STUDIES ON SEASONAL OCCURRENCE OF INSECTS ASSOCIATED WITH THE MAJOR SHADE TREE, *ALNUS NEPALENSIS* D.DON, OF LARGE CARDAMOM AGRO FORESTRY, WITH BIO-ECOLOGY OF SOME COMMON FOLIVORES AT DIFFERENT ALTITUDES OF SIKKIM

THESIS SUBMITTED FOR THE DEGREE OF
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By

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Dedicated to

My

Loving Daughters

Harshita And Umanshi Lall

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SUPERVISOR'S CERTIFICATE

This is to certify that Ms. Nittie Srivastava, M.Sc. (Zoology) has worked on the topic 'Studies on seasonal occurrence of insects associated with the major shade tree, *Alnus nepalensis* D.Don, of large cardamom agro forestry, with bio-ecology of some common folivores at different altitudes of Sikkim' under my supervision and guidance, and that she has fulfilled the requirements relating to the nature and period of research. This is also to certify that the research work embodies original results based on well-planned investigation made by Ms. Srivastava. The dissertation submitted herewith is for partial fulfilment of the degree of Doctor of Philosophy in Science of the University of North Bengal, and has not been submitted for any degree whatsoever by her or any one else. I sincerely wish Ms. Srivastava and her endeavour success.

Date: 20 Nov. 2003

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PREFACE

Sikkim is a beautiful but still undeveloped tiny Himalayan state of North Eastern India. Its hilly and thickly forested land area has very little potential for large-scale agriculture of which the annual production is far- far short of the actual need. The agricultural area can not be enhanced if the forests are to be conserved. Also, because of state's topography, terrain and geology, its potential for large-scale industrialization is next to nil. Some sustenance to the people is available in form of handicrafts and other village based small scale industries like carpet-weaving, cattle rearing, honey production, vegetable growing and the like. Tourism is developing apace but its benefits are yet to reach the masses.

In such a scenario, a rich endowment of nature to Sikkim is large cardamom, in the production of which, the state's share is 53% of the world total. Cardamom plant is perennial, so the soil on the slope where it is grown, is not disturbed year after year as is the case with other crops. So, large cardamom cultivation is very eco-friendly. Moreover, it is a shade loving plant and, therefore, trees of suitable species are also to be planted in between the cardamom crop. Native genius of Sikkimese people have found such a tree in *A. nepalensis* (Himalayan Alder, or, in local parlance, "Utis").

This quick growing multipurpose tree not only provides shade to the large cardamom crop but also cheap timber, firewood and fencing material to the village folk. It is extremely useful in preventing soil-erosion. Its litterfall replenishes lost nutrients to the soil. Thus, *Alnus*- cardamom agroforestry is an irreplaceable means of sustenance for Sikkim villages.

Unfortunately, the tree is depredated by a number of insect herbivores, the chief among them being a lepidopteran *Gazalina chrysolopha* and a coleopteran *Chrysomela chlorina*. The latter attacks both; the shade tree as well as the cardamom crop, alternately. In some years, the defoliation of the tree is so severe that it results in considerable loss of shade and consequently, of the large cardamom yield. Although the two pests have been, in the past, studied as part of the other studies, no comprehensive investigation of their occurrence, behaviour or life- cycle, has been carried out. The present study is the first small step in that direction so that a preventive- cum- control measures against these major folivorous insects species (*G. chrysolopha* and *C. chlorina*), could be taken, using information generated on their bio-ecology in the present research work.

Besides this, the population dynamics and biology of the pests are investigated in detail to understand their influence on *A. nepalensis* and its associated soil system, which may be of help in the management of the *Alnus*-cardamom agro- forestry system.

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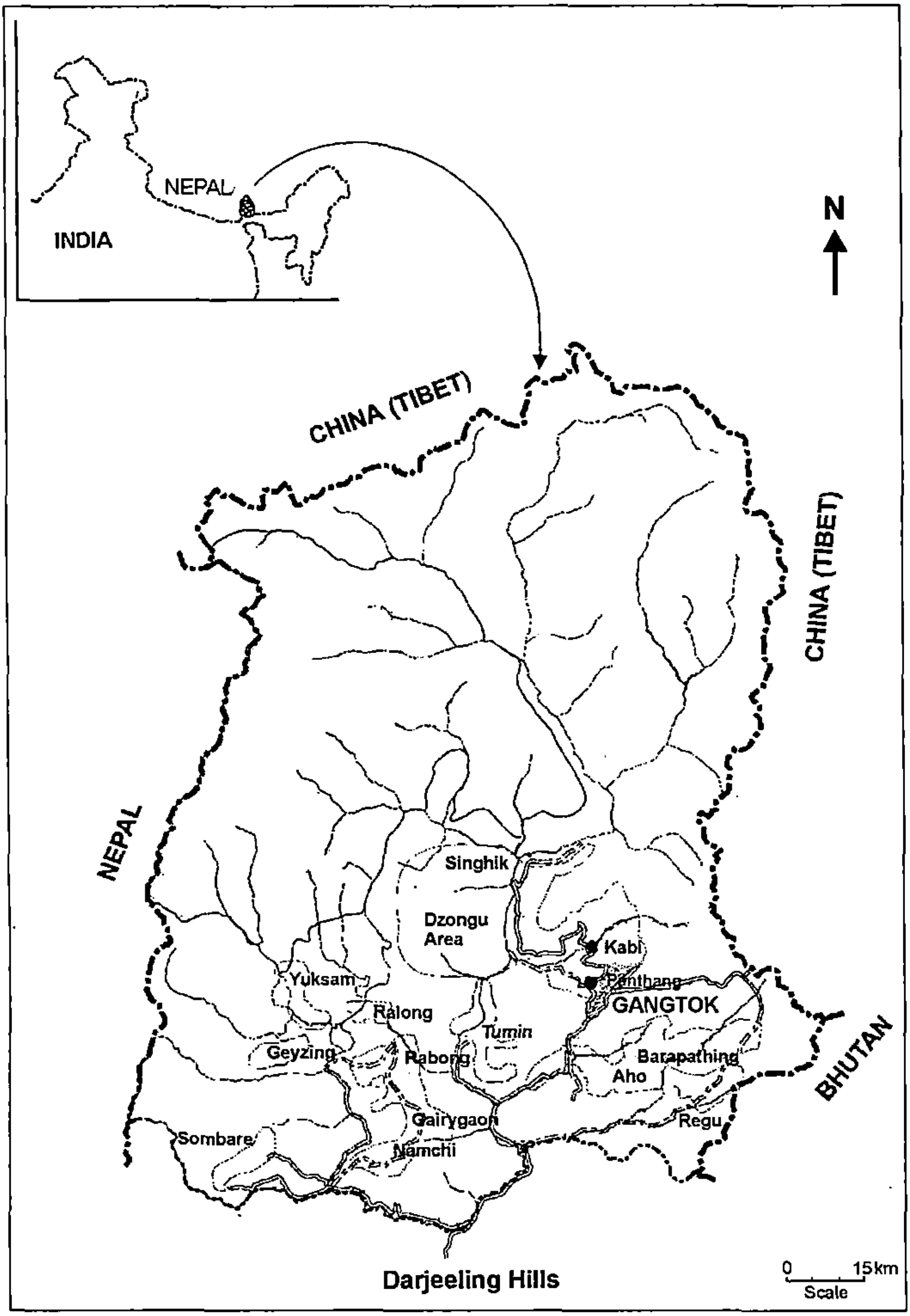
1. INTRODUCTION

Sikkim is a beautiful tiny hill state of India. It lies between 88^0 01' and 88^0 55' E longitude and 27^0 04' and 28^0 07' N latitude. The climate of the state varies from cold temperate in northeast to subtropical in south. The state lies in the eastern Himalayas with Nepal in the west, Bhutan and Chumbi Valley of Tibet in the east and with vast stretches of Tibetan plateau in the north. Sikkim shares its southern boarder with Darjeeling district of the state of West Bengal. The mountain terrain of Sikkim is spread over 7096 sq. Km with elevation ranging from 300 to 8,600 m amsl. The annual rainfall varies from 1300 mm in valleys to 4300 mm on the mountain ridges; 60-75% of which is received in monsoon season. Sikkim is a hot spot for biodiversity. There are 6000 plant species recorded from Sikkim, 4000 of which being flowering plants. Sikkim's 41.9% land area is covered with forest and 25.4% is barren. Out of a total 79,062 hectares of agricultural land, 11,204 hectares are under large cardamom cultivation. The chief means of livelihood for the people of Sikkim is agriculture and about 12% of the land is available for cultivation.

Mountain agriculture in Sikkim consists of traditional and cash crops. Large cardamom (*Amomum subulatum* Roxb.), mandarin orange (*Citrus reticulata*), ginger (*Zingiber officinale*) and potato (*Solanum tuberosum*) are the main cash crops grown in Sikkim. For increasing agricultural production, use of large amount of pesticides, chemical

Fig. 1



Major cardamom growing areas of Sikkim

Source : G.B.Pant Institute of Himalayan Environment and Development, Sikkim

● Showing study areas (Kabi and Panthang)

Plate 1. Utis shade trees (*Alnus nepalensis*) – large cardamom agro-forestry (arrow indicating *A. nepalensis* tree)

Plate 2. Cardamom plantations under the shade tree, *Alnus nepalensis* (arrow indicating large cardamom plant)

Plate 3. Denuded *A. nepalensis* after severe defoliation by insect herbivores (April, 2000)

plate - 1

plate - 2

plate - 3

fertilizers, good irrigation and introduction of high yielding varieties of seeds are required. In Sikkim Himalayan region, these practices, which are integral part of the green revolution and were so successful elsewhere, could not be applied effectively here. Poor availability of fertilizers on time, inappropriate development of irrigation and the fragile soil, low in N and P levels, were the main causes of low yields. Therefore, in an area where accessibility is low and transportation restricted, the farmers always looked for cultivating a non-perishable crop with high-income value and low demand for labour with almost no external input. Large cardamom, being native to Sikkim Himalayas, stood to their expectations. As a result, large cardamom cultivation increased by 135% in total crop area within 20 years after 1975. Income from large cardamom has been sustainably higher as compared to other livelihood options of farming (Sharma *et al.*, 2000).

Large cardamom, locally called "Badi elaichi," is a perennial crop with almost self-contained cropping system. It is grown beneath the forest cover on marginal lands. Its cultivation in Sikkim is a unique example of ecological and economic viability of traditional farming that is based on indigenously evolved agroforestry practices. Lepchas – the tribal inhabitants of Sikkim, collected capsules of large cardamom from the natural forests. Later, when some areas of forests passed into village ownership, the farmers started domesticating the crop. It is cultivated between 600 and 2000m elevation in the subtropical to cool temperate zones. Large cardamom is also cultivated in Darjeeling hills in West Bengal of India, Nepal and Bhutan. Sikkim contributes about 53% of the world's large cardamom's total production.

Large cardamom is a shade loving plant. Appropriate shade conditions, proper humidity and moisture retention, are the key factors for a good yield of its crop. Some common shade trees used in the large cardamom plantation are: *Alnus nepalensis*, *Schima wallichii, Engelhardtia acerifolia, Eurya acuminata, Leucosceptrum canum, Maesa chisia, Symplocos theifolia, Ficus hookerii, Ficus nemoralis, Nyssa sessiliflora, Osbeckia paniculata, Viburnum cordifolium, Litsaea polyantha* and *Macaranga postulata.* It has been established by recent works that *A. nepalensis* D.Don (Himalayan Alder or "Utis") is the best shade tree for large cardamom. Himalayan alder (*A. nepalensis*) regenerates naturally on landslide affected areas and grows in the same agro- climatic range as of large cardamom. It's thin and multiple branches are effective barriers during hailstorm, which causes great damage to cardamom plantation (plate 1). Its senescent leaves are, high in organic matter, quickly decompose and serve as natural manure to the cardamom crop. The agroforestry under the influence of *A. nepalensis,* is more productive because of nutrient cycle rates (Sharma, 2001). The poor and low nutrient use efficiency of the *A. nepalensis*, together with the malleability of nutrient cycling under its influence, make it an excellent associate for cardamom plantation (Sharma *et al.*1994). Farmers have now started predominantly using *A. nepalensis* as shade tree in the new plantations of large cardamom agroforesty (Plate 2). The agronomic yield of large cardamom increases by 2.2% under the canopy shade of *Alnus* (Sharma *et al.*, 2002).

A. nepalensis, a member of family Betulaceae of order Fagales, is a fast growing species. It grows at altitudes between 1000m to 2500m amsl. It is distributed from Pakistan through Nepal, northern India, Bhutan and Upper Burma to southwest China and Indochina. It grows naturally in moist, cool or subtropical mountain climates and grows well in a place having an average annual rainfall of 500-2500 mm with 4-8 months of dry season. It regenerates naturally on landslide affected freshly exposed areas. In northeastern India, it is used in forestry, agroforestry and shifting cultivation. Recently, its use as a nurse tree in cinchona (medicinal plant) plantation and reclamation of degraded habitats in eastern and central Himalayas, has been established. In a hilly area like Sikkim, where landslides are common, it is also planted in landslide affected and prone areas, to control and check the soil erosion and landslips. This relatively short-lived, fast growing tree, has the ability to fix atmospheric nitrogen through its root nodules. It attains the height of 35m in 40years and the tree with 25-30years of age, provides timber. Due to its wide availability and low market price, it is used as "poor man's timber". It sheds its leaves during winters (Jan- March) and new leaves appear from March-April onwards. Shifting agriculture or "Jhum" is a very common farming activity in Northeast India and is successfully practiced in Sikkim. Cultivation of fallow species in Jhum system between two croppings, has become an important issue for sustaining this traditional practice (Sharma *et al.*, 1997). *A. neapalensis* has been an important fallow species for Jhum farmers (Ramakrishnan, 1994). It coppices readily and may be harvested after 5 years interval, thus providing farmers with marketable poles, restoring the soil fertility at same time (Ramakrishna 1992,1994).

The gross income from the large cardamom cultivation in Sikkim has increased from 1.9 million in 1975-76 to 5.7 million in 1985-86 and to 6.4 million US $ in 1995-96 (conversion rate US $ 1= Rs 42). The cash benefit analysis of *Alnus* – large cardamom crop shows that it continues to provide excellent income till 15 to 20 years of plantation. The timber and fuel- wood return by the harvest of *Alnus* tree before replanting with a rotational cycle of 20 years would be around Rs. 576000 ($ 12387) per hectare (Sharma, 2001).

The shade tree, *A. neapalensis* is infested by many insects throughout the year, reducing the shading effect to the cardamom plantation (Pangtey and Thakur, 1986) (Plate 3), indirectly affecting the productivity of large cardamom. Recently, a decrease in per unit area yield of large cardamom, has been reported by the Department of Agriculture, Government of Sikkim. The major cause of this decline has been assigned to infestation by various diseases and lack of shade.

