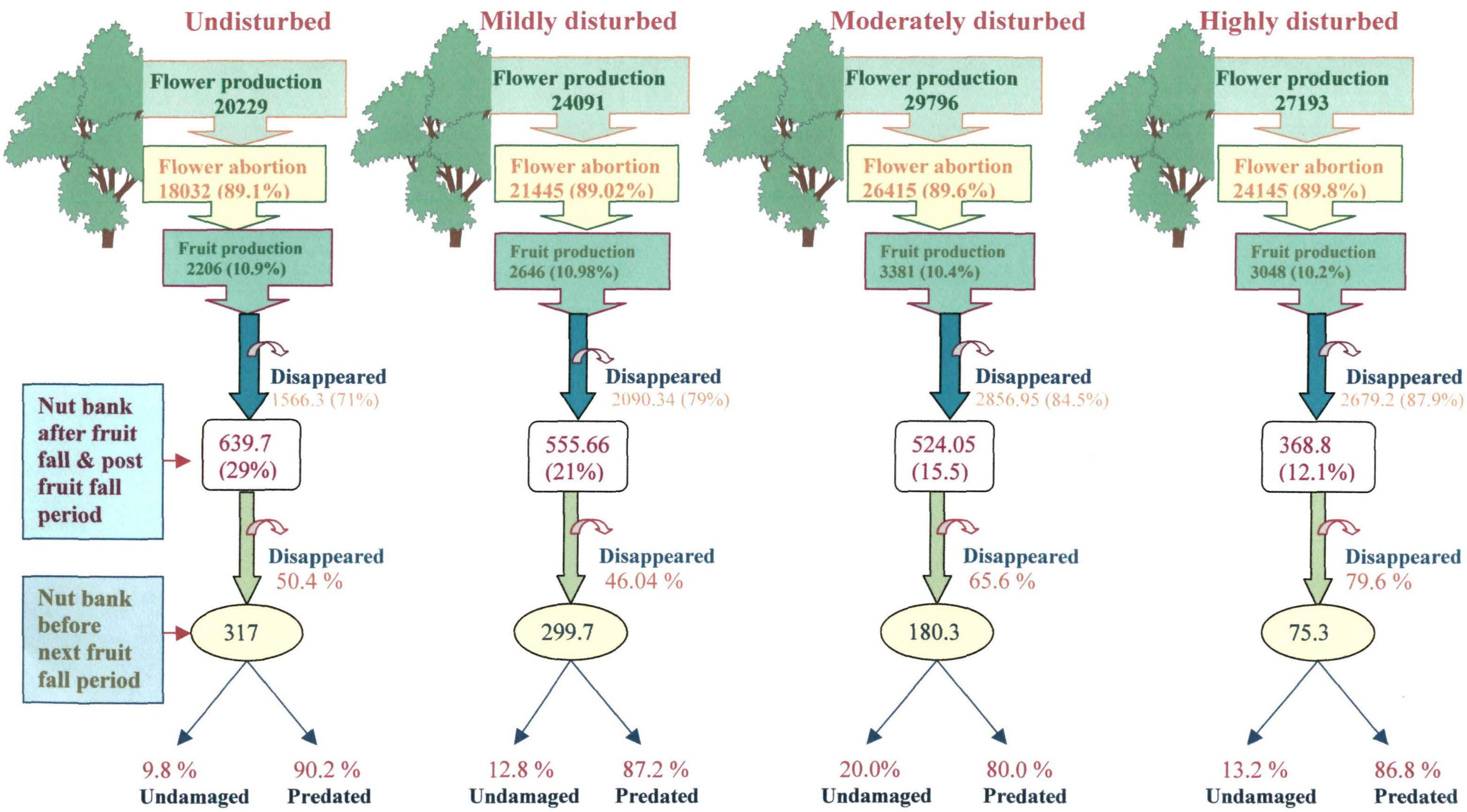


Fig. V. 4. Schematic diagram of general trend of different events in *Rudraksh*.

demanding pioneer species have recorded similar variations. Most hypotheses suggest that resource limitation is the main cause of yearly variation in fruit production in trees (Mounselise & Goldcshmidt 1982, Fenner 1991). Mathews (1963) and Wright *et al.* (1999) argued that elevated fruit production consumes reserves and limits future production in many fruit and timber trees. Certain environmental conditions like prolonged depression of minimum night temperature, increasing length of dry season and a dry sunny year following a wet year may induce heavy fruiting in many tropical tree species (Anonymous 1978, Ashton *et al.* 1988, Van Schaik *et al.* 1993, Wright *et al.* 1999). Rainfall, hailstorm and wind speed, particularly during flowering season, may significantly affect fruit production (Khan *et al.* 1999, Felfili *et al.* 1999). It was noted that a couple of unusual hailstorm events and a higher annual rainfall in 1998 (5461 mm rain in 150 days) than in 1997 (3254 mm rain in 158 days) and 1999 (3189 mm in 161 days) damaged the flowers to a very great extent. Mast fruiting in certain years may be viewed as a strategy to ensure the recruitment of a particular species despite heavy seed and seedling predation by herbivores (Janzen 1971a, Howe 1982, Fenner 1991). Selection may also favour variable fruit production when seed predators are alternately starved and satiated (Janzen 1974a, Kelly 1994).

The increased fruit production in Rudraksh with the increase in disturbances is in conformity with the findings of Barik *et al.* (1996). The greater fruit production in the disturbed stands may be attributed to the stimulation of flowering due to increased availability of sunlight in these stands. High light intensity may elevate bud temperature, which may lead to increase in the concentrations of growth regulators particularly gibberellins (Pharis & Kuo 1977, Ross *et al.* 1983), which stimulate flowering and fruiting. Due to high light regime in disturbed stands, temporary water stress may be created which is known to stimulate bud initiation in some forest trees (Kozlowski 1981).

Fruiting trees of Rudraksh with greater girth produced more flowers and fruits, because of greater height and larger canopy cover. Tall individuals may offer more foraging opportunities and thereby the pollination chances are increased and there is an increased protection from predators (Ducan & Chapman 1999). The fruit production in Rudraksh increased but fruit weight decreased with an increase in disturbance index. Such variations in production of fruits and their weight among different stands could be due to differential environmental influences in the four stands as well as to genetic differences among the parent trees (Barik *et al.* 1996, Howe & Richter 1982). De Viana (1999) argued that plants may adjust resource allocation to fruit and seed production under various environmental conditions via plasticity in fruit/seed mass and in the several traits that affect flower number, ovules per flower, and fruit and seed abortion. Further, the magnitude and pattern of these traits vary in response to environmental conditions (Silvertown 1989, Stephenson 1992). It is generally held that fruit/seed size is inversely related to fruit/seed number, and environmental conditions such as reduced irradiance may cause reduction in seed number and may lead to the production of heavier seeds (Kidd & West 1919).

Fruit dispersal is the process that links generations of established plants both in time and space. Rudraksh fruit has very hard nut containing normally 5 seeds. The nuts have a low ability to be dispersed without transportation by animals. Therefore, nut-dispersing animals are very important for this species as they reduce sibling competition, decrease genetic relatedness of patches and enable it to colonize new areas. During the course of this experiment not a single nut was found germinated up to 45 m distance from the parent tree. This may be due to the hardness of the nuts, which take 2-3 years to germinate. The seeds are also consumed by ants and termites from the nuts if they lie in the soil for a longer period. A large number of nuts were found deposited on rotten logs (Plate V.2), mostly hoarded by rodents. The nuts were also found washed away by the run-off water especially in the disturbed stand and trapped in fallen branches or exposed roots of plants. Seeds of about 90% of the hoarded nuts were eaten either by rodents or destroyed by ants. In this study, germination of the hoarded nuts was not directly examined; however, partial damage to nuts may prove beneficial by making them permeable to water. The degree of ripeness of the fruits and pulp quantity seem to have greatly influenced the fruit dispersal. The ripe fruits were more preferred by dispersers than the unripe fruits and fruits without pulp. Many studies have revealed that fruit colour, nutritional content, pulpiness, aroma, or presentation attract dispersal agents (Herrera 1981, Snow 1981, Janson 1983, Howe 1985, Howe *et al.* 1985) in a variety of ways.

Hornbill and bats, which normally take the fruits of Rudraksh to a greater distance from the crown, appear to be much better dispersal agents than flying squirrel and monkey, which drop the fruits beneath the tree crown after eating the pulp. Though some animals e.g. deer, wild pig, buffalo, mithun etc. were seen eating the ripe fruits fallen on the forest floor, the nuts were not swallowed and normally regurgitated under the crown. This suggests that cost is paid to animals/birds but the species does not get the reward in terms of dispersal (Hedge *et al.* 1991). Elephant seems to disperse the fruits to a greater distance as few nuts were found in the dung balls. However, rodents, viz. *Vandeleuria oleracea*, *Rhizomus pruinosus, Mus musculu, Rattus rattus rufescens* (Gray), *R. rattus brunneusculus* (Hodgson) and *Micromys minutus erythrotis* (Blyth), are the main consumers, dispersers and hoarders of fruits of Rudraksh.

A very large proportion of fruits of Rudraksh got dispersed below the crown of the parent trees. The fruit density decreased with the distance from the parent tree. About 40 to 70% of total fruits disappeared during the fruit fall period and a large fraction (55-99%) of the remaining fruits disappeared during three months after the fruit fall. Fruit disappearance decreased with the increase in distance from the tree. More than 85% fruits disappeared within a 5-m circle, while about 55% fruits disappeared from the concentric circle at a distance of 45m from the tree. Rapid disappearance of fruits/nuts of many tree species has been reported (Smith and Reichman 1984, Jensen 1985, Kikizawa 1988, Darley-Hill & Johnson 1981, Fox 1982, Kawamichi 1980) through the transportation and storage in caches by several animals e.g. blue jays, squirrels, chipmunks, mice, voles and rodents. The greater disappearance of the fruits from the undisturbed stand than the disturbed stand during fruit fall period may be linked with the higher population of wildlife and their frequent visits to hoard pulpy fruits in the former stand. However, collection of nuts by people from the forest floor of the disturbed stand might have caused the greater disappearance during post-fruit fall period.

Analysis of nut bank dynamics of Rudraksh indicated that there were two important stages at which nut losses could occur in this species. Firstly, a very large proportion of nuts (fruit with pulp) dispersed below the crown was removed by dispersers immediately after fruit fall. Secondly, there was a rapid decline in the nut density on forest floor through the year due to secondary dispersers. In the present study, density-dependent predation was clearly indicated. Below the crown of the trees about 89% of nuts was found predated and the remaining was dormant. The dormant fraction might give rise to the seedlings in future. This prediction is supported by the presence of the established seedlings around the trees. Hubbell (1980) also suggested that recruitment might be higher close to the parent plant because of considerably greater seed abundance there, despite very high predation. Presence of the established seedlings near the parent suggests that mortality near the parent is not disproportionate and that most of the regeneration is without animal dispersal intervention. The nut production exceeded the level of consumption by the predators which ensured germination and seedling establishment under the parent. This may be at the cost of producing large quantity of fruit crops to satiate the predators (Janzen 1971a, b, 1978).

The findings on dispersal of Rudraksh may have great implications for regeneration of the species. Prolonged nut dormancy may increase the risk of predation and ultimately reduce the chances of germination. Further, ants damage a large fraction of the nut population hoarded by rodents by eating up cotyledons of seeds. Due to ethnic importance, nuts of Rudraksh are also collected in huge quantities from the forest floor causing shrinkage in its nut bank. These factors might be directly responsible for the threatened status of the species.

CHAPTER VI

Regeneration of Rudraksh: Germination Strategies

Introduction

The population of Rudraksh in North Eastern region of India is depleting at an alarming rate due to deforestation. Further, due to ethnic importance, nuts are collected in huge quantities from the forest floor causing shrinkage in its nut bank. Poor germination coupled with prolonged dormancy owing to the hard nature of the nut coat also causes significant reduction in the population size of this species. In spite of the great importance of this plant, its biology, regeneration behaviour and means of propagation have not been studied so far. For the successful propagation of this species, an understanding of the mechanisms that help overcome the dormancy imposed by the hard nut coat is also required. The objective of the present study was, therefore, to explore some quick and easy methods to bring about the germination of Rudraksh nuts to help in raising the seedlings in nursery and maintaining its population through different plantation programmes.

Methods

Nut collection

Ripe fruits (nuts) were collected in November, 1997 from the natural stand in Deomali Forest Division of Arunachal Pradesh (27° 3′ and 27° 13′ N 95° 22′ and 95° 37′ E). One-kilogram weight contains about 210 fruits with pulp and 340 nuts without pulp. Fruit weight with pulp and without pulp ranges 3.8-5.6 g and 2.0-3.4 g, respectively. The stony endocarp of Rudraksh of about 17 mm diameter, is covered by fleshy green mesocarp that extends fruit diameter to approximately 25 mm. (Plate VI.1). Nuts were cleaned in running tap water physically after fermenting the pulp in soil pit for one week.

Frequency distribution of locules and seeds in the nut

One nut may contain 0-5 seeds. The number of faces or grooves on the nut surface corresponds to the number of locules which may or may not contain seeds. Ten thousand nuts were screened for counting the number of locules (faces or grooves). The five locule nuts were most common (about 90% of the nut population), and so, only such nuts were used for determining the seeding frequency and for testing germination. For determining seeding frequency 500 nuts were cracked with vise and the number of healthy seeds present in each nut was counted. While calculating the seeding frequency empty nuts were discarded. A total of 405 nuts were used for this purpose.