Therefore, in the current scenario of very fast rate of forest depletion in the fragile mountains like Sikkim, a multi-utility tree like *A. nepalensis* calls for serious attention. There is very little information available on the entomofaunal association of the tree, especially from large cardamom agroforesty. Therefore, it was felt necessary to carry out an investigation into the entomofaunal relationships with *A. nepalensis*. The study is meant to furnish a first- hand information and a ready account of the insects that the aerial parts of the tree harbour at different times of the year from this region. Besides this, the population dynamics and biology of the major folivorous insects associated are investigated in detail to understand their influence on *A. nepalensis* and its associated soil system, which may be of help in the management of the *Alnus*-cardamom plantation.

2. OBJECTIVES AND SCOPE OF THE STUDY

1. To record the entomofauna associated with the foliage of the mountain shade tree, *Alnus nepalensis* used in cardamom agroforestry.
2. To record the incidence of the commonly occurring insects associated with the shade tree, during various seasons along with their natural enemies.
3. To study the population dynamics of major folivores, *Gazalina chrysolopha* (Lepidoptera) and *Chrysomela chlorina* (Coleoptera) on *A. nepalensis* for three consecutive years (2000-2002) at two different altitudes, Pangthang (2160m amsl) and Kabi (1630m amsl).
4. To relate the population abundance of the above folivores with weather parameters and to find out the influence of the latter.
5. To study the biological aspects of the above folivores such as life cycle, laboratory-based survivorship and principal mortality factors.
6. To understand the trophic strategies of the above folivores by studying the nutritional indices, including the amount of shade tree leaf depredated and utilized by the larvae.
7. To evaluate the negative and positive ecological role of these major folivores in the cardamom agroforestry:

(a) By assaying their contribution to the soil fertility through their faecal- urine (in form of manure) by estimating the basic chemical components such as Nitrogen, Phosphorous, Potassium and organic carbon of the soil as well as faecal-urine.

(b) By assaying the nature of injury inflicted by one of these folivores to cardamom foliage used as an alternative host, and by estimating the extent of injury done to the shade tree leaves by the major folivores.

3. Review of literature

Certain aspects of ecology, diversity and distribution of shade tree, *Alnus nepalensis* have been studied and related literature on these are available. In an article on "Ecology of Himalayan Alder", Sharma *et al.* (1998) had given a review of its taxonomy, distribution, *Frankia*-symbiosis and nutrient cycle that was helpful in understanding the change in physical and biochemical profile of the tree with changing seasons. Literature on its nutrient dynamics (Sharma, 1993), litterfall, decomposition and nutrient release (Sharma and Ambashta, 1987), dry matter production and nutrient cycling in *Alnus*-cardamom agroforestry system (Sharma *et al.*, 1994) are informative. The article "Large cardamom plantation: An age-old agroforestry systems in eastern Himalayas", by Singh *et al.* (1989) helps in better understanding of the basic facts and figures of large cardamom agroforesty. Sharma *et al.* (2000) in the article, "Large cardamom farming in the Sikkim Himalayas: Boon to the mountain people", has highlighted the optimum performance of *Alnus* –cardamom stands in cardamom agroforestry. In this article he states that dry matter production was found to be higher and nutrient cycling faster in agroforestry system of large cardamom grown under Nitrogen fixing alder (*Alnus*-cardamom) compared to mixed tree species (forest-cardamom). The biomass was found to be 28% higher in the *Alnus*-cardamom stand as compared to forest-cardamom stand, thus supporting the choice of *A. nepalensis* as the best shade tree for large cardamom agroforestry.

3.1. Seasonal occurrence and inventory of insects on *Alnus nepalensis:*

Although, from Sikkim there are a few reports on the insect species that attack "Utis tree" (Pangtey and Thakur, 1986 and Phaloura and Singh, 1991, 1992), no literature is available on detailed systematic account of the occurrence of insects or their seasonal incidence on *Alnus nepalensis*.

From Sikkim, the information is generally available in the form of reports on pest outbreaks, short pest descriptions and their natural enemy associations (Pangtey and Thakur, 1986 and Phaloura and Singh, 1991, 1992). In a published article on "Insect pests of large cardamom in Sikkim", Pangtey and Thakur (1986) reported severe defoliation of the tree mainly by a lepidopteran and a coleopteran species.

There are a few reports on defoliation of *A. nepalensis* by insect pest from Nepal (Mulder, 1983; Das and Raychaudhuri, 1983 and Moestrup, 1985) and eastern and central Bhutan (Raman, 1998). Several species of scarabids with two new species were recorded from Nepal on Himalayan Alder (Sabatinelli and Migliaccio, 1982). In the article "Long horned beetle attacking 'Utis' plantations," in Nepal, Moestrup (1985) reported about severe infestation of the tree by these beetles. Defoliation of 'Utis' plantation by a species of Cryptocephalidae, in Nepal was reported by Mulder (1983). Sharpe (1983) reported some mice, voles, grasshoppers and crickets of 'Utis'. Taxonomic notes on aphids from Nepal and India on 'Utis' are available from Quednau (1973) followed by Quednau and

Chakrabarti (1980). Peter (1990) in his article "*Alnus nepalensis* - A Multipurpose Tree for the Tropical Highlands" has also reported about a number of pests of Himalayan Alder. Some of the insects attacking *A. nepalensis* in Nepal and Bhutan were also found attacking the tree in Sikkim.

Besides Himalayan Alder, literature on the other shade trees of high altitude and their insect fauna association gave useful and parallel information, which was helpful in carrying out the current study. Erelli *et al.* (1998) discussed altitudinal patterns in host suitability for forest insects. In an edited book entitled "The biology and management of Red Alder" (Hibbs *et al.*, 1994), information on insects attacking the tree, *Alnus rubra* was available. The book "Introduction to forest and shade tree insects"(Barbosa and Wagner, 1988), provided an idea of the shade tree pests from India and abroad.

3.2. Incidence and natural enemies of major folivores:

It was observed that *Gazalina chrysolopha* and *Chrysomela chlorina* were the major folivores that defoliated *Alnus nepalensis* in different seasons. Earlier reports also labeled *G. chrysolopha* and *C. chlorina* as the major folivores of *A. nepalensis* (Pangtey and Thakur, 1986; Raman, 1998; Phaloura and Singh, 1991-1992). Incidence of *G. chrysolopha* and *C. chlorina,* on *A. nepalensis* has been reported by Raman (1998) and Phaloura and Singh (1992). Pangtey and Thakur (1986) have also recorded the incidence of *G. chrysolopha* and *C. chlorina* and specially noted that the defoliation of *A. nepalensis* by *G. chrysolopha* was so severe that it affected the shading effect of the tree. Life cycle of *G. chrysolopha* on oak tree in Pakistan, has been worked out by Rehman and Chaudhry (1992) who also reported its caterpillars as serious defoliators. From the temperate zone, similar to that of Sikkim, other lepidopteran, such as winter moth (*Operophtera brumata*) (Pfadt, 1985) and gypsy moth (*Lymantria dispar)* (Speight *et al.*, 1999), were known to attack forest shade trees. Such cases have some resemblance with the nature of depredation caused to Himalayan Alder by *G. chrysolopha*. Similar attacks on the forest tree, *Populus* by *Chrysomela sripta* (Burkot and Benjamin, 1979; Harrell *et al.*, 1982 and Ohmart *et al.*, 1985) at almost similar altitude, are also reported.

From Sikkim, very meager information is available on the natural enemies of *G. chrysolopha*. However, there are a few reports on its natural enemies available from other neighbouring countries. Raman (1998) in his article "Out break of *Gazalina chrysolopha* and defoliation of *Alnus nepalensis* in eastern and Central Bhutan", mentioned about some larval and pupal parasitoids of *G. chrysolopha* attacking *Alnus* tree in Bhutan.

From Sikkim, Phaloura and Singh (1991, 1992) had attempted to study a few natural enemies of *C. chlorina*. However, detailed information on its natural enemies is lacking. In the article, "Coccinellid (coleopteran) fauna associated with Indian alder *Alnus nepalensis*", Phaloura and Singh

(1991) reported seven species of coccinellid preying on the immature stages of *C. chlorine*. This was followed by an article on the biology of *Aiolocaria hexaspilota,* predating on eggs and immature stages of *C. chlorina* from Sikkim (Phaloura and Singh, 1992).

3.3. Population Dynamics of Major folivores:

Since literature on population dynamics of *G. chrysolopha and C. chlorina* is lacking, available information on the insects living in cold conditions and at almost same altitude, defoliating shade trees have been consulted. The incidence of winter moth, *Operophtera brumata* (Pfadt, 1985) is similar to that of *G. chrysolopha*, as the larvae of both these moths are active in winter, defoliating their hosts, the elms shade tree and *A. nepalensis* respectively. Population dynamics and other related matters of the winter moth have been highlighted by Embree (1965), Buse and Good (1996), and Wint (1983). Another work on population dynamics of the lymantriid moth, *Porthetria dispar* is also available from Ramzi (1991).

Some comprehensive reports on population build up of other coleopterans (as that of *C. chlorina*) are available from Rawat and Singh (1980), Banerjee and Nath (1986), Krishnaiah *et al.* (1987) and Chaudhary *et al.*, (2001). These have been cited from time to time to support the findings in present study.

3.4. Population changes and their relation with weather parameters:

G. chrysolopha is perfect example of an insect thriving in cold conditions of Sikkim. Literature on population incidence of Lepidopteran and Coleopteran larvae and their relation with weather parameters, with special reference to thermal tolerance, are available from the works of different authors (Southwood, 1972; Price, 1975,1997; Nayar *et al.*, 1976; Varley *et al.*, 1980; Rawat and Singh, 1980; Miller and Cronhardt, 1982; Wint, 1983; Banerjee and Nath, 1986; Krishnaiah *et al.*, 1987; Hunter, 1993; Kimberling and Miller 1998; Sharov *et al.,* 1999; Koltunov and Andreeva, 1999; Wellington *et al.*, 1999 and Chaudhary *et al.*, 2001). Buse and Good (1996) observed the effect of temperature on the eggs of the winter moth, *O. brumata*. Williams and Liebhold (1995) discussed the influence of weather on the synchrony of gypsy moth outbreaks. In a recent article, Lyamtsev *et al.* (2000) reported the effect of climate and weather on the population dynamics of *L. dispar*.

General information on population dynamics is available from books and articles such as "Pest population and assessment of crop losses"(Atwal and Singh, 1990), "Ecology"(Krebs, 1978), "Biological control, thresholds, and Pest outbreaks"(Berryman, 1982), "Insect ecology"(Price, 1997),"Insects-An outline of entomology"(Gullan and Cranston, 1994), "Fundamentals of ecology" (Das, 1993), "Fundamentals of

Applied entomology"(Pfadt, 1985) and "Ecology of Insects" (Speight *et al.*, 1999).

3.5. Biology of major folivores:

There is no detailed information available on the biology and life cycle of *Gazalina chrysolopha* from Sikkim. However, an article "Observation on outbreak and biology of Oak defoliater, *Gazalina chrysolopha*" (Rehman and Chaudhry, 1992), from Pakistan gave some information on the insect's biology. Pangtey and Thakur (1986) in their article "Insect pest of large cardamom in Sikkim" reported about the outbreak of *G. chrysolopha* and gave an account of the wing expanse of adult moth. There is no report available on the biology of *Chrysomela chlorina*. Phaloura and Singh (1992) worked on the biology of *Aiolocaria hexaspilota*, a natural enemy of *C. chlorina*. In their article they mentioned that the larval stages of *C. chlorina* had synchrony with those of *A. hexaspilota*. Literature available on the biology of different chrysomelid beetles (Burkot and Benjamin, 1979; Jayant and Bali, 1993; Pandey and Tiwari, 2001) have been referred to support the findings of the present study.

In the present study, growth and development of major folivores in question, has been explained on the basis of the quality of food they consumed. Many articles are available on the role of food quality in regulating the growth and development of different insects. As early as 1966, in an article, Carne mentioned that less quantity of nitrogen (N) in food, produced lighter females with lower fecundity in case of the chrysomelid *Paropsis atomaria.* Engelmann (1970) stated that egg production is a function of a multiplicity of factors (many of them species specific) such as temperature, metabolism, food constituents and quality. Later, Scriber and Slansky (1981) found that Nitrogen (N) concentration in tree foliage was lower than in herbaceous plants, which acted as the limiting factor in the development of insect defoliators feeding on trees. Ohmart *et al.* (1985) investigated the effect of food quality, especially Nitrogen (N), on chrysomelid larvae, *Paropsis atomaria.* Lindroth *et al.* (1997) in their work on gypsy moth showed that variation in temperature and dietary nitrogen affected its performance. Effects of food quality on the development and biology of other lepidopterans have been discussed by Mehra and Shah (1970), Devaiah *et al.* (1983), Muthukrishnan *et al.* (1993), Ray and Banerjee (1993), Sharma *et al.* (1994), Cambini and Magnoler (1999), and Kavita and Savirti (2001). Hemming and Lindroth (2000) observed the effect of food quality on performance of forest tent caterpillar. This was followed by similar work on winter moth by Ruuhola *et al.* (2001).

For morphometric and growth studies, some of the classical literatures are that of Dyar (1890), Majeed and Aziz (1979) and Sorensen and Thompson (1979), which has been referred to while determining the larval instars.

3.6. Nutritional Ecology of Major folivores:

Although there is no work done on the nutritional ecology of *Gazalina chrysolopha* and *Chrysomela chlorina,* well discussed article are available on post ingestive nutritional indices of lepidopterans (Scriber 1979 and Ruuhola *et al.*, 2001) that gave a holistic idea on nutritional ecology of tree-feeding caterpillars. There are articles available on food consumption and utilization by tree feeder, *Lymantria dispar* and winter moth, *O. brumata* (Barbosa and Greenblatt, 1979; Sheppard and Friedman, 1990; Kirsten and Topp, 1991; Lindroth *et al.*, 1997; Ruuhola *et al.*, 2001). Harrel *et al.* (1982) studied the food utilization efficiency of the chrysomelid, *Chrysomela scripta,* a congener of *C. chlorina,* which was useful while studying the nutritional ecology of *C. chlorina*.

In the present study, the food utilization efficiencies of *G. chrysolopha* and *C. chlorina* are discussed on the basis of the quality of food they consumed. Therefore, the nutritive quality of the leaves consumed by the major folivores was estimated. There are many reports stating that interaction between the different constituents, especially C and N, of food may determine the efficiencies of utilization of food, growth and reproduction (Muthukrishnan and Pandian, 1987) of the insects. However, certain inorganic elements such as K and P are also required at least in trace amounts for growth and reproduction of an insect (Dadd,1970). Therefore, estimation of K and P was also done along with C and N as a supplementary study.

Some papers dealing with the effect of quality of food on food utilization efficiencies of the insects, are available from different authors such as Waldbauer (1968), Fenny (1968, 1976), Baker (1974), Duncan and Kelekowski (1975), Cates (1980), Fox and Macauley (1977), Slansky and Fenny (1977), Bhatt and Bhattacharya (1978), Barbosa and Greenblatt (1979), Larsson and Tenow (1979), Mattson (1980), Denno and Donnelly (1981), Sciber and Slansky (1981), Muthukrishnan and Pandian (1987), Ohmart *et al.*(1985), Farrar *et al.* (1989), Sheppard and Friedman (1990), Kirsten and Topp (1991), Panda and Khush (1995), Lindroth *et al.* (1997), Schoonhoven *et al.* (1998) and Ruuhola *et al.* (2001). Information on nutritional ecology relevant to some aspects of the present study has largely been obtained from some book articles by Muthukrishnan and Pandian (1987) in "Animal Energetics" and by Slansky and Rodriguez (1987) in "Nutritional Ecology Of Insects, Mites, Spider and related invertebrates". Other general informative material on nutritional ecology and insect-plant interaction is from the article "Insect nutrition: An adaptationist's perspective" (Slansky, 1982).