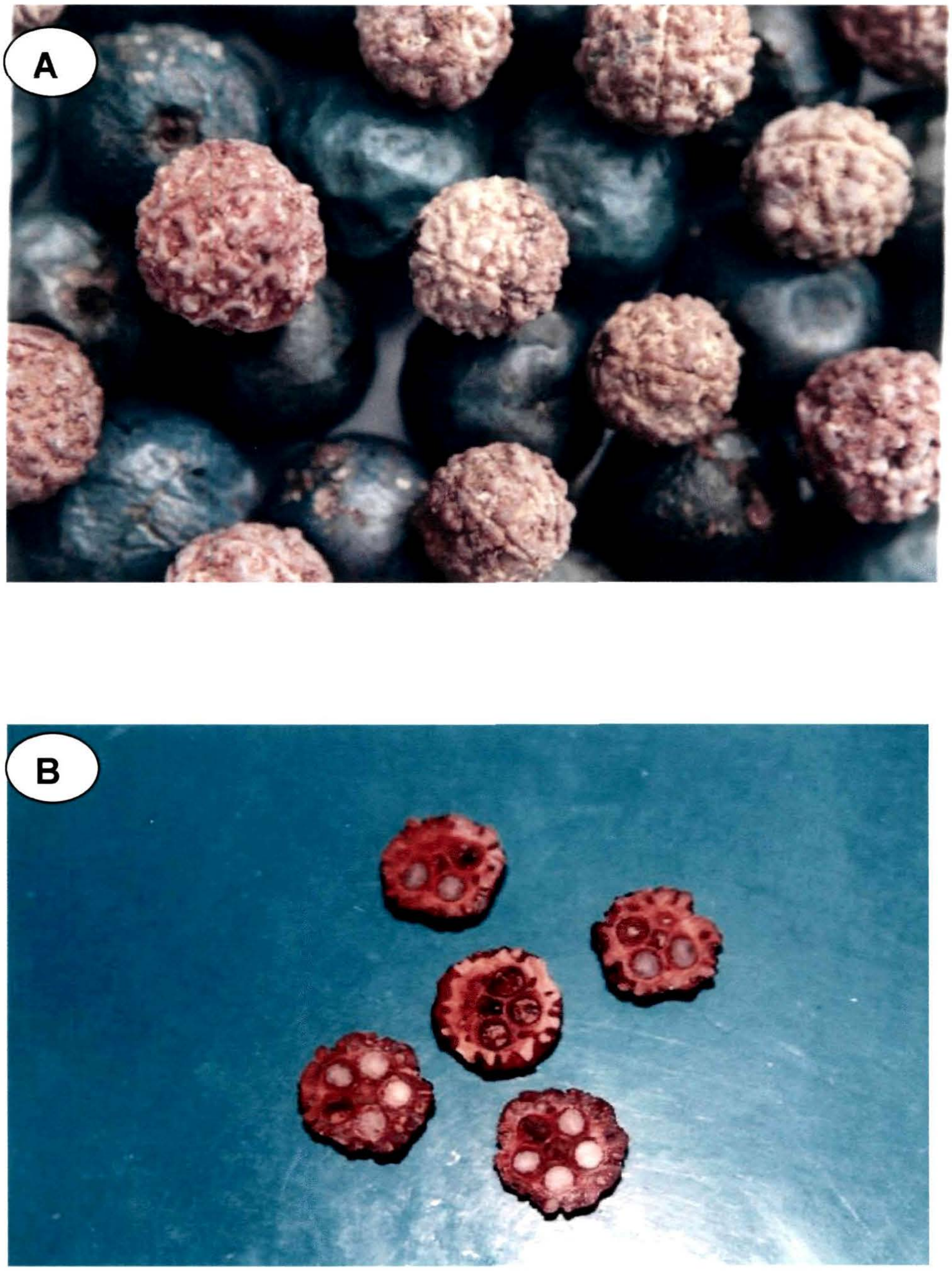


Plate VI. 1. Rudraksh fruits/nuts (A), showing the locules and seeds (B).

Pre-germination treatment of nuts

Nuts were subjected to the following treatments before sowing in the plastic trays.

1. Control.
2. Cracks made on the nut faces vertically by gently pressing with vise (as shown in Plate VI. 2).
3. Nuts scarified on micropyle end with a file near to the embryo surface.
4. Nuts scarified on micropyle end soaked in warm water (45 ^{0}C) for 12 hours.
5. Nuts scarified on micropyle end soaked in boiling water for 12 hours.
6. Nuts soaked in hot water (45 ^{0}C) for 12 hours.
7. Nuts soaked in hot water (45 ^{0}C) for 24 hours.
8. Nuts boiled in pressure cooker for 1 whistle.
9. Nuts boiled in pressure cooker for 2 whistles.
10. Nuts treated with sulfuric acid (95-97%) for 10 minutes.
11. Nuts treated with sulfuric acid (95-97%) for 20 minutes.
12. Nuts treated with sulfuric acid (95-97%) for 30 minutes.
13. Nuts treated with nitric acid (95-97%) for 10 minutes.
14. Nuts treated with nitric acid (95-97%) for 20 minutes.
15. Nuts treated with nitric acid (95-97%) for 30 minutes.

Nuts were dipped in acid solution, stirred by a rod for uniform effect and were washed in running tap water.

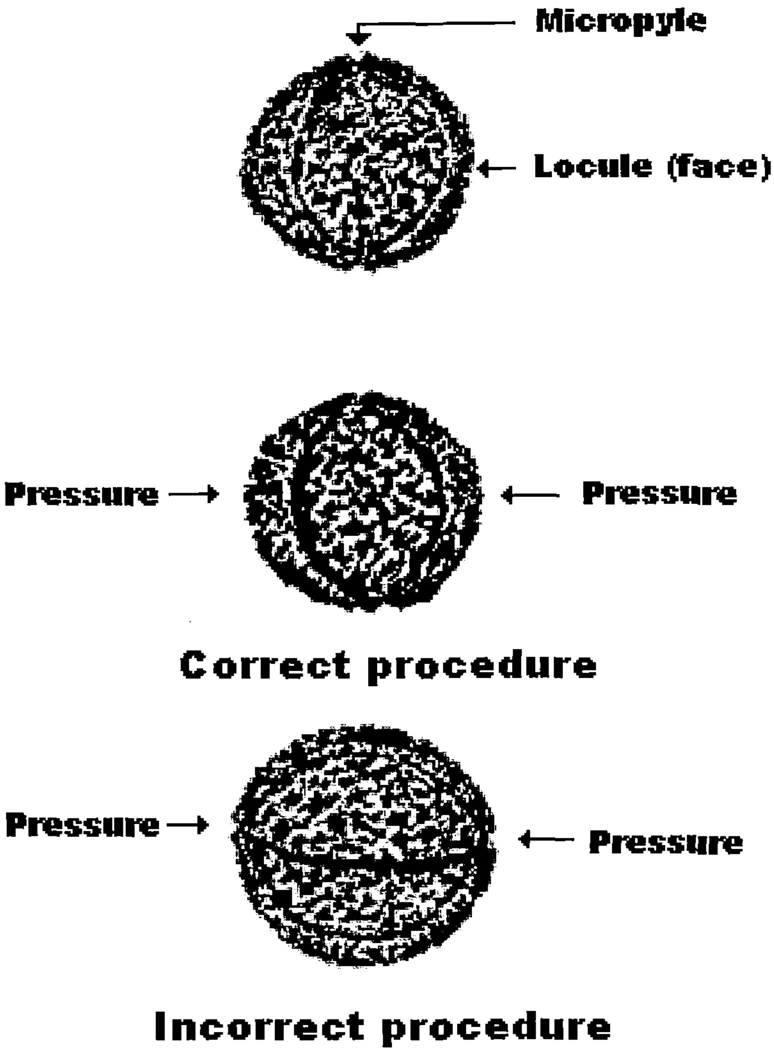


Plate VI.2. Elaborating the correct placing of nut for making the cracks by vise.

16, 17 & 18. A pit was filled with animal excreta and nuts in different perforated bags were immersed in it. The pit was covered. The nuts were taken out for germination after one, two and three weeks.

19. Nuts were placed over fresh cow dung.

20, 21 & 22. A pit was filled with decomposed leaf litter and cow dung. Nuts were put in different perforated bags, which were placed in the pit, and the latter was covered with a thin layer of soil. The nuts were taken out for germination after 10, 20 and 30 days.

23. Nuts were surface burnt with fire of leaf litter.

24. Heating and cooling treatments were given to the nuts by heating them in oven at 90 ^{0}C for half an hour and cooling in freeze (4^{0}C) for one hour. The process was repeated three times.

25. A seedbed was made over which leaf litter and decomposed cow dung was spread. Nuts were placed over it and watering was done at alternate day.

Seed germination

After different treatments the nuts were sown in plastic root trainer trays containing garden soil and decomposed cow dung (3:2). Each hole of the root trainer trays contained 250 gm soil. To study the effect of different treatments on germination, four replicates of 25 nuts each were maintained for each category of the treated seeds. Each tray had 25 holes and one seed was put in each hole of the tray. Each tray served as a replicate. The nuts were sown in April 1998. Watering was done at alternate day. Seeds were considered germinated when radicle protruded about 2 mm beyond the seed coat.

Seedling performance

Single nut may give rise up to five seedlings. Survival and growth of seedlings may be affected by the number of seedlings emerging from each nut. Since quick and comparatively more uniform germination was achieved by cracking the nuts with vise, the seedlings emerged from the nuts which were subjected to this treatment were used for studying the seedling performance. Seedling performance in terms of survival and growth as affected by the number of seedlings emerged from a single nut was determined after one-year from the date of emergence. Growth performance of the seedlings was assessed in terms of their height, collar diameter, leaf number and leaf area. For this purpose four categories of seedlings (n= 10 for each category) were tagged viz., one seedling, two seedlings, three seedlings and four seedlings emerged from one nut. Leaf area was measured using *LICOR-3000A* leaf area meter.

Statistical analysis

Frequency distribution analysis was performed through *Statistica.* Significance of pre-germination treatments, and seedling performance as influenced by the clustering of seedlings was tested by one-way analysis of variance (ANOVA) and Tukey's HSD multiple range tests were used to compare differences among treatments (Zar 1984).

Results

Frequency distribution of nuts with varying number of locules

The frequency distribution of nuts with different number of locules (faces) was negatively skewed (Fig. VI.1). Five locule-nuts are most abundant constituting approximately 90 % of the nut population while four locule-nuts and three locule-nuts constituted 8 % and 1% respectively (Fig. VI.1). The percentage of six locule-nuts is also very low (1%).

Seed frequency

The frequency distribution of nuts having different number of seeds showed a normal distribution (Fig. VI. 2). Each locule is supposed to contain one seed but some of the locules were devoid of seed. 8 % nuts were observed to contain intact seeds in all the locules, however, quite a large number of nuts (19 %) do not have any seed. The nuts with three seeds were most common (26 %) followed by those with four (18 %) and two (17 %) seeds (Fig. VI. 2). On close observation, it was found that seeds are either aborted in some of the locules at early stage or eaten by insect. At the time of screening of the ripe fruits, it was observed that *ca.* 80% of the fruits were infected by *Coleoptera* and some other unidentified larvae.

Germination

Pre-germination treatments had a significant effect ($F=11.04$; $P<0.001$) on seed germination. The nuts cracked by vise (T_2, plate VI.2), soaked in hot water for 12 & 24 hours (T_6, T_7), dipped in animal excreta for 2 & 3 weeks (T_{17}, T_{18}) and fermented for 10, 20 & 30 days (T_{20}, T_{21}, T_{22}) showed significantly improved germination compared to the control (T_1). Some of the pre-germination treatments such as T_5, T_8, T_9, T_{11}, T_{12}, T_{13}, T_{14}, T_{15}, T_{19}, T_{23}, T_{24}, and T_{25} were found ineffective (Table V.1).

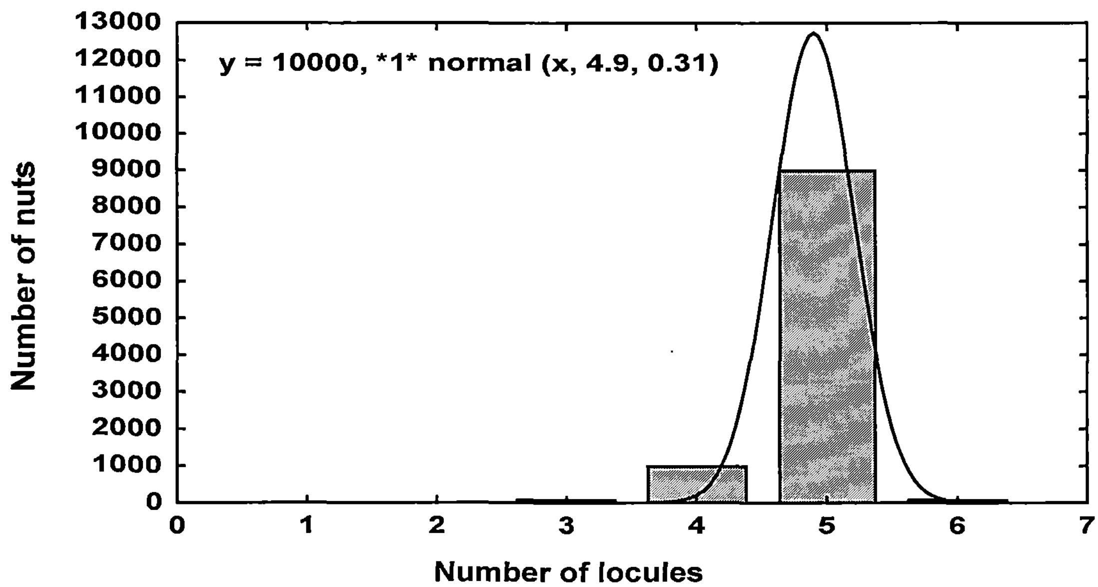


Figure VI. 1. Frequency distribution of 10,000 Rudraksh nuts having different number of locules 'faces'. The frequency distribution was negatively skewed (see the curve).