3.7. Ecological role of the major folivores in the large Cardamom agroforestry ecosystem:

This study was conducted to assess the contribution of faecal urine (in an outbreak, large quantity of frass dropped to the forest floor) to the soil fertility of the forest floor of *Alnus*-cardamom agroforestry.

Outbreaks of defoliating insects can have dramatic effects on forest ecosystem (Lovett *et al.* 2002). Several studies have indicated insect's frass or faecal pallet as contributors to soil fertility to the forest floor. Well documented articles by Mattson and Addy (1975), Lovett and Ruesink (1995) and Lovett *et al.*(2002) speaks for the contribution of decomposing frass of lepidopteran in terms of carbon and nitrogen mineralization and their incorporation into soil organic matter. Weis and May (1989) reported that in one year in Oak forest, insect frass contributed a fair amount of C, K, N and P to the soil enriching its fertility.

However, there is no information available on the contribution of feacal urine (frass) of the major folivores, *Gazalina chrysolopha* and *Chrysomela chlorina* to the *Alnus*- cardamom forest floor.

Negative impact of these major folivores, was assessed by calculating the quantum of leaf consumed (injured) by these insects (Pedigo, 1996). Similar assessment studies are available from other workers such as Simmonds (1949), Manjunatha *et al.* (1987), George and Ipe (2000) and Urban (2000).

4.MATERIALS AND METHODS

4.1. Recording of common insect herbivores and their natural enemies occurring seasonally on the shade tree:

Study areas were selected based on the information obtained from the G.B. Pant Institute of Himalayan Environment and Development and the Spices Board of India, Sikkim branch. The incidence of the insects on the shade tree, *Alnus nepalensis,* were recorded at the experimental plots of large cardamom agroforestry managed by the Spices Board of India (Sikkim branch), at Pangthang (2160m amsl) and Kabi (1630m amsl). Periodic surveys were done round the year at these two altitudes for three years i.e. 2000-2002, to record the insects associated with the tree foliage and branches of the lower accessible bough of the tree belonging to the age group of 2 to 10 years. Since, the sampling was done from the field that had large cardamom plantation, it may be assumed that all the relevant types of insects, i.e., whether true feeders or temporary visitors, have been included in the collection process. The insects were identified to their family to Recognizable Taxonomic Unit (RTU) levels.

Collection techniques like hand picking, beating and aspirating, were applied during survey after the methods prescribed in the handbook "Collection and Preservation Of Animals" (Anonymous, 1990). The eggs and larvae collected in the fields were brought to the laboratory and were reared on the host plant leaves to identify their adults. The adult specimens were brought in the polythene packets and containers and poisoned (ethyl acetate poisoning) in killing bottles. Some insects suspected to be parasitised in nature were kept in the laboratory for emergence of the parasitoids. Identification of major folivores was confirmed by the Zoological Survey of India, Calcutta. Some of the insects causing maximum damage to the shade tree, *A. nepalensis* and those common to *A. nepalensis* and large cardamom both, were identified to their genus/ species level by the help of the expert authorities from the Spices Board of India (Sikkim Branch). Due to the difficulty in identifying a good number of insect associates of *A. nepalensis* to the species level, their study has been done using morphospecies characters to recognizable taxonomic unit (RTU).

4.2. Incidence and population dynamics of the two major folivores attacking the shade tree (*A. nepalensis*).

Although major work related to the present study, was carried out during the three years 2000-2002, some observations on the seasonal incidence of the major folivores, particularly of *G. chrysolopha*, were made towards the end of 1999.

For assessing the pest population, twenty trees were randomly selected and marked during each year i.e. 1999- 2000 to 2002 at two experimental sites, Kabi and Pangthang.

4.2.1. Lepidopteran folivore *Gazalina chrysolopha*: It was found that larvae of *G. chrysolopha,* climbed tall trees during the night to reach the canopy (foliage) for food (Plate 4). During the daytime they rested at the

Plate 4. Caterpillars of *Gazalina chrysolopha* climbing the tree *A. nepalensis* for food (foliage)

Plate 5. Caterpillars of *G. chrysolopha* in resting position

Plate 6. Experimental rearing jars

plate - 4

plate - 5

plate - 6

base of the tree. It was easier to take a count of the larvae at the tree base as they were sluggish and did not move. A quadrate of 10 cm^2 was designed and put on the resting larvae to take a physical count from each marked tree, adopting the method prescribed by Pedigo (1989). Larval count was recorded based on 10 samples from each tree at fortnight interval (life cycle being too long) during the period of occurrence of *G. chrysolopha* at both the experimental plots.

4.2.2. Coleopteran *Chrysomela chlorina*:

Per leaf population count of larvae of *C. chlorina* was taken from each selected and marked tree after Pedigo (1989) at an interval of one week (life cycle of the pest being comparatively shorter), during the period of their occurrence. From each tree, 10 leaves were randomly selected for population- count.

4.3. Influence of weather parameters on the population of the major folivores:

To study the influence of the abiotic factors such as maximum and minimum temperatures, low and high relative humidity, rainfall and cloud cover (day and night) on the pest population, the information on such parameters, was obtained from Agrometeorological Advisory Bulletin, jointly issued by The Indian Meteorological Department and The Department of Agriculture, Government of Sikkim (Year, 2000-2002). Correlation coefficients (using multiple regression) for the relations between the herbivore population and the weather parameters were calculated.

4.4. Study of natural enemies of the major folivores:

To study the natural enemies (predators and parasitoids) associated with the major folivores *G. chrysolopha* and *C. chlorina,* a close observation was made on eggs, larvae and adults in the fields as well as in the laboratory. Eggs and larval stages of the folivores were maintained in the laboratory to observe the emergence of parasitoid or, their acceptability by a predator.

4.5. Life cycle studies of the two major folivores on *Alnus nepalensis:*

To study the life cycle of *G. chrysolopha* and *C. chlorina*, the adults of both were collected from the field and reared in the laboratory conditions. Pairs of male and female were kept in breeding jars (one pair in each jar of height 80 cm., dia. 65 cm.) to lay eggs. Newly emerged larvae were transferred to rearing jars (height 10 cm., dia. 6.5 cm.) (Plate 6) using moist brush and forceps. The lids of the containers were provided with only a few pores to minimize water loss from the food (leaves of *A. nepalensis*).

Duration of each larval and pupal stage was recorded. Size of the head capsule and the length and maximum breadth of each larva and pupa, were measured using stage occulometer. For other general observations in the field, hand lens was used. Freshly emerged pairs of male and female were kept for mating in breeding jars. Cotton balls moist with 5% sugar solution, were provided in the breeding jars as nourishment for the adult moths of *G. chrysolopha* and fresh leaves of *A. nepalensis* were provided to the adults of *C. chlorina*. Premating, mating and preoviposition periods, fecundity and male and female longevity, were observed. The number of eggs laid per day by each female was recorded. The study was conducted using 10 replicates.

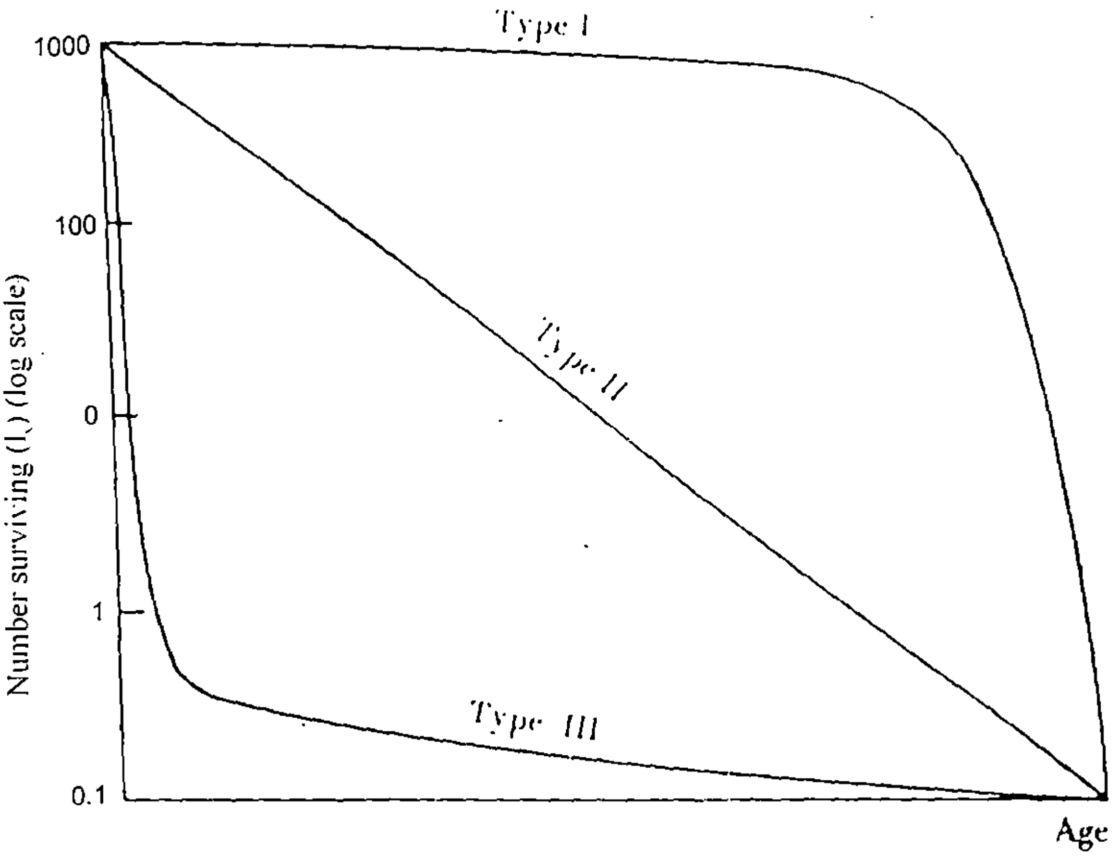
4.6. Survivorship of the major folivores:

Survivorship study was done under laboratory conditions. Rearing cages measuring 10 cm. height, 6.5 cm dia.,were used. Observations were made on the larvae of *G. chrysolopha* and *C. chlorina* at an interval of (age x) 96 hrs. (4 days) and 24 hrs. (1 day) respectively, till pupation. For each observation, 1000 individuals of newly hatched larvae, were reared on leaves of *A. nepalensis* separately in batches of 100 individuals each. The number of larvae surviving at the start of x age interval (l_x), number dying within that age interval (d_x), average number of individuals alive during that age interval (L_x), expectation of life for individuals of X age (e_x) and mortality rate for that age interval (q_x), were determined using formula prescribed by Das (1993). The observations on survivorship were compared using reference curves after Pearl (1928) (Fig 2).

4.7.Age distribution of *G. chrysolopha* and *C. chlorina*:

Using the information from the morphometric studies of the larva, it was possible to analyze the age distribution of the natural population of

Fig. 2



Hypothetical survivorship curves
(After Pearl 1928)

both the folivores in different months of their occurrence. To study this, the number of larvae present in each 10 cm^2 quadrate every fortnight for *G. chrysolopha* and on 10 leaves from each tree after every week for *C. chlorina,* were collected. The samples were then subjected to analysis to find out the average number of larvae present in each instar, using morphometric scale in the laboratory. Repeated sampling (10 replicates) was done to find out the changes in age distribution on selected trees throughout the period of their occurrence after Pedigo, 1996.

4.8. Study of nutritional ecology of the major folivores:

4.8.1. Feeding preference:

Feeding preference of the larvae of *G. chrysolopha* and *C. chlorina* was determined separately by providing them a choice among four types of leaves of varying maturity after Harrel *et al.* (1982). Leaf types ranged from tender, young, mature to senescent leaves. Feeding preference was observed using 10 final instar larvae. Each larva was allowed to feed on weighed quantity of leaf for 24 h. At the end of each feeding period, the left over leaf- weight was noted. This experiment was replicated 10 times and the pooled data was analyzed. Water content of each leaf type used in feeding choice, was determined.

4.8.2. Growth and feeding indices:

Since the early instar larvae of *G. chrysolopha* nibbled on debris/ very tender leaves (in laboratory) found at the base of the host tree, the experimental study on leaf- consumption and utilization was, conducted using the 3^{rd}, 4^{th} & 5^{th} instar larvae. For *C. chlorina*, the study was conducted on the 2^{nd}, 3^{rd} & 4^{th} instar larvae as the first instar larvae were too small to weigh and only nibbled the leaves. The insects were reared on host leaves of *A. nepalensis* in plastic containers (height 10 cm., dia. 6.5 cm) with perforated lids to facilitate ventilation. Discs of filter paper were used as towels at the bottom of the containers to facilitate cleaning and to absorb extra moisture. The experiment was repeated in three successive years with 20 replicates. Weighed quantities of host plant leaves were provided to the insects at every 24 hrs. interval throughout their larval development period. The weight of the residual leaf (left after feeding), initial and final weights of the insects and weight of the faecal pellets, were also recorded after every 24 hrs. Since the work was done on the fresh weight basis, a control leaf quantity of the same weight, was kept under the same conditions and weighed after every 24 hrs to calculate the water loss due to evaporation / transpiration. Low room temperature (8^0C to 18^0C) and high humidity (80% - 90%) within the rearing container, in case of lepidopteran *G. chrysolopha*, helped in keeping the leaves fresh with minimum moisture loss during the feeding experiment. In case of the coleopteran, *C. chlorina*, however, the petioles of the leaves were kept dipped in water. The feeding experiment in this case, was conducted at room temperature (18^0C to 25^0C) and humidity 75% - 85%. Weight of the larva after ecdysis and prior to consumption of food, was recorded as initial weight. Larval weight during spinning stage was taken as the final weight after Waldbauer (1968). Difference in the initial and final weights of larvae in each instar, gave the value of weight gain during the instar.

Consumption and nutritional indices used in this study, were calculated on fresh weight basis after the methods suggested by Ananthakrishnan (1990), Singh and Sehgal (1993) and Shantibala *et al,* (2002). The formulae applied for calculating different consumption, utilization and growth indices were:

Consumption Index (CI)

$$\text{CI} = \frac{\text{Weight of food consumed}}{\text{Mean weight of larva x duration of feeding period (days)}}$$

Approximate Digestibility (AD)

$$\text{AD} = \frac{\text{Weight of food Ingested} - \text{Weight of faeces}}{\text{Weight of food ingested}} \times 100$$

Efficiency of conversion of ingested food (ECI)

$$\text{ECI} = \frac{\text{Weight gained by the larva}}{\text{Weight of food ingested}} \times 100$$

Efficiency of conversion of digested food (ECD)

$$\text{ECD} = \frac{\text{Weight gained by the larva}}{\text{Weight of food digested}} \times 100$$

Growth Rate (GR)

$$\text{GR} = \frac{\text{Weight gained by larva}}{\text{Mean larval weight x duration of feeding period (days)}}$$

4.9. Evaluation of the negative and positive ecological role of these major folivores in the cardamom agroforestry.

4.9.1 Positive role:

To evaluate the possible contribution of the folivores in form of faecal urine as manure to the large cardamom agroforestry, soil analysis was done before appearance of the pest, and, thrice at the time of its maximum occurrence. Basic fertility components (N, P, K and organic carbon) of the soil (*in situ*) were analyzed. The same components were also determined of leaves provided as food to, as well as faecal pallets of, the folivores.

4.9.1.1 Analysis of leaves and faecal pellets:

The leaves and the faecal pallets obtained from the insects were first air dried at 60 °C for 48 hrs. Then separately, they were ground and sieved (.4 mm) for basic nutrient analysis. Phosphorus (P) was estimated by molybdophosphoric blue color method (Jackson, 1967). Estimation of Nitrogen (N) was done by modified Kjeldahl method (Anderson and Ingram, 1993). Potassium (K) content was determined using flame emission method (Allen, 1974). Organic carbon (C) was estimated by wet oxidation by chromic acid (by titration) method (Jackson, 1967).

4.9.1.2. Analysis of soil:

Soil samples from beneath the shade tree, were collected. The first sample (control sample) was collected before the pest appeared. Again at the time of maximum occurrence of the pest, soil samples (when soil was naturally mixed with faecal droppings) from the adjoining spots under the tree were collected at a month's interval for three months. For each sampling, soil from 30 cm deep after Sharma *et al.* (2002) was taken. 5 replicates from 5 plots (1m x 1m) were sampled every time from Feb. to April for *G. chrysolopha* and July to Sept. for *C. chlorina*. After collection, the soil samples were taken to the laboratory and passed through 2mm sieve. After separating roots, debris and stones, the soil samples were dried at 60 °C for 48 hrs. Organic carbon was measured after partial oxidation with an acidified dichromate solution, adopting modified Walkley-Blach method (Anderson and Ingram, 1993). Estimation of N was done by modified Kjeldahl method (Anderson and Ingram, 1993). Estimation of P was done by modified ascorbic acid method (Anderson and Ingram, 1993). Potassium was analyzed using flame photometer and the estimation was done through a calibration curve using K standard (Allen, 1974).

4.9.2. Negative role:

During regular field visits it was found that of the two major folivores (*G. chrysolopha* and *C. chlorina)* the coleopteran, *Chrysomela chlorina* inflicted injuries to large cardamom foliage as alternate host. Therefore, to estimate the injury potential of *C. chlorina* to cardamom leaves, nutrition ecology of the folivores was studied, adopting the methods described earlier.

For a direct assessment of the extent of injury caused by both the major folivores, the leaf area consumed or injured (Pedigo, 1996) by the final instar larvae of both the insects, was calculated (*ex-situ*) in laboratory conditions by planimetric method. Fresh leaves of *A. nepalensis* were provided to each set of larvae of *G. chrysolopha* and *C. chlorina* after every 24hrs. Grubs of *C. chlorina* being small, 10 batches having 10 grubs in each batch, were used at a time for the leaf- area injury study. Photocopies of the leaves were made before and after feeding. The experiment was carried through a period of one-week with 10 replications and the food consumption (leaf area) was calculated based on the method suggested by Hendrix and Marquis (1983). The formula applied for calculating the consumption of leaf in terms of area was: Leaf area consumed = A /B x 100

Where, A = Total area of the leaf eaten

B = Total area of the leaf provided to the larvae

The thickness of the leaves and other circular structures had not been considered for simplicity of the calculation.

The estimation of injury in the field condition (*in-situ*) by direct or indirect method in the mountain terrain was a difficult preposition for lone worker (Ph. D candidate), the same could not be taken under scope of study.

4.10. Computer applications:

Studies on Life cycle, fecundity, age distribution, population dynamics, nutritional indices, feeding preference and morphometrics were subjected to statistical treatments as per requirements which included mean, standard deviation, student's t-test, LSD, ANOVA and multiple regression. SYSTAT and SAS packages in computer were used for computation and Excel was used for graphics.

5. Study area:

Experimental sites selected for the study were located at Pangthang 2160m amsl (East District) and Kabi at 1630m amsl (North District) in Sikkim state in the Eastern Himalayas. These sites are about 70 Km apart, which allowed comparison of field observations at the two sites located at different altitudes. These are major areas of large cardamom cultivation with *A. nepalensis* as shade tree (Fig.1). The study area was covered by monsoon with a temperate climate having winter (November- February), spring (March- May) and rainy (June-October) seasons. The mean monthly maximum and minimum temperature ranged from 23.3-14.3 ^{0}C in spring and rainy seasons and to 15.8-1.4^{0}C during winter. Total rainfall varied with the season. During monsoon it was maximum, with a total of 3000-4500 mm per year at the study site. During rainy season, relative humidity varied between 80-95%, which decreases to about 55% in spring.

6. OBSERVATIONS AND RESULTS

6.1. Recording of insect groups associated with *Alnus nepalensis:*

Insects were found to use *Alnus nepalensis* as true host, as alternate host, as roost and shelter. Familial list of insects found associated with the shade tree has been provided (Tables 1a-1c). The survey work showed dominance of species (RTU) of Coleoptera (43%) followed by Lepidoptera (19%), Homoptera (16%), Hemiptera (7%), Hymenoptera (5%), Orthoptera (4%), Neuroptera (2%), Thysanoptera (2%) and Diptera (2%), when collections from both the altitudes for all the three years of the study were considered (Fig.3).

Maximum occurrence of the insect species on the tree was found in the spring season (March to May) when new leaves appeared. In spring, most of the insects associated, were the coleopterans, along with a few lepidopterans, hymenopterans, thysanopterans and hemipterans. With the onset of summer, which brought in heavy rains from end of May to September, a number of adult moths, few coleopterans, dipterans and neuropterans became prevalent. In winter, the insects occurred in less proportion. However, the dominance of cicadid species was quite apparent during these months. Along with this, in early winter, caterpillars of two lepidopteran species were also found, one of them (Notodontidae) in abundance.

A number of predators and parasitoids were found associated with *A. nepalensis* attacking the above phytophages as their prey/ host. One

Fig.3. Average proportion of orders of insect associated with *Alnus nepalensis* (Shade tree) at Pangthang and Kabi

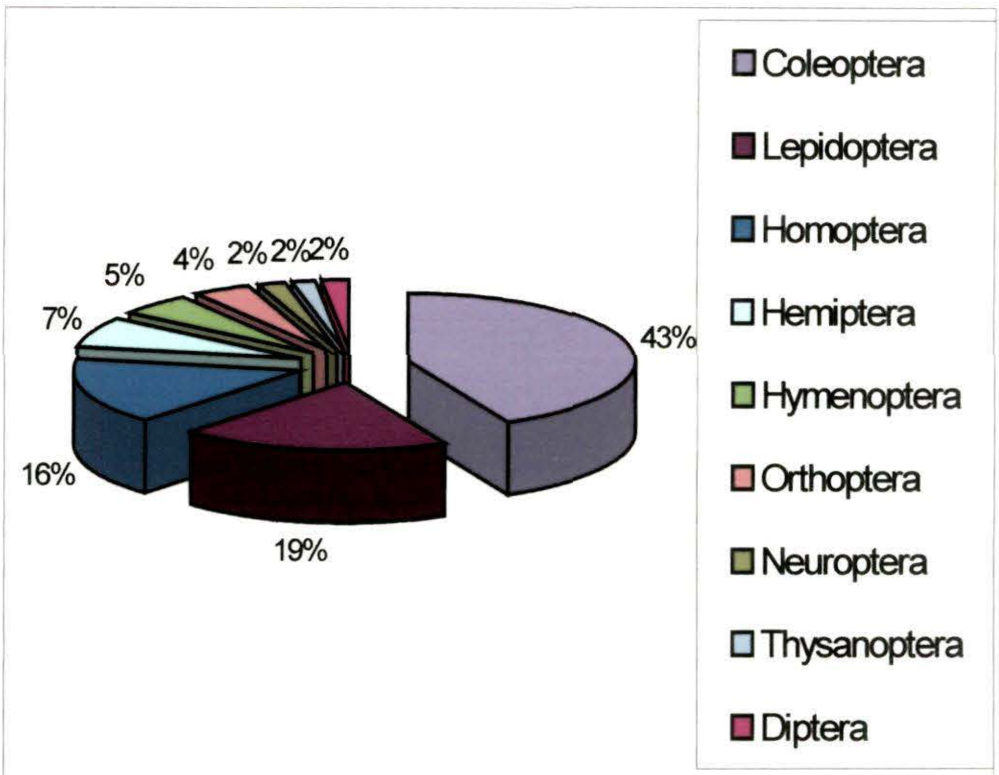


Table: 1a. Insect fauna associated with *Alnus nepalensis* at two altitudes of Sikkim in the Year 2000

		Pangthang (2160m amsl)		Kabi (1630m amsl)	
		No. of species (RTU)	**Month of occurrence**	**No. of species (RTU)**	**Month of occurrence**
Order	**Coleoptera**				
Family	Coccinellidae	7	Jan——Dec	7	Jan-------Dec.
	Scarabaeidae	6	Feb———Oct.	7	March---Oct.
	Chrysomelidae	6	April------Sept.	6	April------Sept.
	Curcûlionidae	3	Jan.-------March	3	Dec.---March
	Galerucidae	1	Jan.----Dec.	0	Not found
	Buprestidae	2	July-------Oct.	0	Not found
	Cerambycidae	0	Not found	1	July------Sept.
Order	**Lepidoptera**				
Family	Noctuidae	4	May———Oct.	4	July-------Sept.
	Pyralidae	1	Aug.——Sept.	1	Aug.-------
	Arctiidae	1	April-------Aug.	1	April-------Aug.
	Eupterotidae	1	June-----July	1	June------July
	Lymantriidae	1	June————Aug.	1	May-------July
	Notodontidae	1	Nov.--------May	1	Nov.--------May
Order	**Homoptera**				
Family	Cicadidae	3	Oct.——March	5	Oct.--------Feb.
	Psyllidae	2	July———Oct.	2	July--------Oct.
	Aphididae	2	Feb.———Aug.	2	March-----July
	Membracidae	0	Not found	1	Nov.-------Dec.

Table 1a continued.....

Order	**Hemiptera**				
Family	Pentatomidae	3	April-------Sept.	3	May-------July
	Miridae	1	July---------Sept.	1	July-------Sept.
	Coreidae		Not found	2	July-----Aug.
Order	**Hymenoptera**				
Family	Braconidae	1	May-------July	1	May-------July
	Formicidae	3	Feb.---------June	3	March-----Aug.
Order	**Orthoptera**				
Family	Phasmatidae	1	Nov.-------Dec.	1	Nov.-------Dec.
	Mantidae	1	Sept.-------Oct.	1	Sept.-------Oct.
	Tetrigidae	1	Jan.-------Dec.	1	Jan.-------Dec.
Order	**Neuroptera**				
Family	Chrysopidae	1	April------July	1	April------July
Order	**Thysanoptera**				
Family	Thripidae	1	April------Aug.	1	June-------Sept.
Order	**Diptera**				
Family	Tachinidae	1	July------Sept.	1	July------Sept.

Table: 1b. Insect fauna associated with *A. nepalensis* at two altitudes of Sikkim in the Year 2001

		Pangthang (*2160m amsl*)		Kabi (*1630m amsl*)	
		No. of species (RTU)	**Month of occurrence**	**No. of species (RTU)**	**Month of occurrence**
Order	**Coleoptera**				
Family	Coccinellidae	7	Jan------Dec.	6	Jan------Dec
	Scarabaeidae	5	Feb———Oct.	6	March——Oct.
	Chrysomelidae	7	April------Sept.	6	April----Sept.
	Curculionidae	3	Jan.———April	3	Dec.— March
	Galerucidae	1	Jan.—-Dec.	1	Jan.—-Dec.
	Buprestidae	0	Not found	0	Not found
	Cerambycidae	0	Not found	0	Not found
Order	**Lepidoptera**				
Family	Noctuidae	4	July———Oct.	4	July———Oct.
	Pyralidae	1	Aug.——Sept.	2	Aug.—— Sept.
	Arctiidae	1	April——July	1	May——Aug.
	Eupterotidae	1	June------July	1	June------July
	Lymantriidae	1	July———Sept.	3	June——Aug.
	Notodontidae	1	Nov.——April	1	Nov.—— April
Order	**Homoptera**				
Family	Cicadidae	5	Oct.------ March	4	Oct.------ Feb.
	Psyllidae	1	July——Sept.	1	July——Sept.
	Aphididae	2	Feb.———July	2	Feb.———Aug.
	Membracidae	*0*	Not found	*0*	Not found

Table 1b continued.....

Order	**Hemiptera**				
Family	Pentatomidae	3	April——Sept.	3	May——July
	Miridae	0	Not found	0	Not found
	Coreidae	1	July——Aug.	2	July——Sept.
Order	**Hymenoptera**				
Family	Braconidae	1	May——July	1	May——July
	Formicidae	3	Feb.——June	3	March—Aug.
Order	**Orthoptera**				
Family	Phasmatidae	2	Dec.——Jan.	1	Nov.—— Dec.
	Mantidae	1	Sept.——Oct.	0	Not found
	Tetrigidae	1	Jan.——Dec.	1	Jan.——Dec.
Order	**Neuroptera**				
Family	Chrysopidae	1	June——Aug.	1	June——July
Order	**Thysanoptera**				
Family	Thripidae	1	April——Aug.	1	June——Sept.
Order	**Diptera**				
Family	Tachinidae	1	July——Sept.	1	July—— Sept.

Table:1c. Insect fauna associated with *A. nepalensis* at two altitudes of Sikkim in Year 2002

		Pangthang (2160m amsl)	2002	Kabi (1630m amsl)	
		No. of species (RTU)	Month of occurrence	No. of species (RTU)	Month of occurrence
Order	**Coleoptera**				
Family	Coccinellidaė	7	Jan------Dec	6	Jan------Dec
	Scarabaeidae	5	May-----Oct.	6	April-----Oct.
	Chrysomelidae	7	April----Sept.	6	April----Sept.
	Curculionidae	3	Jan.----- March	3	Dec.--- March
	Galerucidae	1	Jan.----Dec.	1	Jan.----Dec.
	Buprestidae	0	Not found	0	Not found
	Cerambycidae	0	Not found	0	Not found
Order	**Lepidoptera**				
Family	Noctuidae	3	June------Oct.	4	July-------Oct.
	Pyralidae	1	Aug.----Sept.	2	Aug.-------Sept.
	Arctiidae	1	April-----July	1	April-----July
	Eupterotidae	1	June------July	1	June------July
	Lymantriidae	3	July-----Sept.	3	July-------Sept.
	Notodontidae	1	Nov.----April		Nov.---- April
Order	**Homoptera**				
Family	Cicadidae	5	Oct.------ Jan.	4	Oct.--------Jan.
	Psyllidae	1	July-----Sept.	1	July-------Sept.
	Aphididae	2	Feb.------June	2	Feb.-------June
	Membracidae	0	Not found	0	Not found

Table 1c continued.....