Table VI.1. Nut germination (%), period required for final germination, period required for germination to commence and period required for 50% germination in Rudraksh. Percentages for germination and the mean values of germination period in the same column with different letters differ significantly from each other at $P<0.05$ (Tukey's HSD multiple comparison following ANOVA).

Treatments	Final germination (%)	Period (days) required for final germination	Period (days) required for germination to commence	Period (days) required for 50% germination	Proportion (%) of nuts that gave rise to different number of seedlings — Number of seedlings					
					0	1	2	3	4	5
Control (T_1)	33^{a}	239^{a}	191	218 ± 28	67	10	14	6	3	0
Cracks made by pressing with vise (T_2)	40^{b}	49^{b}	19	25 ± 5	60	22	16	2	0	0
Scarification at micropyle end (T_3)	32^{a}	248^{a}	159	209 ± 27	78	10	12	9	1	0
Scarification + soaking in warm water for 12 hours (T_4)	11^{c}	232^{a}	190	198 ±13	89	7	1	1	2	0
Scarification + soaking in boiling water for 12 hours (T_5)	0	-	-	-	100	-	-	-	-	-
Soaked in hot water for 12 hours (T_6)	36^{a}	276^{a}	190	239 ± 33	64	13	13	1	0	0
Soaked in hot water for 24 hours (T_7)	37^{d}	282^{a}	145	191 ± 30	63	13	10	11	3	0
Boiled in presser cooker – 1 whistle (T_8)	0	-	-	-	100	-	-	-	-	-
Boiled in presser cooker – 2 whistle (T_9)	0	-	-	-	100	-	-	-	-	-
Treated with con. H_2SO_4 for10 min. (T_{10})	14^{c}	230^{a}	144	211 ± 31	76	3	8	3	0	0
Treated with con. H_2SO_4 for 20 min. (T_{11})	3^{f}	258^{a}	85	240 ± 219	97	3	0	0	0	0
Treated with con. H_2SO_4 for 30 min. (T_{12})	1^{f}	202^{a}	202*	202	99	1	0	0	0	0
Treated with con. HNO_3 for 10 min. (T_{13})	2^{f}	387^{c}	352*	387	98	0	2	0	0	0
Treated with con. HNO_3 for 20 min. (T_{14})	0	-	-	-	100	-	-	-	-	-
Treated with con. HNO_3 for 30 min. (T_{15})	1^{f}	239^{a}	237*	239	99	1	0	0	0	0
Dipped in animal excreta for 1 week (T_{16})	18^{j}	210^{a}	142	149 ± 13	82	18	0	0	0	0
Dipped in animal excreta for 2 weeks (T_{17})	31^{a}	237^{a}	58	124 ± 40	69	8	13	8	2	0
Dipped in animal excreta for 3 weeks (T_{18})	32^{a}	247^{a}	68	176 ± 53	68	12	15	4	1	0
Kept on fresh cow dung (T_{19})	2^{f}	224^{a}	222	222 ± 5	98	0	0	0	2	0
Fermented for 10 days (T_{20})	30^{a}	210^{a}	189	153 ± 47	70	6	7	14	3	0
Fermented for 20 days (T_{21})	37^{d}	261^{a}	146	198 ± 44	63	7	12	13	5	0
Fermented for 30 days (T_{22})	30^{a}	244^{a}	56	133 ± 55	71	12	12	6	0	0
Treated with fire scorch (T_{23})	1^{f}	391^{c}	391*	391	99	1	0	0	0	0
Heating and cooling (T_{24})	0	-	-	-	100	-	-	-	-	-
Weathering (T_{25})	0	-	-	-	100	-	-	-	-	-
F value	***11.04***	***6.24***	-	***30.48***						
P level	***0.001***	***0.001***	-	***0.001***						

* Single nut germinated

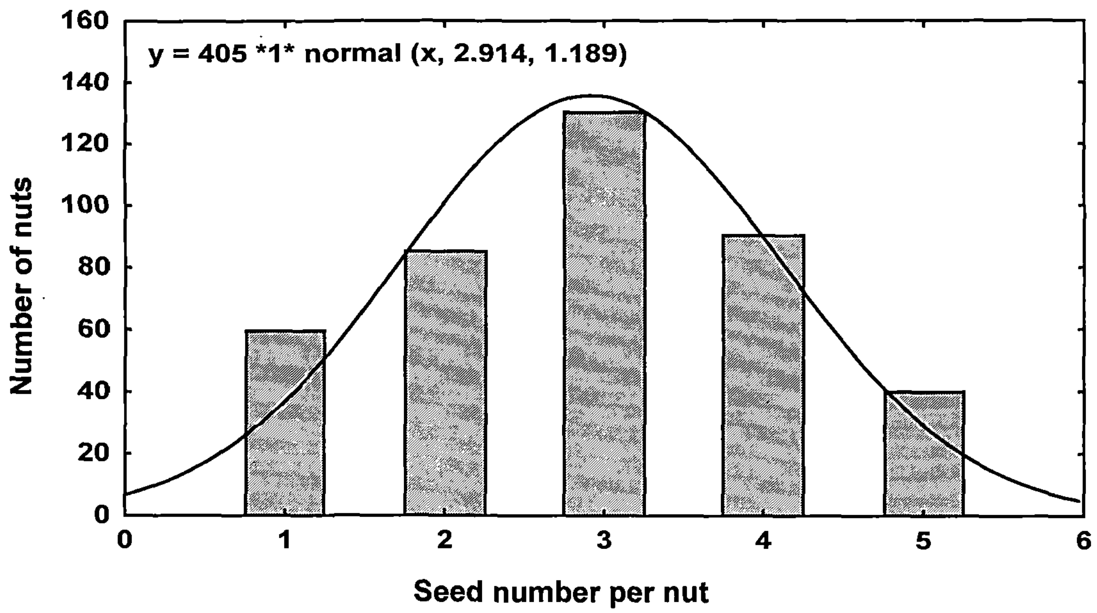


Figure VI. 2. Frequency distribution of seeds per nut (n = 405). Seed number showed normal distribution (see the curve).

The time taken for germination varies greatly amongst the treatments and the difference was significant ($F=6.24$; $P<0.001$). The period required for final germination under treatment T_2 was significantly lower (49 days) as compared to the control and some other treatments where the period required for the final recorded germination was more than 200 days. When compared with the control, some of the treatments (T_4, T_5, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{15}, T_{16}, T_{19}, T_{23}, T_{24}, and T_{25}) retarded and delayed the germination. In some of these cases, the germination was quite erratic and it occurred over a prolonged period. In fact few nuts germinated after more than a year (Table VI.1).

A comparison of the speed of germination (defined as the days required to 50 % of final germination) for different treatments, revealed that germination was quickest for the nuts cracked by vise. However, the duration for 50% germination varied significantly (F=30.45; P<0.001) among different treatments (Table VI. 1).

The number of seedlings emerging from a nut is not uniform. It was observed that a single nut might give rise to 1-4 seedlings (Table VI.1).

Seedling survival and growth

The seedling growth was significantly affected by the number of seedlings emerging from a single nut. The height and collar diameter of seedlings and leaf number and leaf area per seedling decreased with the increase in number of seedlings emerging from the nut (Table VI. 2). However, survival of seedlings did not differ significantly (Table VI. 3).

Table VI. 2. Growth of one-year-old seedlings as affected by number of seedlings emerging from the single nut. The values are means ± SD. The F values and P level are derived from one- way analysis of variance.

Number of seedlings emerged from a single nut	Height (cm)	Collar diameter (mm)	Leaf number per seedling	Leaf area (cm^2) per seedling
One seedling	34.3	3.80	19.0	703.0
	± 7.0	± 0.9	± 3.3	± 140.7
Two seedlings	30.2	3.35	16	460.0
	± 7.0	± 0.6	± 3.5	± 158.2
Three seedlings	17.3	1.75	12.0	158.0
	± 4.6	± 0.7	± 1.8	± 18.2
Four seedlings	15.0	1.30	11.0	141.0
	± 3.0	± 0.3	± 2.0	± 21.0
F value	*21.78**	*21.01**	*11.39**	*44.49**
P level	*0.001*	*0.001*	*0.001*	*0.00*

* Differences are significant.

Table VI. 3. Seedling survival (%) as affected by number of seedlings emerged from the single nut after one year of germination. The values are means ± SD. The F value and P level derived from one-way analysis of variance.

Number of seedlings emerged from single the nut	Survival (%)
One seedling	96.26 ± 6.66
Two seedlings	95.79 ± 6.76
Three seedlings	91.33 ±13.34
Four seedlings	88.33 ±14.38
F value	*1.49**
P level	*0.05*

* Differences are not significant

Discussion

The number of locules or 'faces' in Rudraksh nuts is normally five, but it may be fewer or more. This variation may be due to abnormalities during fruit development. Variation in seed number within a nut may be due to selective abortion of fertilized ovule or maturing seeds (Ganeshaiah & Uma Shaankar, 1991 and references therein). Special religious significance of such abnormalities is described in the *Siva Purana* (Skandha 25- Mani 1964). As per the religious belief, the nuts with five locules or faces are not considered important, and so, there is relatively less demand for such nuts. This may reduce the pressure on normal 'five faced' nuts which are collected only when the abnormal nuts are not available. It may be mentioned that the "five-faced" nuts contain more seeds and germinate better than the other types of nuts and thus a reduced pressure on the former type would enhance regeneration of this tree species. It has also been observed that its seeds are eaten by insect larvae. In view of poor regeneration in *Elaeocarpus ganitrus* as discussed earlier, and a drastic reduction in seed number of Rudraksh nuts due to predation by insect larvae, the religious belief that minimizes the collection of five-faced nuts from the forest assumes a great significance from the conservation point of view.

Findings of the present study on germination show that barrier to water uptake in Rudraksh nuts can be broken by using mechanical scarification e.g. cracks made by vise, hot water and fermentation treatments. It has been demonstrated by several workers that mechanical treatment, boiling/hot water treatment improve the germination in many tree species (Khan & Tripathi 1987b, Todaria & Negi 1992, Negi & Todaria, 1995, Demel Taketay, 1997 and references therein). However, cracking of the nuts enhances the speed of germination significantly by allowing the immediate entrance of water. The cracking of the nuts is relatively simple, convenient, and cheap and requires little skill. Therefore, it can be easily applied for the seedling production in nurseries.

Hard nut/seed coat impermeability, which is a characteristic feature of many leguminous and non-leguminous species, is a mechanism that prevents germination under condition which might be unfavourable for establishment (Ballard 1973, Rolson 1978, Cavanagh 1980, Tran & Cavanagh 1984, Cavanagh 1987, Baskin & Baskin 1989, Egley 1989, Tybirk 1991). To remain dormant for long period is the ability of nut/seed to escape from unpredictable harsh environmental conditions (Fenner 1985, Tybirk 1991, Gutterman 1993). Further, hard nut/ seed coat has several other advantages that allow endozoic dispersal, recolonization after fire and help the seeds to withstand unfavourable condition such as heat, drought, digestive juice as well as mechanical damage (Tybirk 1991). This also helps the nuts/seeds to remain viable for a long period in the soil waiting for the conditions favourable for germination (Coe & Coe 1987, Sabiiti & Wein 1987, Tybirk 1991, Tybirk *et al.* 1994).

The critical objective in hard nut/seeded species is to make the coat permeable to water by breaking dormancy and to induce germination. There are reports to suggest that acting only at specific weak areas/points rather than the whole nut/seed coat can break dormancy. Structural and chemical factors responsible for water impermeability in nut/seed are not well studied. However, most of the evidences indicate the presence of a continuous layer of tightly packed palisade cells in the nut/seed coat which acts as the major barrier to water entry into the nut/seed (Tran & Cavanagh 1984, Cavanagh 1987, Egley 1989). If the specific weak areas in the nut/seed coat could be identified and disrupted either naturally or by several specific treatments, nut/seed coat would become permeable to water. As soon as the nut/seed coat-imposed dormancy is broken, seeds start absorbing water quickly if moisture is available (Demel Teketay 1997).

The study reveals that emergence of more than one seedling from the single nut affected the seedling growth adversely. However, this did not influence the survival of seedlings. In slash (*Pinus elliottii* Engelm. *Elliottii*) and loblolly (*P. taeda* L.), Campbell (1982) found that 1 or 2 seedlings per spot produced fully stocked stands while 5 and 9 seedlings per spot showed a slight reduction in height and diameter growth. In contrast, some workers reported that clustering did affect the seedling growth adversely (Campbell 1964, Lohrey 1970). It may be argued that the effect of clustering may be species- and site-specific. Some species may do better at moderate clustering (Campbell 1964, Lohrey 1970) while others may be affected adversely as is the case in the present study. Clustering may not have much adverse effect if the microsites are favourable, but it may have serious impact on seedling growth on the resource-deficient sites. The present study indicates that the initial number of seedlings emerging from the single nut is highly critical (plate VI.3). Based on the findings of this study, it has been found that if their number is thinned to 1-2 per nut, they would show better growth.

In nature, the germination of Rudraksh nuts is very low and erratic, since nuts are unable to imbibe water because of their hard coat. Therefore, to obtain a good and rapid germination the nuts need to be pretreated to overcome the barrier to water uptake. Mechanical cracking of the nut coat by vise resulted in high, rapid and uniform germination. This method is simple, convenient, and

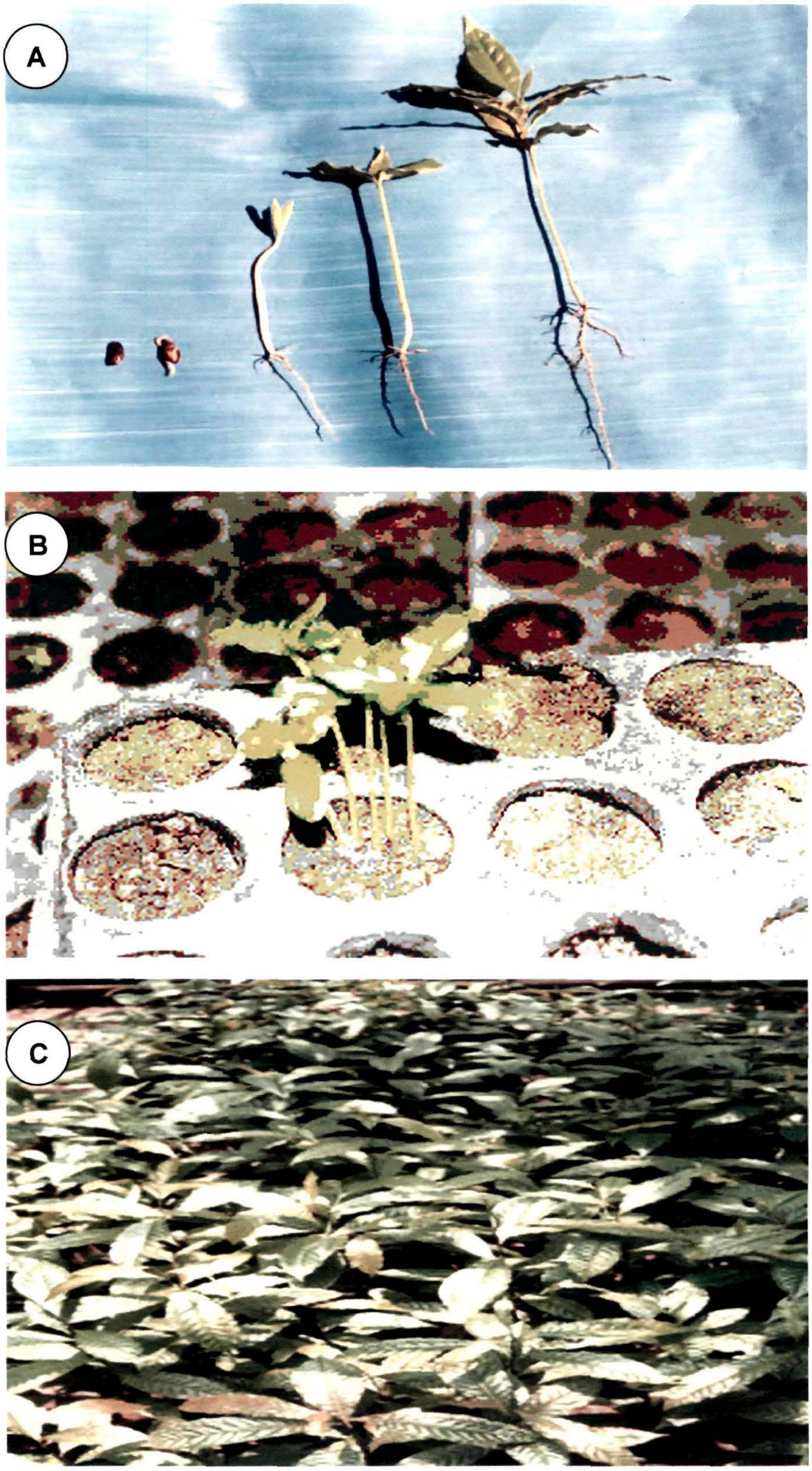


Plate VI. 3. Emergence (A), clustering (B) and seedlings of Rudraksh in nursery (C).

cheap and requires little skill, and so it can be recommended for adoption in the nurseries. Further, seedlings emerging from the single nut should be thinned out at the early age. Such a thinning not only would favor the seedling growth but also would provide the extra seedlings that can be transplanted.

CHAPTER VII

Survival and Growth of Seedlings in Nursery and Forest Stands

Introduction

Success of regeneration of trees in a forest depends upon the response of naturally growing and transplanted seedlings to the prevailing microenvironment (Whitemore 1975, Gause & Stone 1979). Survival and growth of tree seedlings are determined by the interactive influence of biotic and abiotic factors of the forest environment (Augspurger 1984b). The effects of certain factors such as light intensity (Whitemore 1975, Fetcher *et al.* 1983, Burton & Muller- Dombois 1984, Vance & Running 1985, Clark *et al.* 1996), soil moisture (Muller- Dombois *et al.* 1980, Lawrence & Oechel 1983), soil temperature (Wyant *et al.* 1983), soil nutrient (Van Den Dricssche1982), pathogen (Muller-Dombois *et al.* 1983, Augsperger 1984b) and burning (Abott & Loneragan 1984, O'Dowd & Gill 1984) have been studied on seedlings growing in natural or in control conditions, but there is conspicuous lack of studies on the response of transplanted seedlings to different micro environmental conditions prevailing in the forest.

There is considerable difference in the responses of tropical forest tree species to irradiance, particularly in photosynthetic responses (Oberbauer & Strain 1984, Pearcy 1987, Turnbull 1991, Kitajima 1994, Chazdon *et al.* 1996, Press *et al.* 1996, Zipper & Press 1996) and relative growth rate (Coombe & Hadfield 1962, Okali 1972, Whitemore & Gong 1983, Pompa & Bongers

1991, Kitajima 1994, Agyeman *et al.*1999). In tropical rain forest, generally 1-2% of the radiation above the canopy reaches the forest floor (Chazdon 1988, Clark *et al.* 1996). Accordingly, growth rates of seedlings in the understory vary with availability of light.

Thus an experiment was carried out to study the growth and survival of nursery grown seedlings of Rudraksh under different canopy conditions.

Materials and Methods

Growth of seedlings in nursery:

One year old nursery-raised seedlings with uniform growth were picked up after cessation of germination trail. Seedlings were separated from root trainers in the month of May, 1999 and transplanted to polythene bags filled with well-mixed cow dung and farmyard manure in 2:3 proportions. Seedlings were tagged and numbered for future studies. Shoot elongation, collar diameter, leaf number and leaf area of the seedlings were measured over a period of one year at two month interval for the seedlings kept in nursery.

Growth of seedlings transplanted in forest stands:

Three forest stands having the mixed plantations of *Ailenthus grandis, Michelia champaca, Lagerstromia flosregini, Anthocephalus kadamba, Terminalia chebula, T. arjuna, Syzigium cumini, Bauhinia verigata, Cassia* sp. etc. and varying in terms of canopy and incoming solar radiation were selected Itanagar (27°07′ N latitude, 93 °22′ E longitude, 100 m altitude).

Environmental parameters of the three forest stands where the seedlings were transplanted are given in table VII.1. Stands I, II and III have open (canopy cover: 40%), sparse (canopy cover: 60%) and dense (canopy cover: 84%) canopy, respectively. Seedlings were transplanted on 15 May 1999 in all the three forest stands at a spacing of 3 m × 3 m distance. Prior to transplantation the seedlings were measured for shoot length, collar diameter, leaf number and leaf area.

In each forest stand the growth and survival of the transplanted seedlings were monitored over a period of one year at two-month interval. On each observation date, the shoot elongation, collar diameter, leaf number and leaf area of the seedlings were recorded. All the leaves of each seedling were measured for leaf area by portable leaf area meter (*LICOR 3000A*). Leaf infestation by different herbivores was counted individually on each seedling in the above mentioned three forest stands. Growth rate of the seedlings was determined by subtracting the values for height, collar diameter, leaf number and leaf area of each seedling obtained at a given observation date from the corresponding values for these parameters recorded at the subsequent observation date.

Humidity of air was measured by a digital hygrometer and air temperature by a thermometer. Soil temperature was measured by inserting the soil thermometer down to 10 cm depth. The samples were collected from each stand at different dates and soil moisture content was determined. Besides, the water holding capacity of the soil samples was also recorded following Keens up method. Light intensity was measured by a digital lux meter at 9 a.m., 12 noon and 3 p.m. on sunny days in different seasons (thrice in a month) and the means were calculated. Soil texture was determined by hydrometer method.

Results

Growth and survival of seedlings in nursery

As expected the growth rates of seedlings in nursery in terms of shoot length, collar diameter, leaf number and leaf area increased with time. The rate of shoot elongation was found more in September-October. Thereafter the shoot growth decreased and it was least in December-January and from February-March onwards it again increased. Seedling growth rate in terms of collar diameter decreased during September-November and was least in December, and from February-March onwards it increased again. Growth rate in terms of leaf number decreased from August to December and increased thereafter. Seedling leaf area also followed the same pattern; it decreased from August to December and thereafter it increased steadily. No seedling mortality was recorded in the nursery condition (Fig. VII.1).

Growth and survival of seedlings transplanted in the three forest stands

Shoot elongation:

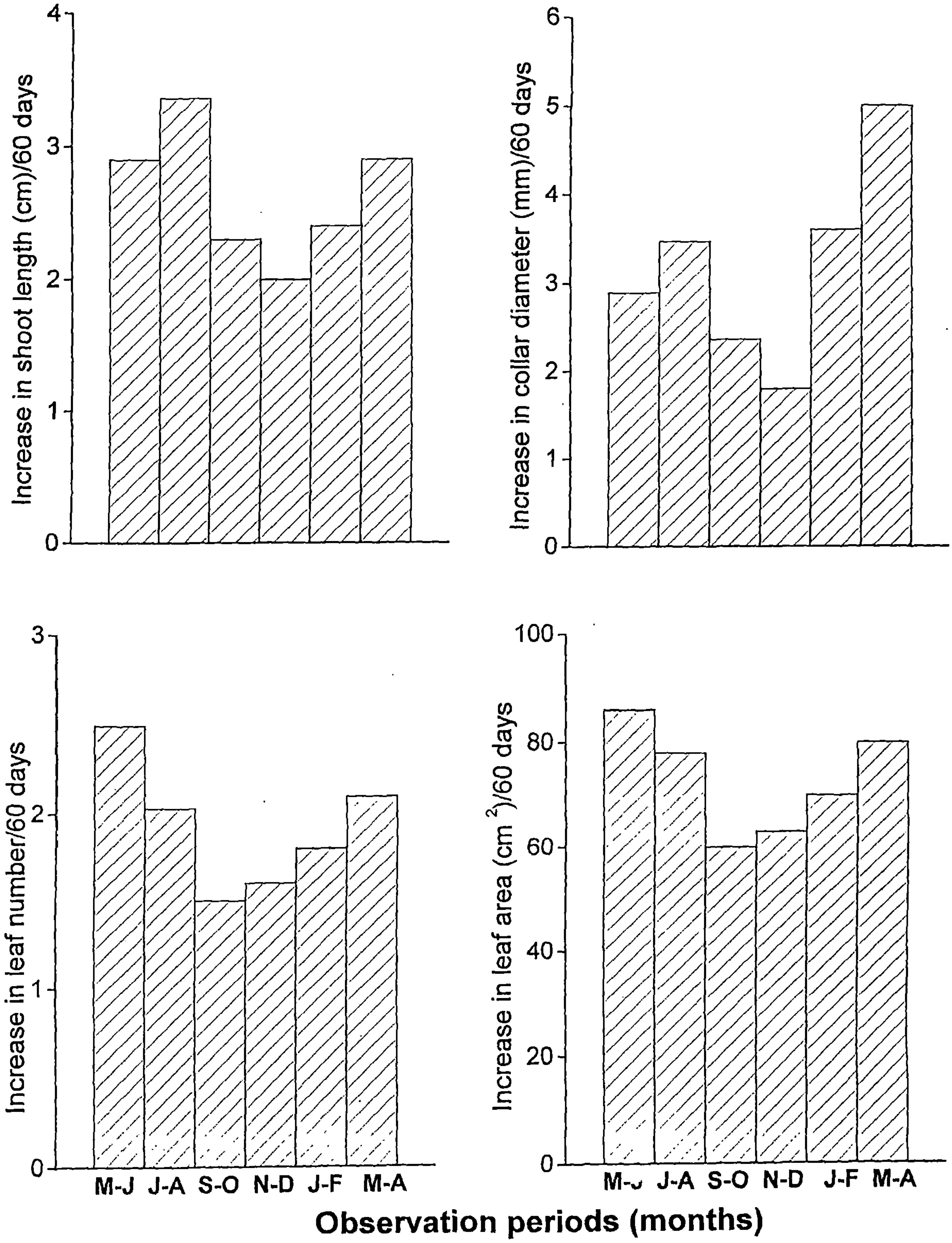


Figure VII.1. Seedling growth in terms of shoot elongation, collar diameter, leaf number and leaf area under nursery conditions.(M-J: 1 May to 30 June, J-A: 1 July to 31 August, S-O: 1 September to 31 October, N-D: 1 November to 31 December, J-F: January to 29 February, M-A: 1 March to 30 April).

Mean seedling shoot elongation rate varied significantly between the forest stands (F=20.97, P<0.000). Shoot elongation rate also differed significantly between the seedlings growing in a forest stand (Stand I, F=29, P<0.01; Stand II, F=73, P<0.01; Stand III, F=192, P<0.01). Stand III with dense canopy recorded relatively higher shoot elongation followed by stand II with sparse canopy (Fig. VII. 2 a).

Table VII. 1: Environmental parameters of the three forest stands where seedlings were transplanted (open canopy - stand I, sparse canopy – stand II and dense canopy – stand III).