Order	**Hemiptera**				
Family	Pentatomidae	3	April----Sept.	3	May-------Sept.
	Miridae	0	Not found	0	Not found
	Coreidae	1	July-----Aug.	2	July-----Sept.
Order	**Hymenoptera**				
Family	Braconidae	1	May------July	1	May------July
	Formicidae	3	Feb.----- June	3	March---Aug.
Order	**Orthoptera**				
Family	Phasmatidae	1	Dec.------Jan.	1	Nov.----- Dec.
	Mantidae	1	Sept.-----Oct.	0	Not found
	Tetrigidae	1	Jan.------Dec.	1	Jan.-------Dec.
Order	**Neuroptera**				
Family	Chrysopidae	2	June-----Aug.	2	June------July
Order	**Thysanoptera**				
Family	Thripidae	1	April----Aug.	1	June-----Sept.
Order	**Diptera**				
Family	Tachinidae	1	July-----Sept.	1	July------Sept.

tachinid fly (Diptera) species was found to parasitise lepidopteran larvae. Lacewings were also found predating on eggs of lepidopterans in the summer. Many coccinellids were found predating on the immature stages of coleoptera and aphids. Pentatomid bug was found throughout the spring season preying on larvae of coleopterans. Almost a similar occurrence of the shade tree associates were recorded in all the three years and at both the altitudes excepting representatives of families like, Buprestidae, Cerambycidae and Miridae, which were not found in years 2001 and 2002 (Table 1b-1c). On the other hand, a species of Membracidae (cow bug) that sporadically occurred in the year 2000 in Kabi was not found in Pangthang in the same year and in the subsequent years at both the altitudes (Table 1a-1c). So also, a species of Galerucidae (coleoptera) which was found to occur throughout the year on *A. nepalensis* in Pangthang was not found in Kabi in year 2000 but was found present at both the altitudes in the subsequent years (Table 1a-1c).

6.1.1. Insects common to *Alnus* and large cardamom plants:

A list of insect species found to attack and damage both, cardamom and *Alnus* plants has been presented in Table 1d. Although there were variations in the time of their occurrence, these insects were present in all the three years of observation and at both the altitudes. The insects common to both the plants were: seven species of coleopterans, two species of hairy caterpillars (Lepidoptera), one species of green aphid (Homoptera: Aphididae), one spieces of thrips (Thysanoptera: Thripidae,

Table 1d: Insect species common to *Alnus* (Shade tree) and large cardamom plants

Order	Species
Coleoptera	*Lema nigricollis* Jacoby
	Chrysomela chlorina Maulik
	Basilepta femoratum Jacoby
	Cleorina metallica Lef.
	Miltina balyi (Jac.)
	Cyphicerus alsus Mshl.(Weevil)
	Cerogria quadrimaculata Hope.(Scarab-beetle)
Lepidoptera	*Cyana effracata* hope.
	Pericalia galactina Hoev.
Homoptera	*Neomyzus circumflexus* (Buckton) (Aphid)
	Kolla opponens (Walker) (White cicada)
Orthoptera	*Mazorradia* sp. Boliyar (Grass hopper)
Thysanoptera	Not identified

in det.), one species of grasshopper (Orthoptera) and a species of white Cicada (Homoptera).

6.2. Seasonal incidence of the major folivores:

An ecological investigation to find out the incidence of the major folivores on *A. nepalensis* shade tree was carried out for three consecutive years. It revealed that although the shade tree was continuously attacked by many insects, the maximum injury was done to its foliage by a lepidopteran, *Gazalina chrysolopha* Kollar (Notodontidae) and a coleopteran, *Chrysomela chlorina* Maulik (Chrysomelidae) at different times of the year. The injury caused by other insects to its foliage was negligible in comparison.

6.2.1. Incidence and population of *G. chrysolopha*:

6.2.1.1. At Pangthang (2160m amsl) (Fig. 4a-4c):

During observations on the seasonal incidence of *G. chrysolopha* at Pangthang, the caterpillars were seen from November 1999 till May first week in the year 2000, while in the subsequent years, i.e., 2001 and 2002, they appeared in December of the previous year and were active till April. The adults of the insect, in the year 2000, started appearing in June-July. However, in the year 2001 and 2002 they were active only in July- August.

The observations on the last three instars (as the larvae of the first two instars nibbled only on the debris/very tender leaves found at the base of the shade tree) of *G. chrysolopha* on the shade tree, revealed that the pest started appearing

Fig.4a. Population change of larvae of *Gazalina chrysolopha* in relation to weather parameters (Pangthang, 2000)

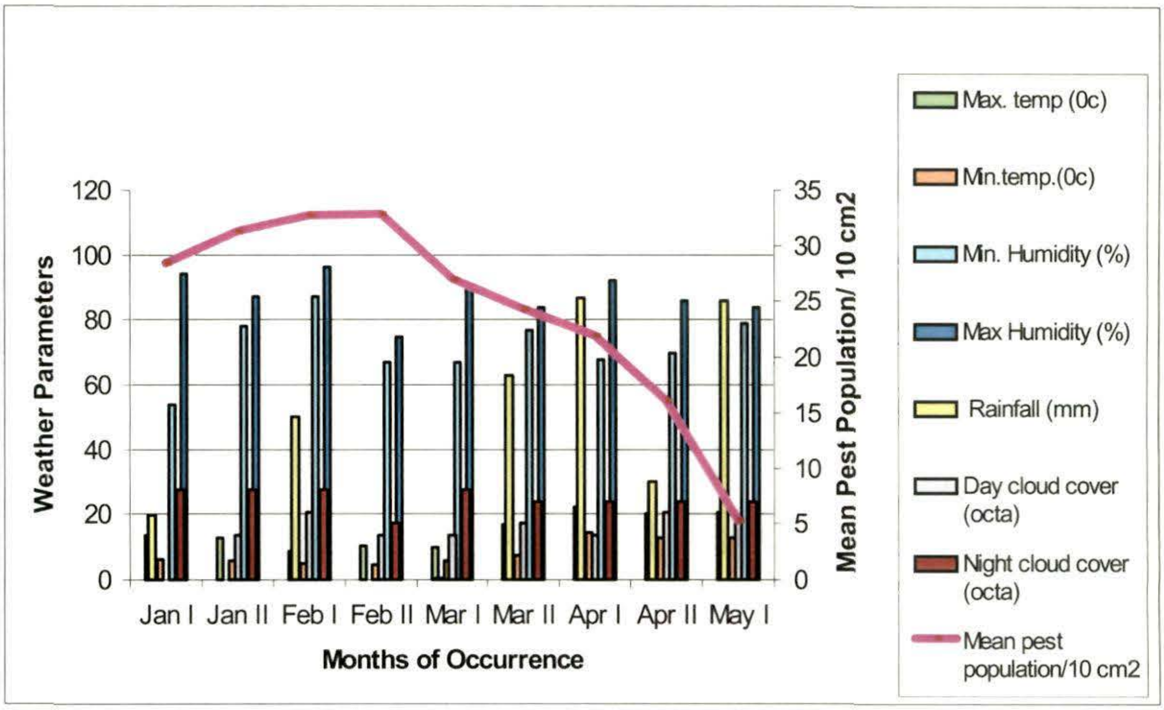


Table: 2a. Relation of population of *G. chrysolopha* larvae with abiotic factors (Pangthang, 2000)

	Weather parameters	Correlation coefficient
Pest population vs	Max. temperature^{0}C	-0.759(*)
	Min. temperature^{0}C	-0.821(**)
	Relative humidity (day)(%)	0.101
	Relative humidity (night)(%)	0.139
	Rainfall(mm)	-0.631
	Cloud cover (day) (Octa)	-0.275
	Cloud cover (night) (Octa)	-0.271

* = Significant at 5% level ** = Significant at 1% level

Fig.4b. Population change of larvae of *G. chrysolopha* in relation to weather parameters (Pangthang, 2001)

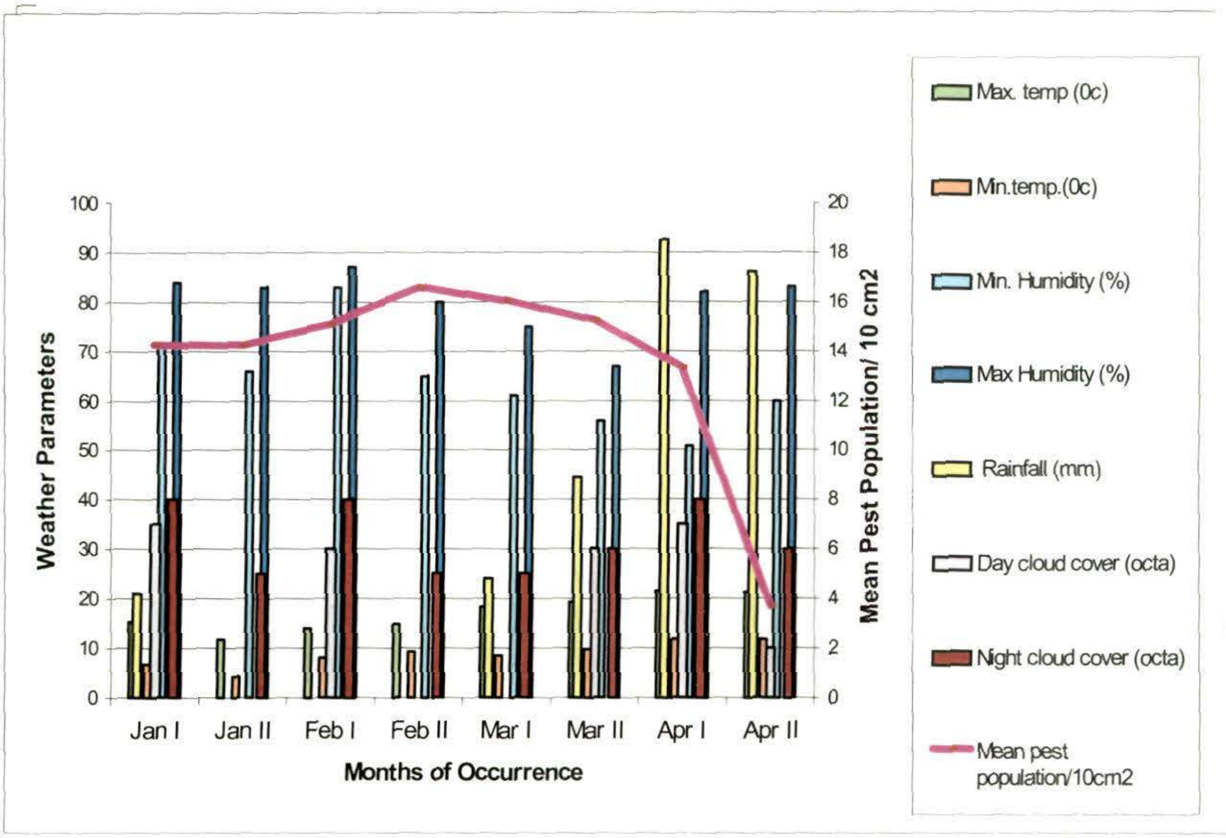


Table: 2b. Relation of population of *G. chrysolopha* larvae with abiotic factors (Pangthang, 2001)

	Weather parameters	Correlation coefficient
Pest population vs	Max. temperature^{0}C	-0.634(**)
	Min. temperature^{0}C	-0.576(*)
	Relative humidity (day)(%)	0.202
	Relative humidity (night)(%)	-0.284
	Rainfall(mm)	-0.730(**)
	Cloud cover (day) (Octa)	-0.085
	Cloud cover (night) (Octa)	-0.159

* = Significant at 5% level ** = Significant at 1% level

Fig.4c. Population change of larvae of *G. chrysolopha* in relation to weather parameters (Pangthang, 2002)

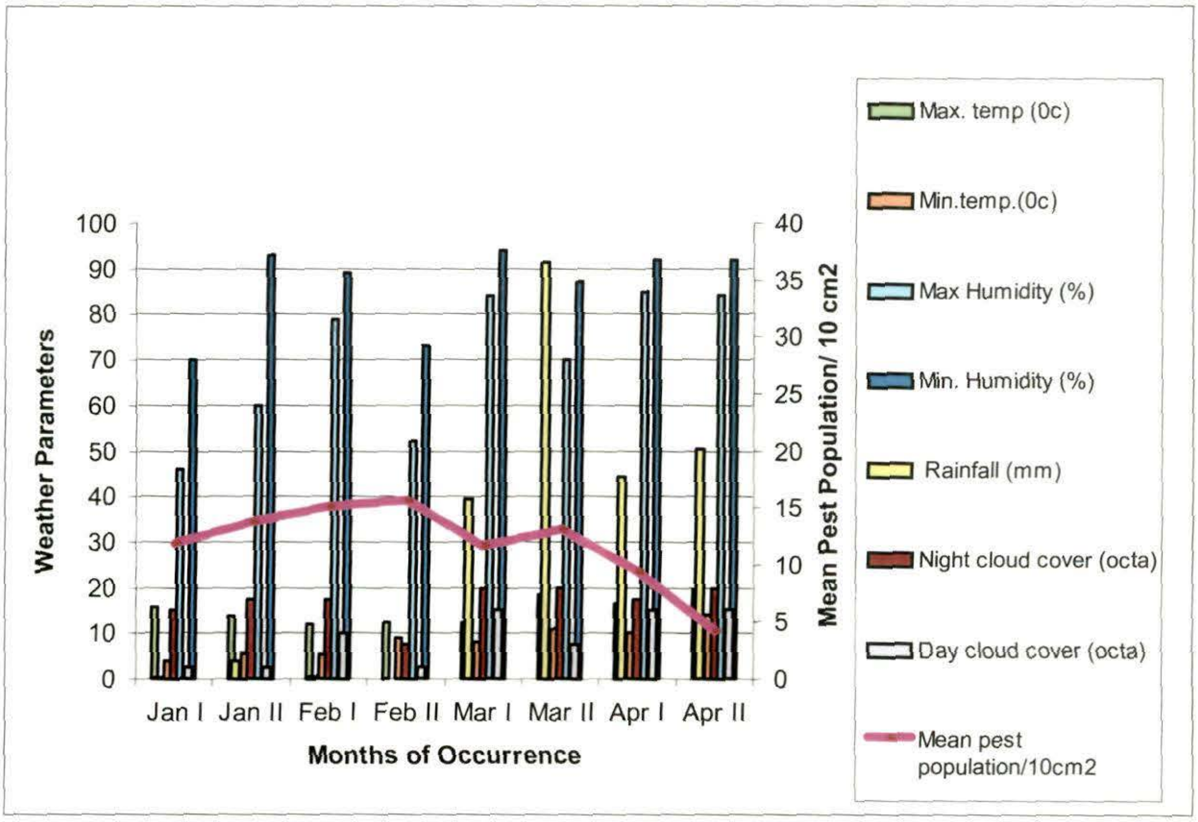


Table: 2c. Relation of population of *G. chrysolopha* larvae with abiotic factors (Pangthang, 2002)

	Weather parameters	Correlation coefficient
Pest population vs	Max. temperature^{0}C	-0.782(*)
	Min. temperature^{0}C	-0.661(**)
	Relative humidity (day)(%)	0.365
	Relative humidity (night)(%)	-0.513(*)
	Rainfall(mm)	-0.639
	Cloud cover (day) (Octa)	-0.65
	Cloud cover (night) (Octa)	-0.511

* = Significant at 5% level ** = Significant at 1% level

in the first week of January in cold weather. As the weather got colder, the population gradually increased. The pest population reached its peak in the second week of February. As the temperature rose, it declined. This trend was observed in all the three years i.e. 2000, 2001 and 2002. An exceptionally high population was observed in the year 2000, which was more pronounced at the peak population period (February to March). Population in the peak period was nearly double than that recorded in the years 2001 and 2002.