Parameters	Stands		
	I	II	III
Light intensity (lux)	23000-28000	15000 - 8000	8000- 10000
Canopy cover (%)	40.0	60.0	84.0
Mean annual humidity (%)	65 ± 3.68	72 ± 2.47	80 ± 1.69
Mean annual soil temperature (^{0}C)	29.5 ± 3.73	28 ± 3.23	27.2 ± 3.26
Mean annual air temperature (^{0}C)	32.33 ± 4.57	30.16 ± 4.81	28.5 ± 2.81
Average soil moisture (%)	12.2 ± 0.65	16.41 ± 1.49	20.5 ± 2.13
Water holding capacity (%)	63 ± 10.27	67± 8.85	70 ± 8.45
Soil texture	Loamy sand. Sand-82.6% Silt-7.4% Clay-10%	Loamy sand. Sand-78.6% Silt-9.6% Clay-11.8%	Loamy sand Sand-79.1% Silt-6.5% Clay-14.4%

Seedling collar diameter

Mean collar diameter differed significantly between the forest stands (F=54.73, P<0.01). Collar diameter also varied significantly between the seedlings growing in a stand (Stand I, F=32, P<0.01; Stand II, F= 216.70, P<0.00, Stand III, F=44.76, P<0.01). Seedlings were of relatively greater diameter in stand III with dense canopy and of least diameter in Stand I with open canopy (Fig. VII. 2b). Growth rate of collar diameter was least in November-December and thereafter it increased steadily.

Leaf number

Leaf number differed significantly between the forest stands (F=54, P<0.01). Number of leaves differed significantly between the seedlings growing in a stand (Stand I, F=27.61, P<0.01; Stand II, F=118.25, P<0.01, Stand III, F=62.91, P<0.01). Seedlings grown in stand III with dense canopy had greater number of leaves. Growth rate in terms of leaf number decreased from July-August to January-February and thereafter it increased steadily (Fig. VII. 2c).

Leaf area

Leaf area per seedling differed significantly (Stand I, F= 54.62, P<0.001; Stand II, F=174.91, P <0.001; Stand III, F= 44.76, P<0.01) among the three forest stands. Highest leaf area was recorded in stand III with dense canopy and least in stand I with open canopy. Leaf area increment was rapid in May-June to July-August and thereafter it decreased and was the least in January-February due to leaf fall, and after February it again increased steadily (Fig. VII. 2d).

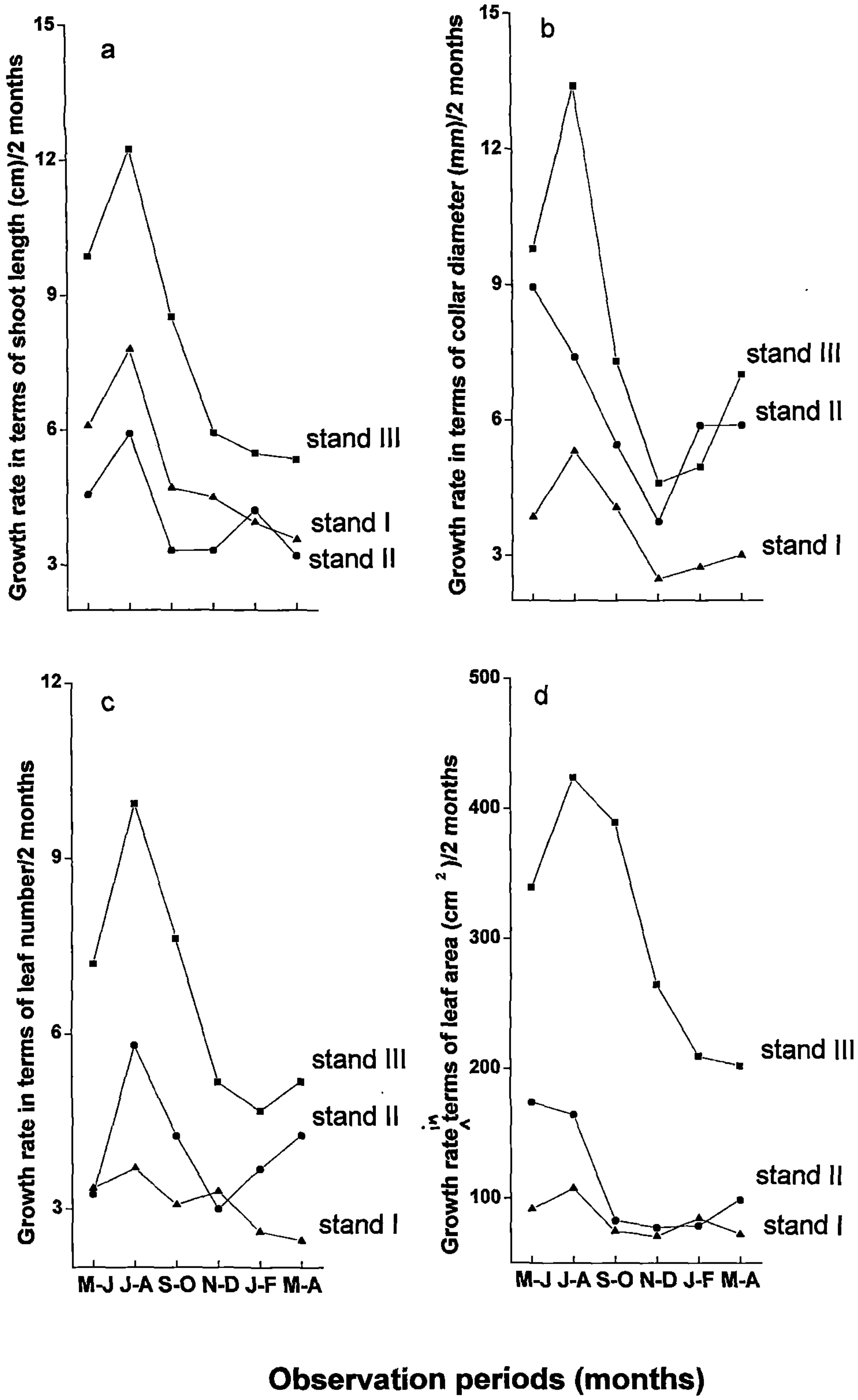


Figure VII.2. Growth rate of seedlings in three forest stands; open canopy (stand I), sparse canopy (stand II) and dense canopy (stand III). (M-J: 1 May to 30 June, J-A: 1 July to 31 August, S-O: 1 September to 31 October, N-D: 1 November to 31 December, J-F: 1 January to 29 February, M-A: 1 March to 30 April).

Seedling mortality and infestation by various herbivores are given in Table VII. 2. Highest seedling mortality was recorded in stand I with open canopy and least in stand III with dense canopy. However, spider web infestation was highest in stand III with dense canopy and least in stand I with open canopy. Insects with silken cocoon were observed in stand III with dense canopy. The shoot length, collar diameter, leaf number and leaf area of seedlings in the nursery and in the three forest stands after one year growth are given in figure VII. 3. The seedlings planted in stand III with dense canopy showed relatively better growth than those in stand II with sparse canopy and stand I with open canopy.

Table VII. 2. Survival of Rudraksh seedlings and their infestation by various agents in different forest stands.

Forest sites	Survival (%)	Pest Infestation (%)			
		Pathogen	Herbivory	Spider web	Unknown
Open canopy	75	17	75	8	-
Sparse canopy	80	6	57	31	6
Dense canopy	85	0	72	21	8

Discussion

Better growth and survival of the seedlings in stand III with dense canopy can be attributed to the microclimatic conditions favourable for growth. Further, the seedling growth might have been stimulated in open edges due to

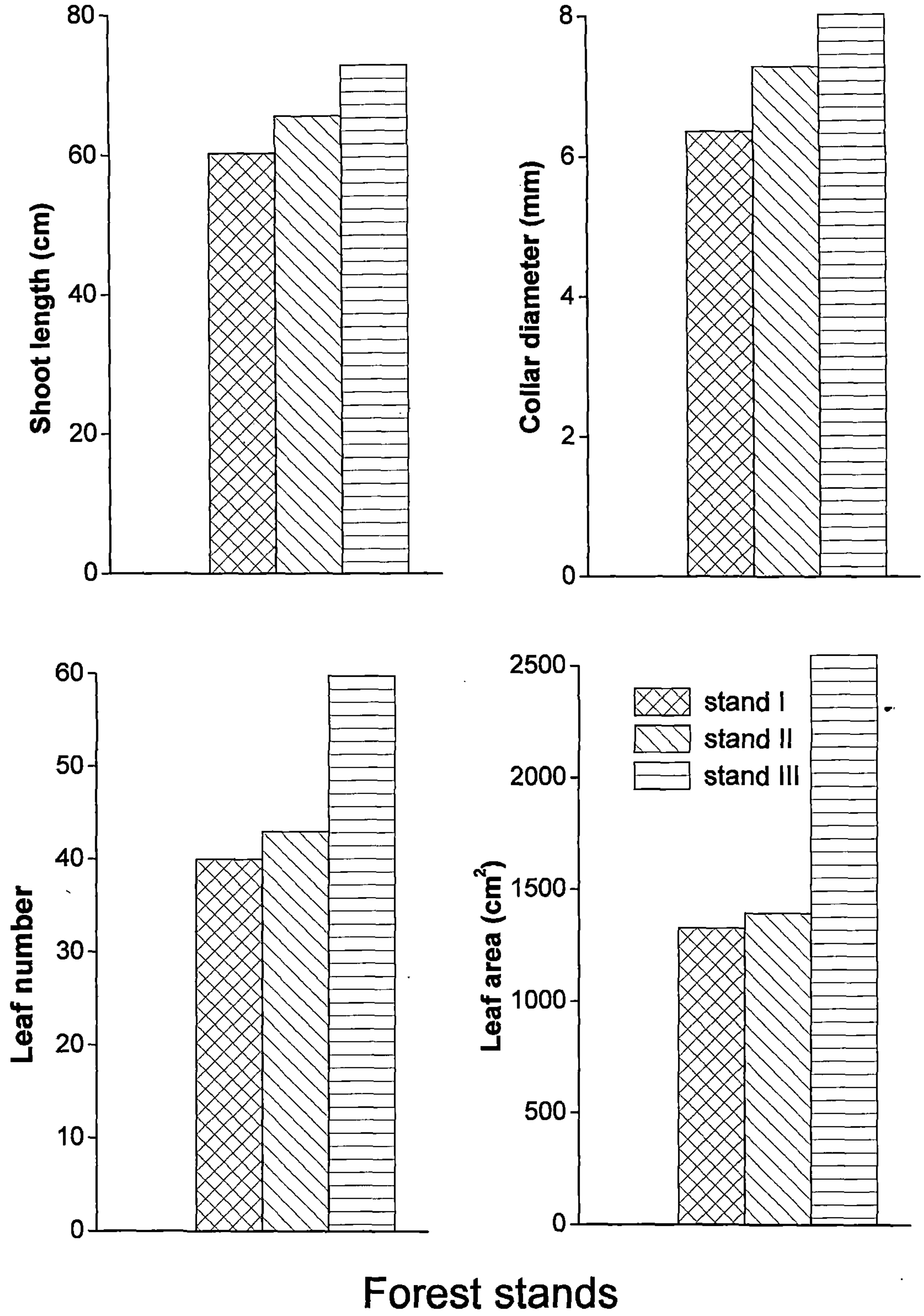


Figure VII.3. Growth of seedlings in terms of shoot length, collar diameter, leaf number and leaf area in stand I (open canopy), stand II (sparse canopy) and stand III (dense canopy) after one year period of transplantation.

better availability of light. Khan and Uma Shanker (2001) have reported better growth and survival of seedlings of *Quercus semiserrata* in medium light conditions. However, many studies have shown better growth and survival of seedling in sunny areas (Longman & Jenik 1974, Whitemore 1975, Hartshorn 1978, Lee 1978). Studies conducted by Augsperger (1984b) on tropical trees, Khan *et al.* (1986) on subtropical trees, Sasaki & Mori (1981) on some *Dipterocarpus* seedlings have also shown better growth and survival in sunny areas.

Relative increase in the leaf area was more in stand III with dense canopy. Seedling leaf area decreased with the increase in radiation. At low light plants enhance light interception by means of a high biomass allocation to leaves and the formation of thin leaves with high leaf area. On the other hand, under high radiation plants reduce transpiration loss and increase carbon gain by making small sized, thick leaves with low leaf area. Small size leaf area has thin boundary layer, which allows for a better convective heat loss to the environment and cooling down of the leaf in high light environment (Parkhrust & Loucks 1972, Givnish 1988). Leaf thickness is increased in high radiation owing to the formation of several photosynthetically active parenchyma layers enhancing photosynthetic capacity. Similar pattern has been reported in the seedlings and leaves of trees along a light gradient in the forest canopy (Oberbauer & Strain 1986, Poorter *et al.* 1995).

Growth rate of seedlings in terms of shoot elongation, collar diameter, leaf number and leaf area was more under the dense canopy with intermediate light radiation than in the other two stands. At full sun light net assimilation rate compensates for the decline in leaf area (Poorter 1999). Plants grown in full light suffered from water limitation in high soil temperature, which might have caused reduction in the above growth parameters, in the case of seedlings grown in the other two stands (stand I & II) which had open and sparse canopy. At high irradiance level photosynthetic system may be damaged causing bleaching of leaves (Oberbauer 1985, Chairiello *et al.*1987). High radiation load requires a larger biomass allocation to roots for water uptake to compensate for transpiration losses. Therefore, less biomass may be invested in leaf material, which slightly reduces photosynthetic rate and potential growth rate (Kormer 1994). In a study on the growth of *Liviodendron* under controlled light and water conditions, Holmgern (1996) found that maximum growth was realized at light level as low as 1%. Veenendaal *et al.* (1996) compared the growth of seedlings of 15 West African tree species at various light levels and reported that shade-tolerant species showed higher relative growth rate at 16 to 27% light, above which it declined while the pioneer species showed optimum growth between 26 and 100% light intensity in the field. Biomass loss is minimized by low leaf turnover (King 1994) and due to the storage and defense. Trees, which are less prone to herbivory, are characterized by high leaf toughness and low inherent growth rate (Cornelissen *et al.*1998). Shade plants and shade-tolerant plants allocate more resource to leaf production, giving rise to higher leaf area ratio, and lower root to shoot ratio or relative root mass. They may show greater activity in the apical meristem, leading to reduced branching and more slender stems (Poorter 1999).