6.2.1.1.1. Relations with weather parameters (Table: 2a-2c):

A negative significant correlation between the maximum and minimum temperatures and the pest population was observed in all the three years . A negative significant correlation existed between rainfall received and the population incidence in the year 2001. In all the three years, both day and night cloud cover, showed a negative but non-significant correlation with the pest population. A negative low significance of correlation with the night humidity was, however, observed for the population in the year 2002 (Table 2c).

6.2.1.2. At Kabi (1630m amsl) (Fig. 4d-4f):

The population trend observed at Kabi was, by and large, similar to that at Pangthang. Although, the initial incidence of pest population appeared a little lower at Kabi as compared to Pangthang in the first week of January, it rose gradually resulting in higher population during the peak period i.e. February, in the year 2000. In the years 2001 and 2002,

Fig.4d. Population change of larvae of *G. chrysolopha* in relation to weather parameters (Kabi, 2000)

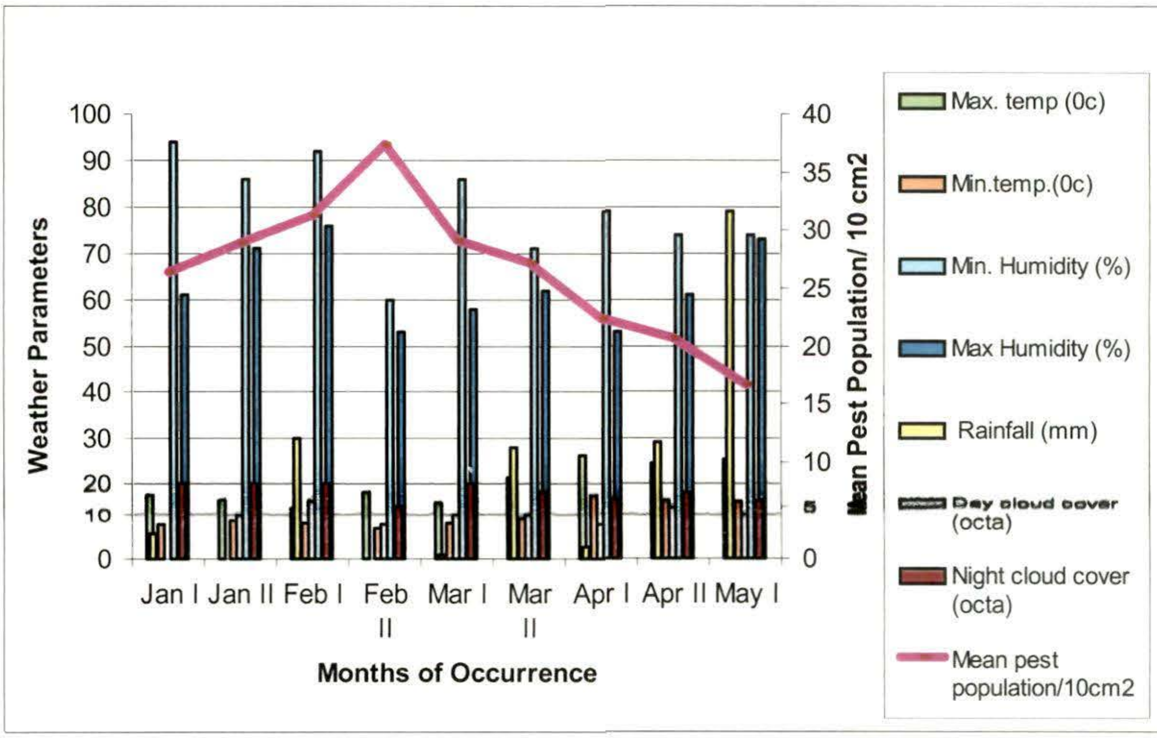


Table: 2d. Relation of population of *G. chrysolopha* larvae with abiotic factors (Kabi, 2000)

	Weather parameters	Correlation coefficient
Pest population vs	Max. temperature ^{0}C	-0.766(**
	Min. temperature ^{0}C	-0.876(**
	Relative humidity (day)(%)	-0.10
	Relative humidity (night)(%)	-0.38
	Rainfall(mm)	-0.22
	Cloud cover (day) (Octa)	-0.22
	Cloud cover (night) (Octa)	0.02

* = Significant at 5% level ** = Significant at 1% level

Fig.4e. Population change of larvae of *G. chrysolopha* in relation to weather parameters (Kabi, 2001)

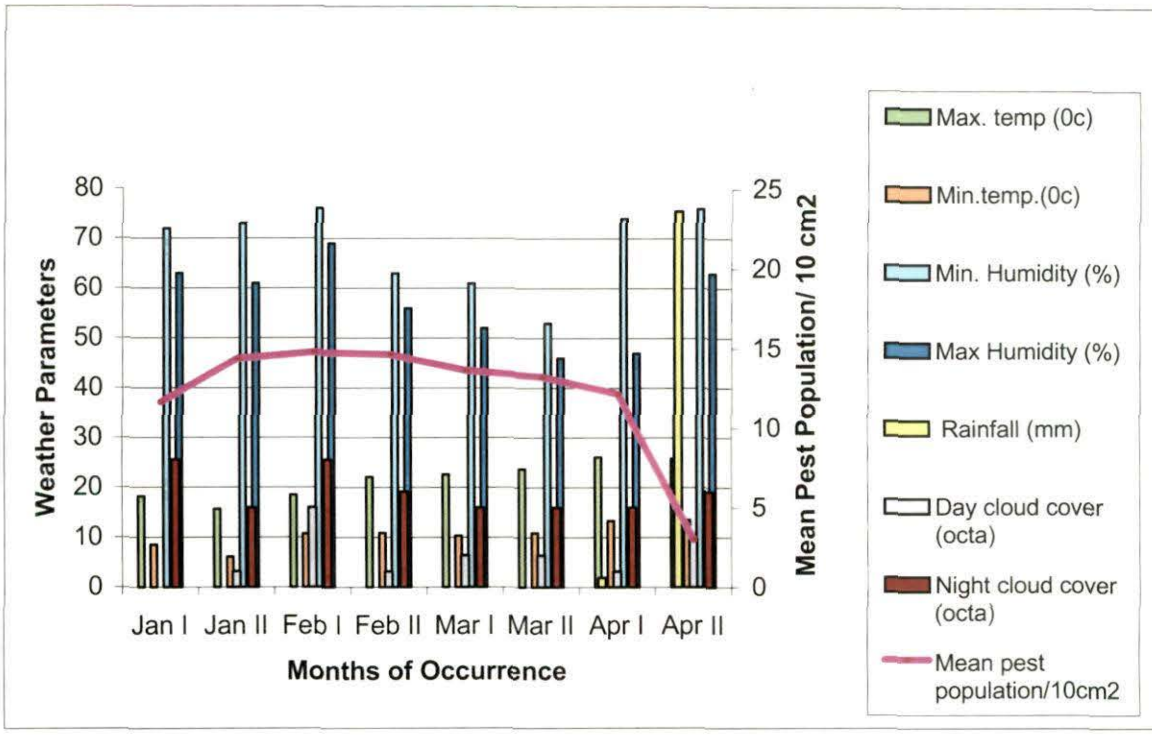


Table: 2e. Relation of population of *G. chrysolopha* larvae with abiotic factors (Kabi, 2001)

	Weather parameters	Correlation coefficient
Pest population vs	Max. temperature^{0}C	-0.363
	Min. temperature^{0}C	-0.915(**)
	Relative humidity (day)(%)	-0.510
	Relative humidity (night)(%)	-0.327
	Rainfall (mm)	-0.938(*)
	Cloud cover (day) (Octa)	-0.156
	Cloud cover (night) (Octa)	-0.127

* = Significant at 5% level ** = Significant at 1% level

Fig. 4f. Population change of larvae of *G. chrysolopha* in relation to weather parameters (Kabi, 2002)

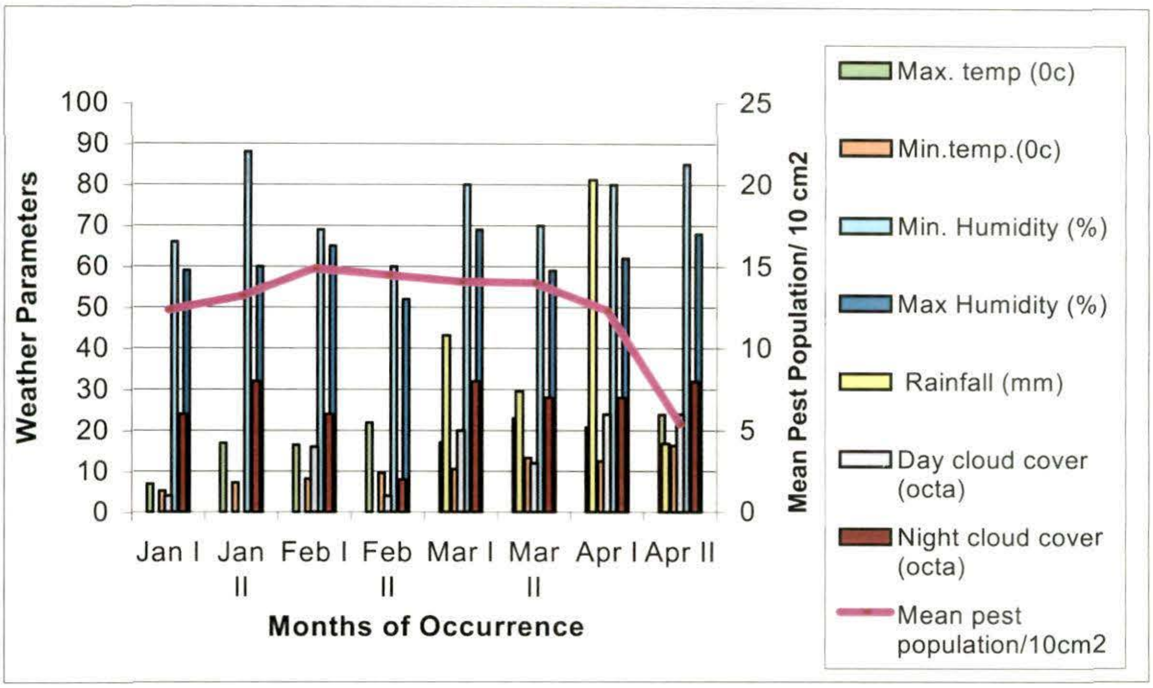


Table: 2f. Relation of population of *G. chrysolopha* larvae with abiotic factors (Kabi, 2002)

	Weather parameters	Correlation coefficient
Pest population vs	Max. temperature^{0}C	-0.212
	Min. temperature^{0}C	-0.848(**)
	Relative humidity (day)(%)	0.032
	Relative humidity (night)(%)	0.332
	Rainfall(mm)	0.437
	Cloud cover (day) (Octa)	-0.020
	Cloud cover (night) (Octa)	-0.415

* = Significant at 5% level ** = Significant at 1% level

however, population, in peak period, was lower at Kabi than at Pangthang. The peak period of the pest population remained the same in all the three years i.e. during first and second week of February. The population declined in the following months.

6.2.1.2.1. Relations with weather parameters (Table: 2d-2f):

Maximum and minimum temperatures were found to be having a negative correlation with the pest population. In the year 2000, a negative significant correlation with both minimum and maximum temperature was observed. However, in 2001 and 2002, only minimum temperature was found significantly influencing the pest population. A significant negative correlation between pest population and rainfall was also observed in year 2001. In all the three years, both day and night cloud cover and relative humidity showed a non-significant effect on the pest population.

6.2.2. Incidence and population of *C. chlorina*:

6.2.2.1. At Pangthang (2160m amsl) (Fig. 4g-4i):

Trend of population change of *C. chlorina* was similar in all the three years of study at Pangthang. The first incidence of the pest was observed in the third week of May with very low population. Subsequently, the population increased and attained its peak in the second week of June. Population started declining thereafter and by the end of the fourth week of June, only traces of population remained. This trend continued till the population reappeared in the third week of July

Fig. 4g. Population change of larvae of *Chrysomela chlorina* in relation to weather parameters (Pangthang, 2000)

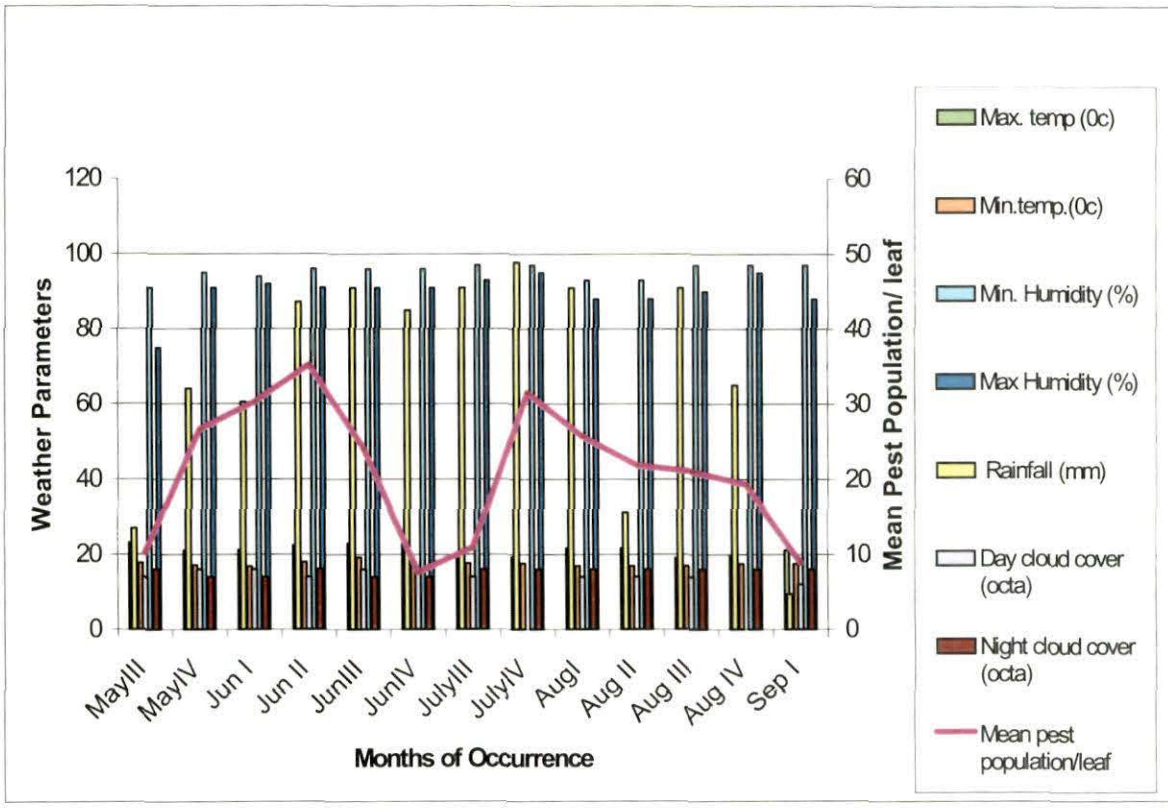


Table: 2g. Relation of population of *C. chlorina* larvae with abiotic factors (Pangthang, 2000)