Pathogen attack, insect herbivory and infestation with spider webs were the major causes of seedling mortality in all the stands. Pathogen and herbivory were more frequent in stand I with open canopy as compared to the other stands. Necrosis of stem tips during early stage of growth is the cause of seedling mortality. Relatively greater proximity of the transplanted seedlings to the trees in the dense canopy stand may increase the chances of pathogen infection since the parent trees act as host for a number of pests. Kitajima & Augspurger (1989) reported that the proportion of seedlings of *Tachigalia versicolor* killed by damping-off disease was significantly higher near the parent trees.

Damage to seedlings by insect herbivory in forest stand is the result of complex interactions between the direct and indirect responses of both plants and herbivores to shading and other micro-environmental conditions. In the present experiment, the damage by herbivory was more in stand I (with open canopy) and stand III (dense canopy) as compared to stand II with sparse canopy. The insect especially the caterpillar, beetle, fly and other coleopteran insects damaged the leaf blade along with the midrib resulting in the falling of leaf and sometimes scaletonized appearance of leaf (plate VII.1). The frequency of insect infestation indicated that the herbivores preferred the aged leaves to the younger leaves. This is in contrast to the findings of Coley (1983) who reported that insects preferred young leaves due to lack of

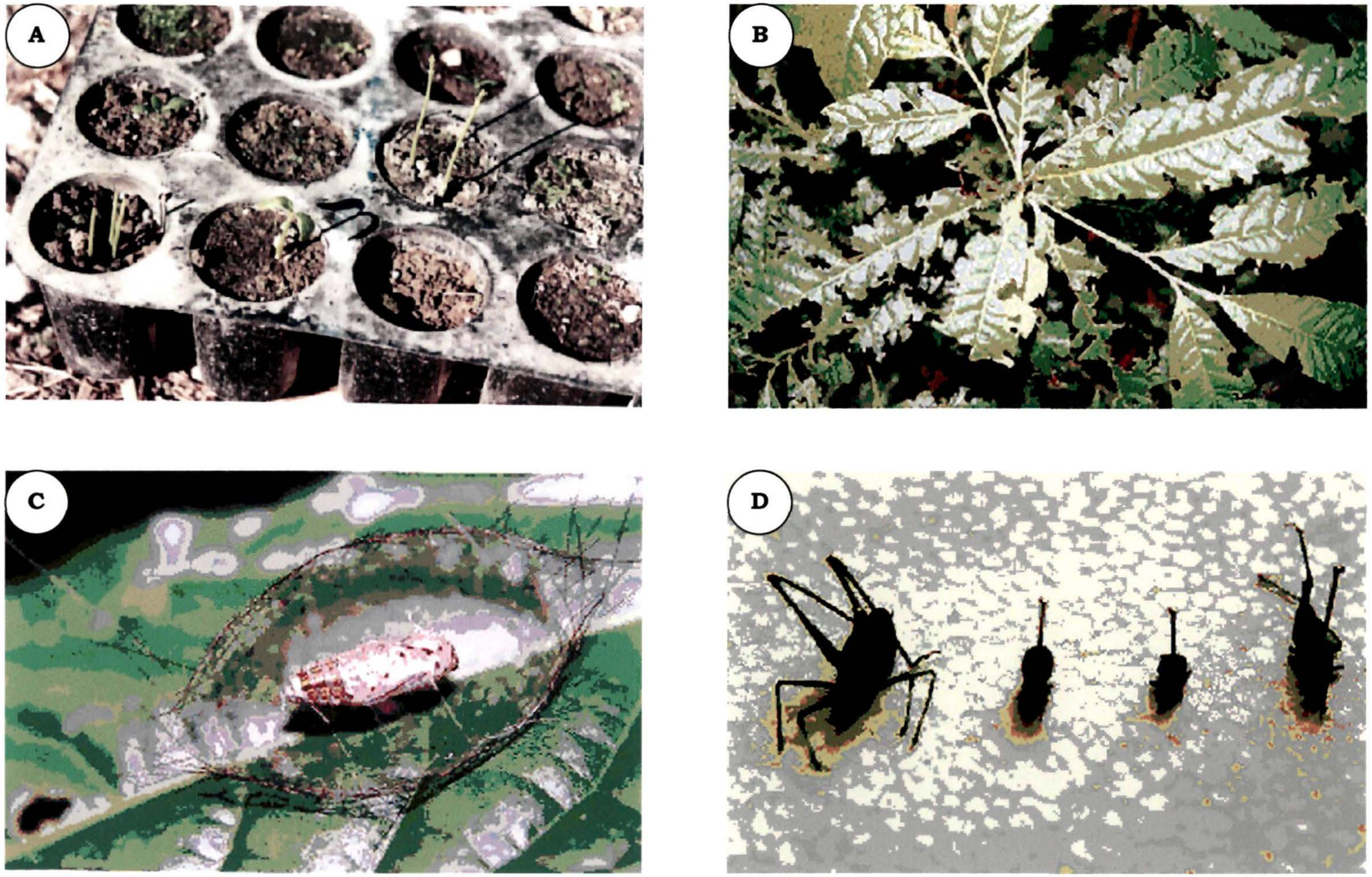


Plate VII.1. Herbivory in Rudraksh seedlings in nursery conditions (A) and in forest stands (B). Insects cocoon (C) and grasshoppers (D) noticed on the Rudraksh seedlings.

toughness, higher level of water and nitrogen. There was greater damage during rainy season which may be due to faster multiplication of insect herbivores on the luxuriantly growing neighbouring weeds especially in stand I and III which had open and dense canopy, respectively.

As mentioned above, the mature leaves were damaged more than the young leaves. This could be simply because the new leaves emerge during pre-monsoon period when insect herbivores are scarce, while the mature leaf stage is attained during the wet season when the herbivore populations are abundant. Degree of herbivore damage in stand I and III with open and dense canopy, respectively was more compared to stand II with sparse canopy, which may be due to higher frequency and good growth of weeds in the former two stands. The weed growth causes increase in insect and herbivore populations (Coley *et al.* 1985). However, frequent weeding might have reduced the herbivore populations in stand II whereby the damage by herbivores was minimized.

In general Rudraksh is a sub-canopy tree species expressing full growth and development in shaded condition. In the present experiment, relatively vigorous growth and development was observed in dense canopy conditions. Based on the present observations, it is suggested that plantation of Rudraksh should be raised as understory in the established forests/plantations with small canopy gaps or in slightly shaded localities for better success.

CHAPTER VIII

Vegetative Propagation of Rudraksh Through Branch Cuttings

Introduction

The population of Rudraksh is depleting in nature due to its overexploitation. The ripened fruits of Rudraksh are collected by man in huge quantity from the forest floor for making 'malas' or to sell them in market at higher prices. The Rudraksh plants are also used by the people as fuel and timber. Moreover, the stony nuts of Rudraksh germinate hardly up to 5% in natural conditions and its seedlings are eaten/killed by wild animals. Thus, its regeneration is very poor. As the seeds do not germinate easily in nature, it was thought worthwhile to examine whether this tree species can propagate through vegetative means by giving some growth hormone treatments to stem/branch cuttings in different seasons under the green house conditions.

Materials and Methods

Branch cuttings of Rudraksh were collected from the healthy mother plant (8-10 years old) in four seasons of the year viz., spring (February), summer (May), rainy (August) and winter (November). The uniform-sized cuttings of 15-20 cm length and 5 cm diameter were selected (20 cuttings for each treatment) and treated with 100, 200, 500 ppm (mg/l) each of IAA (Indole acetic acid), IBA (Indole-3 buteric acid), NAA (Napthalene acetic acid) and 2, 4-D (Dicholorophenoxy acetic acid) respectively by dipping about 5 cm basal cut ends in the respective solution for 24 hours. Twenty cuttings were separately soaked in distilled water to serve as the control. The treated cuttings were planted during aforesaid seasons in polythene bags containing equal amount of garden soil and sand and small amount of farmyard manure. The polythene bags were kept in the net house and watered regularly. The observations on sprouting were made after 30, 45, and 60 days from the date of treatment. Rooting response of the cuttings was observed by uprooting them from the bags.

Results

Sprouting

Sprouting was observed only in February and May in the most treatments except NAA_{100}, IBA_{200}, 2,4-$D_{100,\ 200\ \&\ 500}$. The cuttings planted in February sprouted better than those planted in May. No sprouting was observed in the cuttings planted in August and November. Moreover, number of sprouts per cutting and average sprout length were more in the case of cuttings planted in February than those planted in May (Table VIII.1).

Rooting responses

No rooting was observed in any of the cuttings which sprouted. Though sprouting was observed in both the seasons, sprouts were dead after about one month from the date of sprouting. Thus the hormonal treatments failed to stimulate rooting in the cuttings.

Table VIII.1. Response of cuttings to various growth hormones in different seasons.

Treatments (ppm)	No. of cuttings planted.	No. of cuttings sprouted				Average sprouts per cutting.		Average sprout length (mm)		Rooting (%)		Survival (%)
		Feb.	May	August	Nov.	Feb.	May	Feb.	May	Feb.	May	
IAA-100	20	3 (15)	2 (10)	Nil	Nil	1.33	1	4.5 ±1.1	4.5 ±0.5	Nil	Nil	Nil
IAA-200	20	5 (25)	2 (10)	Nil	Nil	1.20	1	4.2 ±1.6	4.2 ±1.2	Nil	Nil	Nil
IAA-500	20	9 (45)	5 (25)	Nil	Nil	1.55	1.2	4.1 ±1.8	4.6 ±1.9	Nil	Nil	Nil
IBA-100	20	7 (35)	1 (5)	Nil	Nil	1.14	2	5 ±1.3	5 ±1.0	Nil	Nil	Nil
IBA-200	20	10 (50)	- (0)	Nil	Nil	1.20	-	4.9 ±2.4	- -	Nil	Nil	Nil
IBA-500	20	15 (75)	9 (45)	Nil	Nil	1.37	1.4	6.5 ±2.9	5.9 ±2.8	Nil	Nil	Nil
NAA-100	20	- (0)	- (0)	Nil	Nil	-	-	- -	- -	Nil	Nil	Nil
NAA-200	20	2 (10)	1 (5)	Nil	Nil	1.50	1	8.6 ±2.9	4 ±1.1	Nil	Nil	Nil
NAA-500	20	7 (35)	8 (40)	Nil	Nil	1.42	1.5	8.3 ±3.3	7.3 ±2.4	Nil	Nil	Nil
2,4-D-100	20	- (0)	- (0)	Nil	Nil	-	-	- -	- -	Nil	Nil	Nil
2,4-D-200	20	2 (10)	- (0)	Nil	Nil	1	-	6 ±2	- -	Nil	Nil	Nil
2,4-D-500	20	- (0)	- (0)	Nil	Nil	-	-	- -	- -	Nil	Nil	Nil
Control.	20	5 (25)	3 (15)	Nil	Nil	1.40	1.3	4.3 ±1.2	7.7 ±2.3	Nil	Nil	Nil

Values in the parentheses are the percentage of sprouted cuttings.

Discussion

The results of the present investigation and those reported by earlier workers (Momose 1978, Halle & Hanif Kamil 1981, Srivastava & Manggil 1981, Khosla *et al.* 1982b, Smits 1983, Puri & Nagpal 1988, Puri & Shamet

1988, Radwan *et al.* 1989, Bhatt & Todaria, 1993a, b, Chauhan *et al.* 1993, Gauttam & Negi 1997b, Bhatt & Todaria 1990b) show a wide variation in rooting and sprouting ability of cuttings and inconsistent effect of different concentrations of various auxins.

Several workers have reported that exogenous application of hormones induces rooting in a number of species (Bhagawati & Badani 1993, Puri & Shamet 1988, Bhatt & Todaria 1993a, b). The present study suggests that no general conclusion can be drawn regarding the effect of a particular auxin on vegetative propagation of Rudraksh. Though sprouting was induced in cuttings during spring (February) and summer (May) seasons, the hormone treatments could not induce rooting in any of the cuttings in any season.

Seasonal stimulus plays an important role in the callus formation in trees. Only two seasons stimulated sprouting in the stem cuttings of Rudraksh. A number of workers have shown that rooting of cuttings is facilitated when carbohydrate reserve foods are in abundance (Kraus & Kraybill 1918, Knight 1926, Carlson 1929, Duguma 1988). Much of the growth activities remain at minimum during winter. As the temperature starts rising from February onwards, the reserve food material (carbohydrate) is mobilized, which helps in growth flushes. Thus, in February the cuttings are full of reserve food materials. The mobilization of carbohydrates and rising temperature in February stimulates sprouting and rooting. Thus, vegetative propagation can be done more easily in February as compared to the other months of the year during which the cuttings were planted.

Callus tissue plays an important role in vegetative propagation (Satoo, 1956). In this experiment callus formation might have failed probably due to lack of sufficient food reserve, unfavorable temperature and moisture, and some internal factors as reported by Bonga & Durzan (1982).