	Weather parameters	Correlation coefficient
Pest population vs	Max. temperature^{0}C	0.417
	Min. temperature^{0}C	0.228
	Relative humidity (day)(%)	0.061
	Relative humidity (night)(%)	-0.279
	Rainfall(mm)	0.610(*)
	Cloud cover (day) (Octa)	0.392
	Cloud cover (night) (Octa)	0.809(**)

* = Significant at 5% level ** = Significant at 1% level

Fig. 4h. Population change of larvae of *C. chlorina* in relation to weather parameters (Pangthang, 2001)

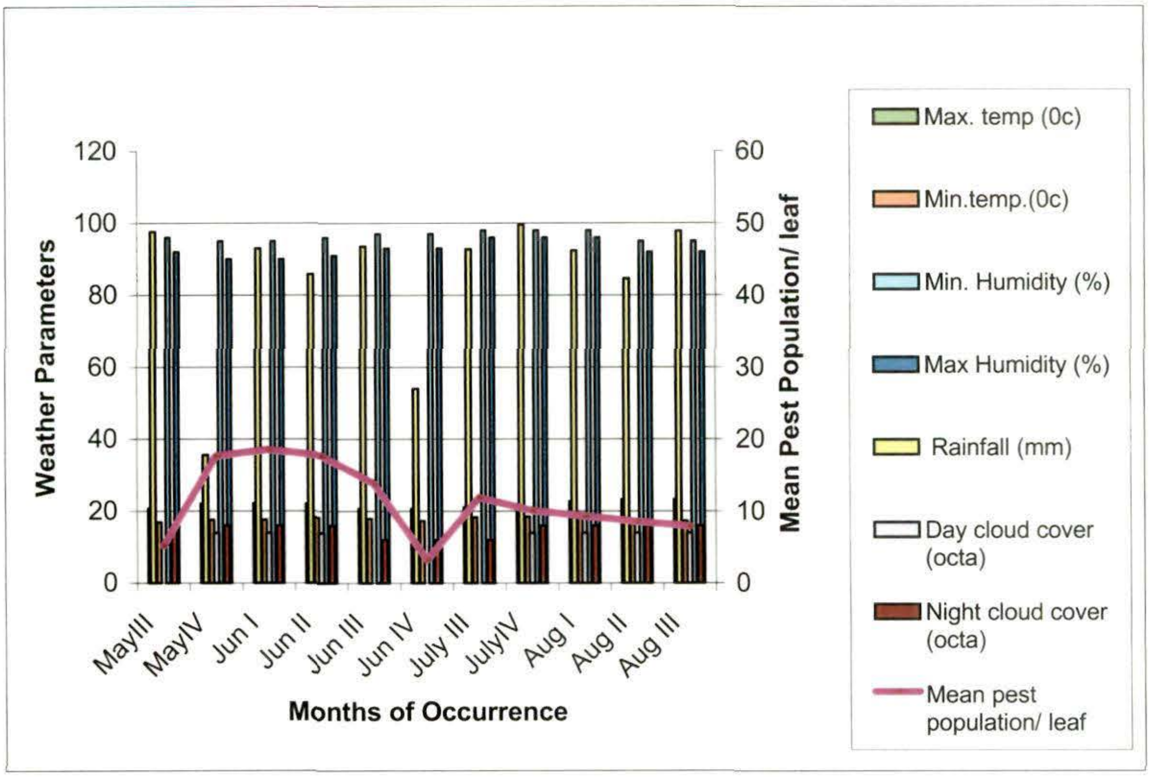


Table: 2h. Relation of population of *C. chlorina* larvae with abiotic factors (Pangthang, 2001)

	Weather parameters	Correlation coefficient
Pest population vs	Max. temperature ^{0}C	0.161
	Min. temperature ^{0}C	0.314
	Relative humidity (day)(%)	-0.272
	Relative humidity (night)(%)	-0.419
	Rainfall(mm)	0.792(**)
	Cloud cover (day) (Octa)	0.620(*)
	Cloud cover (night) (Octa)	0.201

* = Significant at 5% level ** = Significant at 1% level

Fig. 4i. Population change of larvae of *C. chlorina* in relation to weather parameters (Pangthang, 2002)

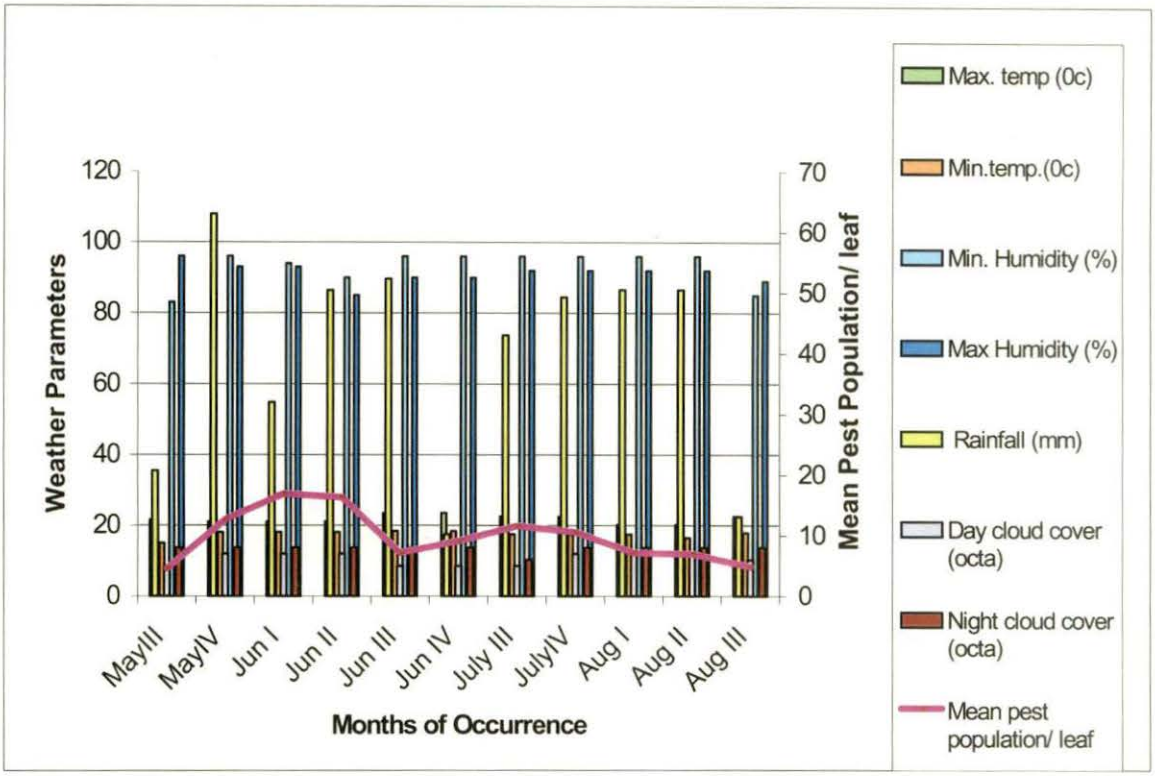


Table: 2i. Relation of population of *C. chlorina* larvae with abiotic factors (Pangthang, 2002)

	Weather parameters	Correlation coefficient
Pest population vs	Max. temperature^{0}C	0.134
	Min. temperature^{0}C	0.542
	Relative humidity (day)(%)	0.449
	Relative humidity (night)(%)	-0.089
	Rainfall(mm)	0.621(*)
	Cloud cover (day) (Octa)	0.014
	Cloud cover (night) (Octa)	0.055

* = Significant at 5% level ** = Significant at 1% level

and attained its second peak in the fourth week of July. The population of *C. chlorina* in the year was quite high in 2000 and continued till September. However, in year 2001 and 2002, the pest disappeared by the third week of August.

6.2.2.1.1. Relations with weather parameters (Table: 2g-2i):

Correlation coefficient between the population and different abiotic factors observed, during the three years, showed that rainfall had positive significant correlation with the pest population in all the three years at Pangthang. In year 2000, night cloud cover showed positive significant correlation with the pest population while in the year 2001, it was the day cloud cover. Relative humidity however, showed non-significant effects. The correlation of temperature and pest population was non-significant.

6.2.2.2. At Kabi (1630m amsl) (Fig. 4j-4l):

At Kabi, the pest appeared in May and continued till August in all the three years. The population trend showed pattern similar to that at Pangthang. Two peaks of the pest population were evident, one in the second week of June and other in the third -fourth week of July.

6.2.2.2.1.Relations with weather parameters (Table: 2j-2l):

The meteorological observations showed significant positive correlation between the pest population and rainfall in all the three years. In the year 2000, significant positive correlation was observed with day cloud cover while in year 2001,it was night cloud cover, which showed it.

Fig. 4j. Population change of larvae of *C. chlorina* in relation to weather parameters (Kabi, 2000)

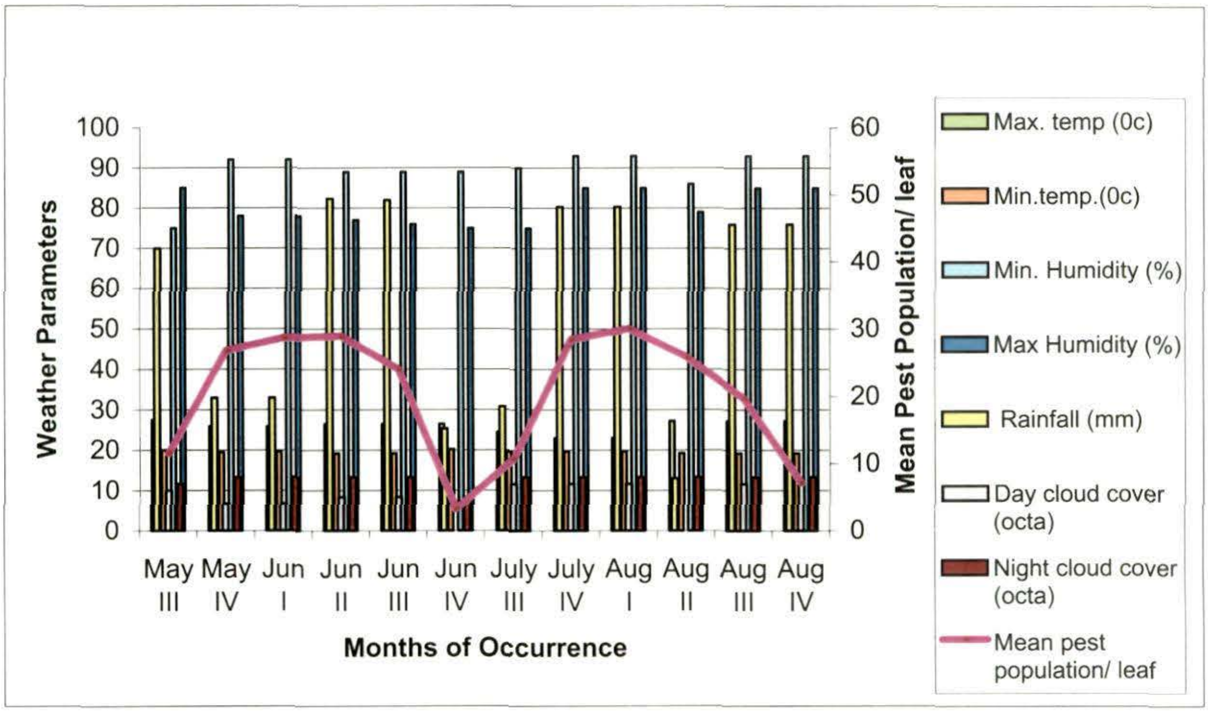


Table: 2j. Relation of population of *C. chlorina* larvae with abiotic factors (Kabi, 2000)

	Weather parameters	Correlation coefficient
Pest population vs	Max. temperature ^{0}C	0.594
	Min. temperature ^{0}C	0.256
	Relative humidity (day)(%)	0.369
	Relative humidity (night)(%)	-0.176
	Rainfall(mm)	0.613(*)
	Cloud cover (day) (Octa)	*0.616(*)*
	Cloud cover (night) (Octa)	0.572

* = Significant at 5% level ** = Significant at 1% level

Fig.4k. Population change of larvae of *C. chlorina* in relation to weather parameters (Kabi, 2001)

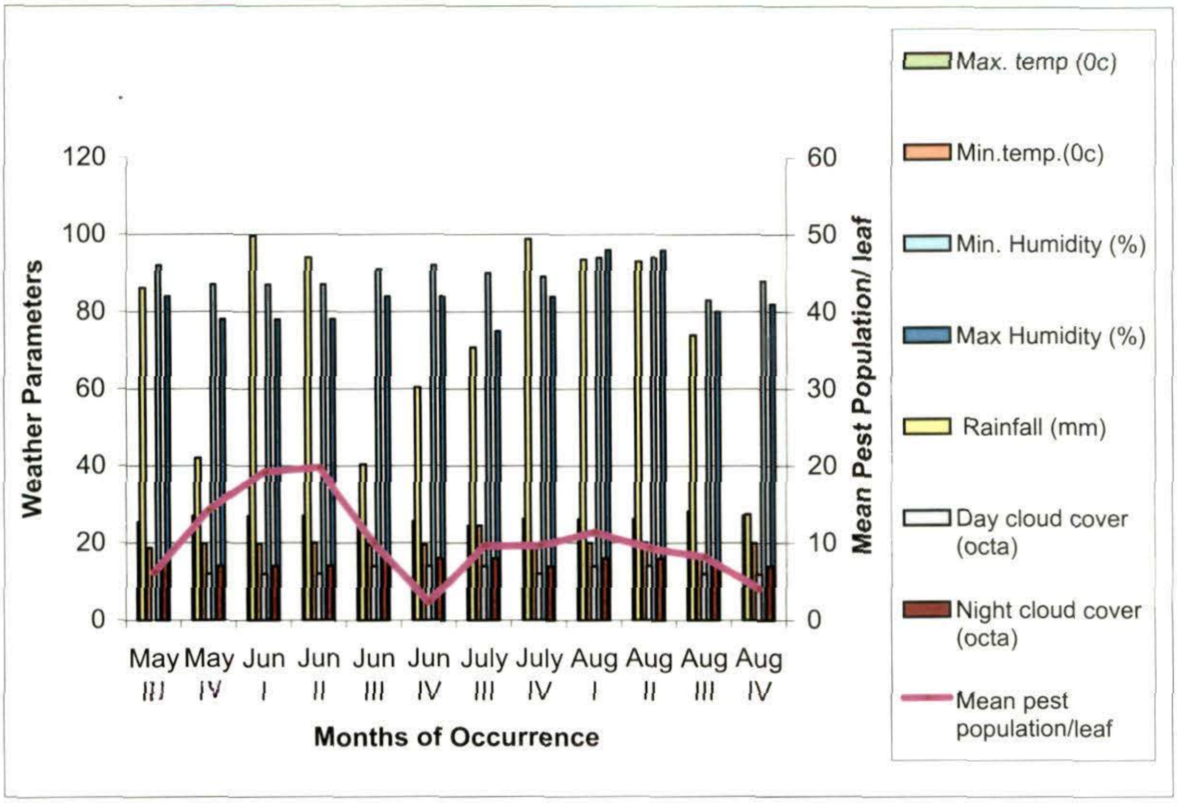


Table: 2k. Relation of population of *C. chlorina* larvae with abiotic factors (Kabi, 2001)