During vegetative propagation early growth of sprouts depends on food reserve available in the cuttings (Wright 1975) followed by shoot formation. However, where root formation lags very much behind shoot formation, survival rate becomes very low and the plant is likely to die (Duguma 1988). In this study good sprouting was observed in some treatments but root formation did not take place. According to Adriance and Brison (1955) low carbohydrate/N ratio encourages better shoot growth but poor root formation. Thai (1977) reported flagging (drying of shoots) in *Palaquium maingayi* cuttings. He suggested that early shoot formation might have an unfavorable effect on root formation because this creates a competitive relation between root and shoot formation for nutrient reserve in the cuttings. The causes of failure of the rooting in the sprouts emerging from the stem cuttings of Rudraksh and the mechanism to overcome this problem need further investigation. A thorough understanding of these aspects may be helpful in devising techniques that may augment vegetative propagation in this rare species, which shows poor germination.

GENERAL DISCUSSION

The Rudraksh tree occurs sporadically in all districts of Assam and Meghalaya, but is more frequent in Arunachal Pradesh. In Arunachal Pradesh it is common along the foothill of all districts except Tawang and Upper Subansiri and some other high altitude areas. The Rudraksh is found in tropical evergreen forest, which is characterized by three-tier forest structure. Rudraksh is usually present in the second story. However, tropical forests of Arunachal Pradesh are being modified and degraded due to increased anthropogenic pressure. The age-old practice of shifting agriculture is one of the potent factors for changing the forest microenvironment and reduction of forest cover. Rudraksh population in the natural as well as planted forest stands has been decreasing day by day due to household and other industrial uses. Moreover, nut collection for beads has caused the shrinkage of the seed bank in the soil, which has adversely affected the regeneration of the species. Thus the species is being pushed to the threatened category (Rao & Haridasan 1983). The species bears very low regeneration power and mainly reproduces through seeds. However, the germination of Rudraksh is very poor and erratic, and so it is a difficult task to raise the species in nursery.

The overall structural pattern of the community reveals that the studied four forest stands harbouring Rudraksh and experiencing different degree of disturbances are dominated by *Dipterocarpus macrocarpus, Shorea assamica, Castanopsis indica, Terminalia* spp., *Vatica lancefolia, Duabanga* sp. etc. The forest stands have highly heterogeneous distribution of trees like other forests of Eastern Himalayas (Singh & Singh, 1987). *Dipterocarpus,* *Shorea, Duabanga*, and *Terminalia* form the top canopy layer, restricting the availability of light to the ground vegetation especially in the undisturbed stand. However, in the other stands which were exposed to human disturbance, the microsites created were such that they facilitated the occurrence and growth of light demanding and opportunistic tree species like Rudraksh (Ohsawa *et al.* 1986). Thus human induced disturbances (mining, timber extraction etc.), livestock grazing, etc. cause changes in species number, tree diversity, basal area (Rao *et al.* 1990, Vetas 1993, Murali *et al.* 1996). Removal of over-story trees might have favoured germination and seedling establishment through increased solar radiation on the forest floor and consequent increase in surface temperature, and through reduced competition from the trees of upper canopy (Koller 1972, Oliver 1981, Noble & Slatyer 1988). Variation in regeneration behaviour of tree species and vegetation structure of the forest stands signifies the role of prevailing disturbance (Whitmore 1975, Saxena & Singh 1984, Primack 1985, White *et al.* 1993). Positive role of mild disturbance on the regeneration of trees has been reported by Harris & Farr (1974), Boring *et al.* (1981) and Khan *et al.* (1987).

Species composition of the forest depends on the magnitude of disturbances caused due to collection of timber, fodder and firewood by the people of the adjacent human settlements. The highly disturbed stand was devoid of the dominating over-story species. Moreover, due to human intervention in many areas, the forests are being converted to *Taungya* plantations and cash crop plantation such as tea and coffee plantations. Forest composition is also being changed in certain cases due to pest and disease attack especially in the dense forest stand where light penetration is poor (Augspurger 1984b, Sundriyal *et al.* 1994). Many species face the threat of extinction due to biotic pressure, and absence of regeneration in the natural forest.

Rudraksh population was very erratic, discontinuous and sporadic compared to the canopy species. The canopy species were regenerating with abundance of seedlings and saplings, but the Rudraksh population was very small with a few seedlings and saplings that too in the undisturbed stand (Chapter IV). This disparity in abundance may be attributed to the canopy condition and human disturbance in the disturbed stands. The age structure of Rudraksh population indicates that this species has poor regeneration potential. Though the seedlings were found, the saplings were absent in most localities and the adults were scattered and had very few girth classes (Figure; IV. 3, Chapter IV). Discontinuous population structure has been reported for a number of other tropical light demanding pioneer species such as *Endospermum medullosum* in Solomon Island (Whitmore 1984), *Trema micrantha* (Brokaw 1987) in Panama, *Scalesia penduculata* (a pioneer tree) in Galapages Island (Itow & Muller-Dombios 1988) and *Grewia pandaica* in Western Ghats (Parthasarathy & Karthikeyan 1997b).

Folivory by leaf eating caterpillars, other beetles, and spider webs were more frequent in the undisturbed stand due to gregarious tree habitation

(Chapter IV & VII). Moreover, seedling mortality was of common occurrence due to lack of light interception and pathogenesis as also reported in the case of other species (Stewart 1975, Horsely 1977, Augspurger 1984b).

Human settlement nearby forest area is a common phenomenon and people depend on forest for fulfilling their various requirements. The collection of firewood and non-timber forest produce as well as timber operations are quite common. Timber operations leave the stumps of cut trees both in planted and natural forests. Resprouting of cut stumps was observed both in natural forests and plantations, but resprouting ability varies with stump diameter and forest stands. Stumps in natural stands resprout more frequently compared to planted stands.

In nature germination of Rudraksh is very low and erratic, since nuts are unable to absorb water because of their hard stony nature. Hard seed coat impermeability which is a characteristic feature of many leguminous and non leguminous species, may be considered as a delaying mechanism that prevents germination under conditions unsuitable for establishment (Ballard 1973, Cavangh 1980, Baskin & Baskin 1989, Tybirk 1991). Further, hard seed coat confers several advantages on seeds. It allows endozoic dispersal, recolonization after fire and helps the seeds to withstand unfavourable conditions such as heat, drought and mechanical damage remaining viable for a long period in the soil waiting for the conditions favourable for germination (Coe & Coe 1987, Sabitii & Wein 1987, Tybirk 1991, Tybirk *et al.* 1994).

Mechanical treatment of hard coated nuts improves germination in many tree species (Khan & Tripathi 1987b, Todaria & Negi 1992, Negi & Todaria 1995, Demel Takety 1997). It was found that in the case of Rudraksh, the cracking of nuts enhances the speed of germination significantly by allowing immediate entrance of water in the nut. However, most of the evidences indicate that continuous layer of tightly packed palisade cells in the nuts/seed coat acts as major barrier to the entry of water into the nut (Tran & Cavanagh 1984, Cavanagh 1987, Egley 1989). It has been shown that the decomposition process in nature or mechanical injury by several specific treatments make the seed/nut coat permeable to water in most of the cases. It is true for Rudraksh too.

Seed number in a nut of Rudraksh varies from 1-5, which may be due to selective abortion of fertilized ovules of maturing seeds (Ganashaiah & Uma Shaanker 1991). Generally, the number of seedlings arising from a single nut varies from 1-4. However, clustering of seedlings adversely affects their growth and development (Campbell 1964, Lohrey 1970) and if the seedlings arising from a nut is less in number, they develop faster and grow better than when they are more crowded (Chapter VI).

Flower and fruit production in *Elaeocarpus ganitrus* varied greatly in time and space. Barik *et al.* (1996) and Khan *et al.* (1999) also reported similar results on shade-tolerant species and Milton *et al.* (1982) and DeViana (1999) in light demanding pioneer species. Fruit production may differ among populations of the same species and individual trees within a population may also vary in fruit set (Howe 1982, Grubb 1977, Schupp 1990, Barik *et al.* 1996, Khan *et al.* 1999). Resource availability may be one of the causes of yearly variation in fruit production (Fenner 1991). Many extrinsic factors such as rainfall, hailstorm, and wind speed, particularly during flowering season may affect fruit production (Khan *et al.* 1999, Felfelli *et al.* 1999). Unusual rainfall in a particular year may significantly decrease flower and fruit production (Chapter V). With the increase in disturbance intensity the flower and fruit production increases. Higher fruit production in the disturbed stands may be attributed to stimulation of flowering in sunlight. The high light intensity may elevate bud temperature, stimulating growth regulating chemicals especially gibberellins (Phrais & Kuo 1977, Ross *et al.* 1983), which induce flowering and fruiting. Tall individuals offer more foraging opportunities thereby increasing pollination chances and protection from predators (Ducan & Chapman 1999).

Fruit dispersal is the process that links generations of plants both in time and space. The fruit/nut of Rudraksh is very hard, heavy and has low ability to be dispersed without transportation by animals. Therefore, fruit dispersing animals are very important for this species for reducing sibling competition, decreasing genetic relatedness of patches and enabling it to colonize new areas. A large number of fruits was found deposited in rotten logs hoarded by rodents. The ripe fruits were preferred by dispersers over the unripe fruits and fruits without pulp. Fruit colour, nutritional content, pulpiness and aroma attract dispersal agents (Herrera 1981, Snow 1981, Janzen 1983, Howe 1985, Howe *et al.* 1985).

Hornbill, bat and flying squirrel are the dispersal agents that take away the fruits from the crown, while monkey drops the fruits beneath the tree crown. Some animals like deer and wild pig were seen to eat ripe fruits fallen on the forest floor. The nuts are not swallowed and normally regurgitated under the crown, suggesting cost paid to animals but the species did not get the reward in terms of dispersal (Hedge *et al.* 1991). Rodents viz, *Vandeleuria oleracea* and *Rhizomus prunosus* are the main consumers, dispersers and hoarders of the fruits. In general about 40-70% fruits disappeared during fruit fall period and large proportion of the remaining fruits dispersed during post fruit fall period. Fruit dispersal decreased with increase in distance from the tree.

The study on the nut bank dynamics reveals important stages at which nut losses could occur. The major loss of fruits occurs immediately after the fruit fall. The fruits that are still left on the forest floor disappear gradually due to the activities of secondary dispersers. About 89% of the nuts present on the forest floor were found predated and the remaining 11% were intact but not readily germinable (Figure V. 5, Chapter V). The dormant fraction may give rise to seedlings in near future. Hubbell (1980) suggested that recruitment is higher close to the parent tree due to greater seed abundance. A large fraction of nuts hoarded by rodents is damaged by ants which eat up cotyledons of the seeds. Moreover, due to ethnic importance nuts are collected in huge quantities from the forest floor causing reduction in nut bank.

Seedling growth and survival are determined by interactive influence of biotic and abiotic factors of the forest environment (Augsperger 1984a), such as light intensity (Whitmore 1975, Vance & Running 1985, Clark *et al.* 1996), soil moisture (Muller-Dombois *et al.* 1980) and pathogen (Augspurger 1984b). Tree canopy in the upper layer determines the light penetration to the ground vegetation and subsequent growth process of the plants growing beneath the tree canopy. In low light condition the biomass allocation to leaves tends to be greater (Poorter *et al.* 1995, Poorter 1999) and so, there was an increase in leaf area (Chapter VII). On the contrary, in high light condition plant reduces transpiration losses by producing small size, thick leaves with low leaf area (Poorter 2001).

Relative growth rate of Rudraksh was more under the intermediate light condition than the full sun light. At full sunlight net assimilation rate compensates for a decline in leaf area. Plants grown in full sunlight suffer from limitation of soil moisture and high temperature. At high irradiance level photosynthetic system may be damaged causing bleaching of leaves (Oberbauer 1985). Higher irradiance load requires a larger biomass allocation to roots for water uptake to compensate for transpiration loss. Therefore, less biomass can be invested in leaf material, which reduces photosynthetic rate and potential growth rate (Kormer 1994). It was found that shade-tolerant species showed optimum relative growth rate at 16 to 27% radiation level, above which RGR declined (Veenendaal *et al.* 1996). Pioneer species show optimum growth between 26 and 100% light intensity in the field.

In the dense forest stand where light penetration was very less, the incidence of pest disease attack was more (Chapter VII). Likewise in the dense canopy condition predators and pathogen attack were more frequent. Insects like caterpillar, beetle, fly, and other coleopteran insects damage the leaf blade along with the midrib resulting in falling of leaves sometimes giving scaletonized appearance. It was recorded that herbivores preferred the older leaves compared to the younger ones. However, Coley (1983) reported that insect preferred young leaves due to lack of toughness, and higher levels of water and nitrogen. Barboni *et al.* (1994) reported that alkaloid content is higher in young plants, and reproductive organs as a defensive strategy of the species and more so in pioneer species.

Vegetative propagation is an easy and quick method of plant propagation. However, the study on vegetative propagation in Rudraksh using branch cuttings did not show satisfactory results. Branch cuttings in February and May resulted in sprouting but no rooting. A number of workers have shown that rooting of cutting is facilitated when carbohydrate reserve food is in abundance (Kraus & Kraybill 1918, Knight 1926, Carlson 1929, Duguma 1988).

Seasonal stimulus plays an important role in callus formation in cuttings of trees. Much of the growth activities remain suspended during winter and as soon as the temperature starts rising from February onwards the reserve food material is mobilized, which helps in growth flushes. Thus the cuttings made in the beginning of February are full of reserve food materials and the rising temperature gives stimulus to sprouting and rooting. During vegetative propagation, growth of the sprouts depends on food reserve available in the cuttings (Wright 1975). But where root formation lags behind the shoot formation, survival rate becomes very low and the cutting is likely to die (Duguma 1988). According to Adraince and Brison (1955) low carbohydrate/nitrogen ratio encourages better shoot growth but poor root formation. Thai (1977) suggested that early shoot formation might have unfavorable effect on root formation because this creates a competition between root and shoot formation for nutrient reserve in the cuttings.

It is concluded that the seed production, dispersal and regeneration of the tree species depend on the influence of biotic and abiotic factors of the environment. Though the prevailing disturbances directly influence the availability of dispersers and ultimately affect the regeneration of the Rudraksh, still a thorough study is required. Mild disturbances have a positive role in the regeneration of Rudraksh. Seedling population requires favourable microsites for better survival and growth. Thus populations are regulated by overhead canopy, ground vegetation, pest attack and other biotic interactions.

The present investigation throws light on certain important aspects of dispersal and regeneration of Rudraksh. However, in order to gain deeper insight into the regeneration of the species, following studies need to be undertaken in detail:

1. Detailed studies on the impact of prevailing disturbances on regeneration of Rudraksh and to identify the intensity of disturbance that may favour the regeneration of species.

2. Study on secondary dispersal and identification of the dispersers involved in such dispersal.

3. Studies on the identification of predators, pests and pathogens in different habitats that influence the regeneration.

4. A study to develop quick method of vegetative propagation.

Results of the present study could be quite useful in understanding the regeneration behaviour and population dynamics of Rudraksh, and based on these findings, appropriate strategies could be evolved to conserve this threatened species.

SUMMARY

The thesis embodies scientific information on some of the important and hitherto less understood aspects of regeneration of Rudraksh (*Elaeocarpus ganitrus*), an endangered tree species, growing in the tropical rain forests of Arunachal Pradesh. The studies presented in the thesis focus on the following aspects.

1) Species richness, population structure and regeneration status of tree species in relation to different degree of anthropogenic disturbances.
2) Population structure and regeneration status of Rudraksh in the undisturbed and disturbed (highly disturbed, moderately disturbed and mildly disturbed) forest stands.
3) Fruit set, dispersal and nut bank dynamics of Rudraksh in the four forest stands.
4) Growth of nursery grown seedlings when transplanted in the forest stands under different ecological conditions with a view to find out suitable sites for transplantation.
5) Survival and growth of seedlings in the green house condition.
6) The nuts of Rudraksh being very hard possess nut coat dormancy. Different methods were investigated to enhance the germination.
7) Vegetative propagation through application of different hormones on the branch/stem cuttings.

Tree diversity and population structure in the undisturbed and human impacted forest stands

Species richness, tree density, basal area, population structure and distribution pattern were investigated in the undisturbed, mildly disturbed, moderately disturbed and highly disturbed stands of tropical rain forests of

Arunachal Pradesh. The species richness was highest in the mildly disturbed forest stand (54 species per hectare) and lowest in the highly disturbed stand. The stand density was highest in the undisturbed stand (5442 stems per hectare belonging to 28 families and 51 genera) and lowest in the highly disturbed stand (338 stem per hectare belonging to 14 families and 16 genera). Fabaceae, Dipterocarpaceae and Clusiaceae were the dominant families, and these three families contributed 53% of the total density in the undisturbed stand, 51% in the mildly disturbed stand, 42% in the moderately disturbed and 49% in the highly disturbed stand. Basal area was highest (104.60 m^2 per hectare in the undisturbed stand) and lowest (18.60 m^2 per hectare) in the moderately disturbed stand. Species composition and distribution pattern of tree species were more or less similar in the undisturbed, mildly disturbed and moderately disturbed stands with *Dipteriocarpus macrocarpus, Shorea assamica*, *Terminalia chebula*, *Vatica lancefolia*, and *Bischofia javanica*, as the canopy species and *Elaeocarpus ganitrus*, *Mesua ferrea* and *Canarium* sp. as the sub-canopy species.

Out of the 47 species in the undisturbed stand only 26 were found to be regenerating. Twenty species showed good regeneration, 1 species had fair regeneration and 5 species showed poor regeneration. No regeneration was recorded for other species. In the mildly disturbed stand, out of 54 species 36 species were found regenerating out of which, 23 species had good regeneration, 9 showed fair regeneration and 4 had poor regeneration. Out of 42 species in the moderately disturbed stand, 22 were found regenerating and good regeneration was recorded in 11 species, 7 species showed fair regeneration and 4 species had poor regeneration. No regeneration was recorded in the highly disturbed stand.

Population structure and regeneration status of Rudraksh

Population structure and regeneration status of Rudraksh (*Elaeocarpus ganitrus*) was carried out in the aforesaid forest stands. The mean density of adult trees was 16 trees per hectare. Total population of the species was greater in the undisturbed stand as compared to other stands. The regeneration was recorded in the undisturbed, mildly disturbed and moderately disturbed stands, while the regeneration was absent in the highly disturbed stand. The basal area was highest in the undisturbed stand (4190 cm^2/ha), followed by mildly and highly disturbed stands (2564 & 2785 cm^2/ha) and least (1875 cm^2/ha) in the moderately disturbed stand. Seedling survival and growth was more in the undisturbed stand. No cut stump was recorded in the undisturbed and highly disturbed stands.

Resprouting ability of the cut stumps with less diameter was more in the natural stands as compared to the plantation.

Fruit set, dispersal and nut bank dynamics in relation to cultural disturbances

Flower and fruit production and dispersal system of Rudraksh were investigated during 1997-99 in four stands of a tropical rain forest exposed to varying degrees of disturbance. Flower and fruit production in Rudraksh significantly increased with the increase in girth of fruiting trees. The year-wise variation in flower and fruit production was also significant. Production of flowers and fruits also differed significantly in the four forest stands experiencing different degrees of disturbance; it was highest in the moderately disturbed forest and lowest in the undisturbed forest. The mean fruit weight (both with pulp and without pulp) of Rudraksh varied significantly among the stands; it decreased with the increasing disturbance index. The number of fruits per unit area of the forest floor decreased significantly with increase in distance from the parent tree crown in all the four stands. 40-70% of the total fruits produced by Rudraksh disappeared during the fruit fall period. Disappearance of fruits was mainly attributable to the eating of fruit pulp by certain birds and other animals which drop the nuts away from the parent tree. The disappearance of fruits was also attributable to hoarding by rodents.

During post-fruit fall period, a large proportion (55-99%) of the remaining fruit population disappeared, and the magnitude of disappearance increased with the increase in disturbance index. During this period not a single nut was found germinated. In general, about 80% of the total fruits produced by Rudraksh disappeared from the forest floor. This includes the nuts damaged by insects especially by ants and termites. The fruit disappearance decreased significantly with the increase in distance from the parent tree. Disappearance also differed significantly among the forest stands. It was highest in the highly disturbed stand and lowest in the undisturbed stand. Disappearance of fruits largely depended upon the quality of fruits. The ripe fruits with their pulp intact disappeared more than the unripe fruits without pulp. Soil nut bank of Rudraksh significantly varied in different forest stands showing a decrease with the increase in disturbance index. Nut bank in soil was maximum in the undisturbed stand and minimum in the highly disturbed stand. More than 85% nuts of the soil nut bank were predated.

Regeneration of Rudraksh: germination strategies

Rudraksh nuts are provided with a very hard coat which prevents germination. The nuts show nut-coat dormancy. In order to find out the most effective means to overcome this type of dormancy in Rudraksh, nuts were subjected to different types of scarification and other relevant treatments. Altogether, 25 treatments were tested involving mechanical scarification such as making cracks by vise, chemical scarification with sulfuric and nitric acid treatments for 10, 20, 30 minutes, dipping in animal excreta and fermentation for 1, 2 and 3 weeks. The nuts were also subjected to fire treatments, weathering, and soaking in warm and hot water. The results showed that the hard nut coat, which acts as a barrier to water intake, is the root cause of dormancy that can be broken by different treatments which cause damage to nut coat or make it soft. The best (40%) and quick (19 days required for germination to commence) germination was obtained when the cracks were made with nutcoat by vise. The nuts subjected to this treatment germinated within 49 days after sowing. The other treatments that helped in germination of Rudraksh nuts were: soaking in hot water, dipping in animal excreta for 1-3 weeks and fermentation of nutcoat by putting the nuts in pits filled with cowdung and leaf litter for 10-30 days. It was observed that one to four seedlings may emerge from a single nut. The seedling growth was influenced significantly by the number of seedlings that emerged from a single nut. The growth was significantly greater if only one seedling emerged from the nut than when the number of seedlings emerging from a single nut was more. However, survival did not differ significantly due to seedling clustering.

The germination experiment indicates that cracks made by vise is the best method because of its low cost, ease with which it can be used, and its efficacy in inducing germination in the nuts of Rudraksh. Hence, this method can be recommended for use in nurseries for raising the seedlings of Rudraksh.

Growth and survival of Rudraksh seedlings: Effect of forest canopy on the transplanted seedlings

An experiment was carried out to study the survival and growth of the nursery seedlings transplanted in the forest stands having dense, sparse and open canopy. The transplants exhibited better growth in terms of shoot length, collar diameter, leaf number and leaf area and survival in dense than in sparse and open canopy. The pathogen and herbivory attack on seedlings were more in the open forest stand whereas spider webs were more commonly seen on the transplanted seedlings under the dense canopy.

Vegetative propagation of Rudraksh through branch cuttings

Branch cuttings of Rudraksh were treated with 100, 200 and 500 ppm (mg/l) solutions of each of the three hormones viz. IAA (Indole-3 acetic acid), IBA (Indole-3 buteric acid), NAA (Naphthalene acetic acid) and 2, 4-D (Dicholorophenoxy acetic acid) for 24 hours in the month of February, May, August, and November, 1999-2000 and observations on sprouting and rooting were recorded after 30, 45, 60 days from the date of planting of the cuttings. Sprouting was recorded only in those cuttings which were planted in February and May. However, the cuttings planted in February sprouted better than those planted in May. The highest sprouting was observed in the cuttings treated with IBA_{500}. No rooting was recorded in of the sprouted cuttings and they died within 45 days.

The fundamental scientific information gathered on various aspects of population structure, regeneration status, fruit set, nut dispersal, nut population dynamics, nut germination and seedling fitness may be utilized for management of Rudraksh populations in the tropical rain forest of Arunachal Pradesh and elsewhere. As Rudraksh shows sporadic occurrence and its natural regeneration is poor, there is a strong need to formulate strategies for its conservation. The present study could be useful in this respect.

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* Original not seen.

APPENDIX (i)

Publications arising from the thesis

Paper published:

1. Bhuyan P., Khan M. L. & Tripathi R. S. 2001. Tree diversity and population structure in disturbed and human-impacted tropical wet evergreen forests of Arunachal Pradesh, North East India. *In: Tropical Ecosystems: Structure, Diversity and Human Welfare. Proceedings of the International Conference on Tropical Ecosystems.* K. N. Ganeshaiah, R. Uma Shaanker & K. S. Bawa (eds.), Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi.
2. Bhuyan P. & Khan M. L. 2002. The blue marble tree- Rudraksh. *In: Resource Management Perspective of Arunachal Agriculture.* K. A. Singh (ed.). Silver Jublee publication, ICAR Research Complex for NEH Region, Arunachal Pradesh Centre, Basar.

Papers communicated/under revision:

1. Bhuyan P., Khan M. L. & Tripathi R. S. Tree diversity and population structure in undisturbed and human-impacted stands of tropical wet evergreen forest in Arunachal Pradesh, Eastern Himalayas, India. *Biodiversity and Conservation* (UK) (submitted the revised MS).

2. Bhuyan P., Khan M. L. & Tripathi R. S. Regeneration status and population structure of Rudraksh (*Elaeocarpus ganitrus*) in relation to cultural disturbances in tropical wet evergreen forest of Arunachal Pradesh. *Current Science* (submitted the revised MS).

3. Khan M. L., Bhuyan P. & Tripathi R. S. Fruit set, dispersal and nut bank dynamics in a threatened tree species Rudraksh (*Elaeocarpus ganitrus* Roxb.) in Eastern Himalayas in Relation to cultural disturbances. *Acta Oecologica* (France).

4. Khan M. L., Bhuyan P. & Tripathi R. S. Regeneration of Rudraksh (*Elaeocarpus ganitrus* Roxb.), a threatened tree species: germination strategies. *Current Science.*

5. Bhuyan P., Khan M. L. & Tripathi R. S. Survival and growth of seedlings of Rudraksh (*Elaeocarpus ganitrus*) in nursery and forest stands. *Tropical Ecology.*

6. Bhuyan P. & Khan M. L. Vegetative propagation of Rudraksh (*Elaeocarpus ganitrus*) through branch cuttings. *Journal of Hill Research.*

APPENDIX (ii)

Bio-data

Name : Putul Bhuyan

Father's Name : Shri Tulan Ch. Bhuyan

Permanent address : Town-Dhemaji(Ram Nagar), District-Dhemaji. Assam, PIN- 786057.Phone-037532-5223(R)

Address for communication: IFAD, Hamren-782486, Dist.-Karbi Anglong, Assam, and Phone-03677-70123 (O)

Nationality : Indian

Religion : Hinduism

Educational Qualification:

Exam. passed	Year of passing	University/ Board	Division	% of marks
M.Sc.(Agri)	1997	Assam Agril. Univ., Jorhat	First	75
B. Sc. (Agri)	1995	College of Agriculture, Jorhat.	First	68
HSSLC (Sci.)	1990	Assam Higher Secondary Education Council, Guwahati.	First	63
HSLC	1987	Sec. Education Board of Assam	First	68

Experience:

1. Worked as a Junior Research Fellow in a DST project from October, 1997 to September, 1999.
2. Worked as a Senior Research Fellow in a CSIR project from Oct, 1999 to June, 2001
3. Working as Natural Resource Management Organiser in the Karbi Anglong Community Resource Management Society, funded by International Fund for Agricultural Development since June, 2001.