	Weather parameters	Correlation coefficient
Pest population vs	Max. temperature^{0}C	0.329
	Min. temperature^{0}C	0.274
	Relative humidity (day)(%)	-0.371
	Relative humidity (night)(%)	-0.368
	Rainfall(mm)	0.849(**)
	Cloud cover (day) (Octa)	0.134
	Cloud cover (night) (Octa)	0.787(**)

* = Significant at 5% level ** = Significant at 1% level

Fig. 4l. Population change of larvae of *C. chlorina* in relation to weather parameters (Kabi, 2002)

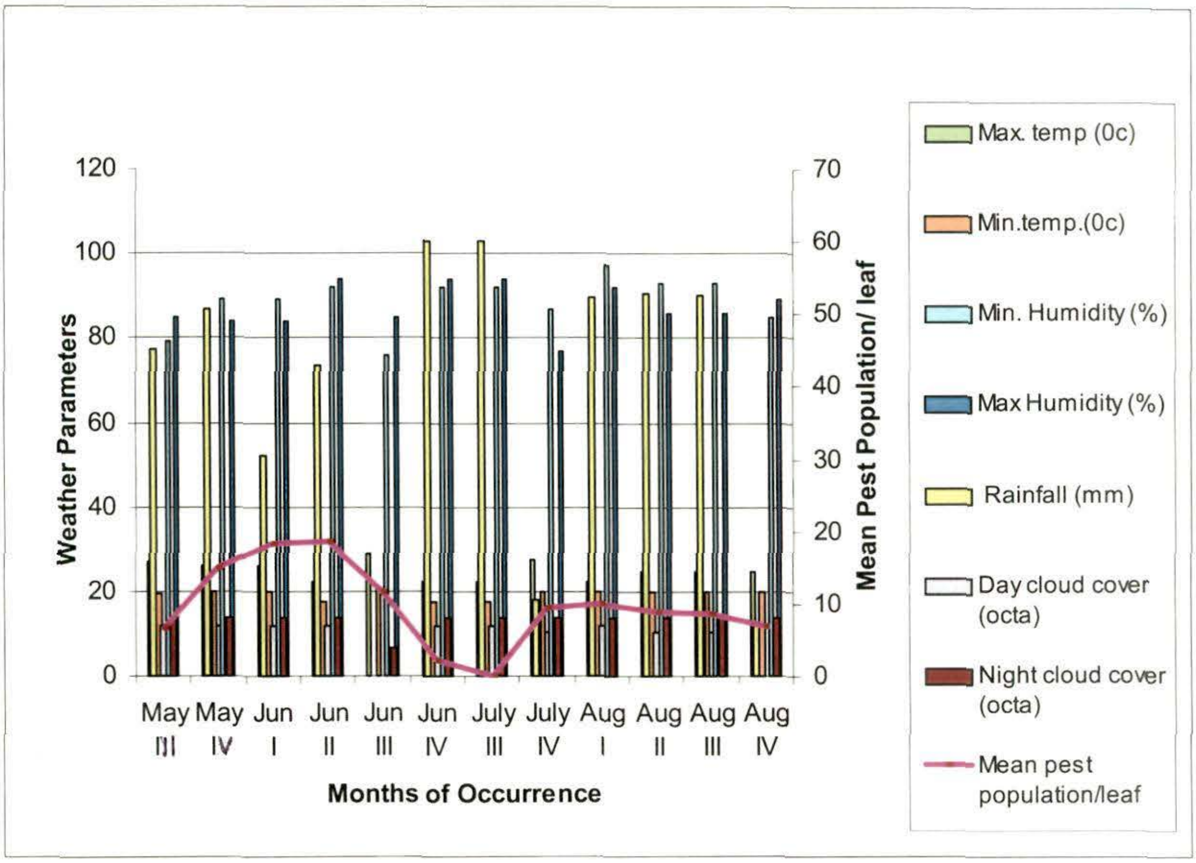


Table:2l. Relation of population of *C. chlorina* larvae with abiotic factors (Kabi, 2002)

	Weather parameters	**Correlation coefficient**
Pest population vs	Max. Temperature0C	0.285
	Min. Temperature^{0}C	0.277
	Relative humidity (day)(%)	0.026
	Relative humidity (night)(%)	-0.285
	Rainfall (mm)	0.660(*)
	Cloud cover (day) (Octa)	0.168
	Cloud cover (night) (Octa)	0.067

* = Significant at 5% level ** = Significant at 1% level

However, in the year 2002, both day and night cloud cover had non-significant positive correlation with the pest population. Maximum and minimum temperatures showed a positive but non-significant correlation with the pest population in all the three years. Relative humidity had no significant effects on it.

6.3. Life cycle of *G. chrysolopha*:

6.3.1. Egg: Eggs, small sized (0.67 mm in diameter), brown with slight central depression on top. Egg mass covered with brown hair like scales or setae from female body. Hatching (incubation) period about 65 days, percent of hatching almost hundred percent (in laboratory conditions) (Plate 7a).

6.3.2. First and second instar larvae: The 1^{st} and 2^{nd} instar larvae closely resembled one another. Newly emerged larvae, light brown in color, later turned dark; head brown-red with slight depression having a crescent mark. Generally sluggish, body covered with thin light brown hair (Plate 7b). Hair caused irritation and itching. The first and the 2^{nd} instar larvae had similar stadial periods. They fed and nibbled on the debris/very tender leaves (in lab.) found near the base of the tree. Measurements of their head capsule, length and breadth are provided in Table 3a.

6.3.3. Third, fourth and fifth instar larvae:

The 3^{rd}, 4^{th} and 5th instar larvae resembled one another except for their measurements (Plates 7c, 7d, 7e). Head deep red, having slight depression with a crescent mark. Newly moulted larvae dark brown, tufts of long pale brown hair on

Plate 7a. Eggs of *G. chrysolopha* covered with hair released by female moth

Plate 7b. Early instar larvae of *G. chrysolopha*

Plate 7c. Third instar larvae of *G. chrysolopha*

plate - 7a

plate - 7b

plate - 7c

Table 3a. Morphological data of *G. chrysolopha* on *A. nepalensis*

Particulars/Stages	Measurements (mm)
Egg	
(a) Length	0.67 ± 0.050
(b) Width	0.67 ± 0.050
1stinstar larva	
(a) Length	1.69 ± 0.081
(b) Width	0.33 ± 0.015
(c) Width of the head capsule	0.33 ± 0.012
2ndinstar larva	
(a) Length	3.55 ± 0.176
(b) Width	0.61 ± 0.065
(c) Width of the head capsule	0.63 ± 0.039
3rd instar larva	
(a) Length	15.70 ± 0.073
(b) Width	2.50 ± 0.042
(c) Width of the head capsule	1.18 ± 0.019
4th instar larva	
(a) Length	26.10 ± 0.588
(b) Width	4.50 ± 0.125
(c) Width of the head capsule	2.46 ± 0.019
5th instar larva	
(a) Length	35.50 ± 0.677
(b) Width	5.95 ± 0.159
(c) Width of the head capsule	3.00 ± 0.024
Pupa	
(a) Length	22.5 ± 0.215
(b) Width	12.05 ± 0.115
Adult Moth	
1.Male	
(a) Length	24.00 ± 0.789
(b) Width	15.00 ± 0.635
(C) Wing Expanse	36.00 ± 1.15
2.Female	
(a) Length	24.50 ± 0.778
(b) Width	8.50 ± 0.645
(C) Wing Expanse	36.50 ± 1.18

Mean values of 10samples with SD

Plate 7d. Late instar larvae of *G. chrysolopha*

Plate 7e. Late instar larvae of *G. chrysolopha* in resting position

Plate 7f. Pupa of *G. chrysolopha*

plate - 7d

plate - 7e

plate - 7f

back along with a dorsal series of short fulvous tuft. Five pairs of prolegs on III-VI and X segments.

The 3^{rd}, $4^{th}$and 5^{th} instar larvae were very active and climbed tall trees at night for food. In the field, the later instars (3^{rd}, 4^{th}, 5^{th}) of *G. chrysolopha,* showed nocturnal movement (migration) in procession. On disturbance, they vomited a dark green fluid. They secreted a white sticky fluid while climbing up and built a silken cover (web) at the base of the tree to rest during daytime. The $4^{th}$and 5^{th} instar larvae took almost the same time (30-35 days) to complete their respective stadial periods. Measurements of width of their head capsule and length and breadth of body are provided in Table 3a.

It was observed that the width of head capsule and the length of the *G. chrysolopha* larvae grew in regular geometrical progression. The growth of head width of *G. chrysolopha* was observed to fall into five distinct classes each indicating an instar (Fig.5a).

6.3.4. Pupa: Brown, covered by silken cocoon and very fine and thin hair (Plate 7f). Pupation took place in the debris found at the base of the tree. Measurement of pupa and duration of pupal stage, are provided in Table 3a, 3b.

6.3.5. Adult:

Male (Plate 7g)**:** Male moths white in colour, head and thorax white, legs black, shaft of antennae black, palpi very minute, antennae plumose with long setae, abdomen black with white fringed segments. Fore and hind

Fig: 5a. Relation between progressing width of head capsule and length of the larvae of *G. chrysolopha*

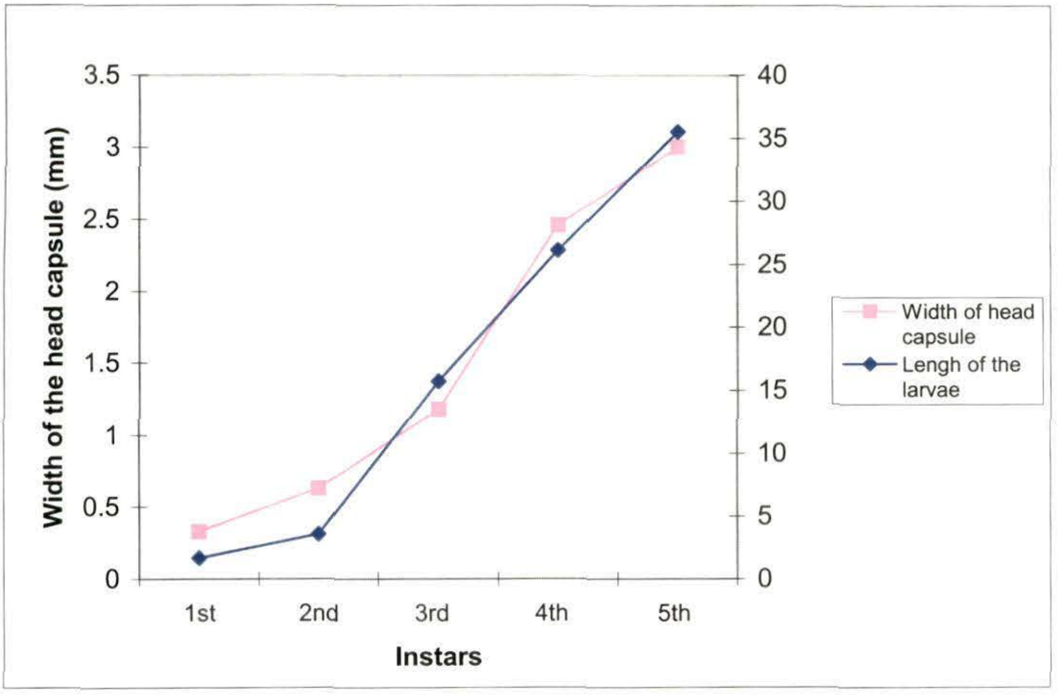


Plate 7g. Adult (Male) of *G. chrysolopha*

Plate 7h. Adult (Female) of *G. chrysolopha*

Plate 7i. Parasitoid pupa emerging from the larva of *G. chrysolopha*

plate - 7g

plate - 7h

plate - 7i

wings white with black veins. Wing expanse of male moth measured 36.00 ± 0.15 mm. Male lived longer than female (Table 3b).

Female (Plate 7h): Females similar to males, but their abdominal segment less fringed, large fulvous anal tuft, barbed setae in anal tuft. Segmental white fringes of abdomen narrower in females. Female wing expanse measured 36.50 ± 0.18 mm. Female released setae of anal tuft over the eggs (Plate 7a), which was carried easily by the wind.

6.3.6. Fecundity and oviposition: Female laid eggs once or sometimes twice in life -time. Mating took place two to three days after emergence. Female moth laid eggs in clusters, piling on and glued to one another in a horizontal pattern. The total number of egg laid/female was 150-250 with an average of 230 eggs. Eggs were generally laid at night on the dorsal side of the leaves and were covered by abdominal hairs released by female moth. In fields, they were also found deposited on the trunk of trees, nearby walls and the light poles. Duration of premating, preovipositing and ovipositing periods are provided in Table 3b. No significant difference was observed in the life cycle pattern and development performance in all the three years of study.

6.3.7. Natural enemies associated with *G. chrysolopha*:

In the fields the eggs of *G. chrysolopha* were predated by lacewings. Attack by ants (*Crematogester* sp.) was also seen. Maximum parasitism was observed in the larval stages of the insect. Larvae of a tachinid fly parasitised late instar larvae of *G. chrysolopha* (Plate7i-7j).

Table 3b. Duration (mean ±SD) of different stages of life cycle of *Gazalina chrysolopha* on *Alnus nepalensis*

Stages	Average (Days)
Premating period	3.50 ± 0.69
Preoviposition period	3.20 ± 0.70
Oviposition period	1.50 ± 0.15
Incubation period	65.50 ± 4.25
Larval periods	
1st instar larva	20.85 ± 1.65
2nd instar larva	22.55 ± 2.24
3rd instar larva	25.50 ± 3.25
4th instar larva	32.96 ± 2.76
5th instar larva	30.61 ± 4.15
Total larval period	165.50 ± 8.59
Pupa	35.50 ± 3.54
Longevity of adults	
(a) Male	7.50 ± 0.15
(b) Female	5.50 ± 0.42
Total life cycle (Egg-Adult)	265.50 ± 8.25

Mean values of 10 samples

Plate 7j. Parasitoid of *G. chrysolopha* (Tachinid fly and its pupa)

plate -7j

In the field, the larvae of *G. chrysolopha* ate the eggs of the tachinid fly along with the leaves of the host tree leading to their infestation. The pupa of the parasitic fly mostly emerged rupturing the body of the host larva (*G. chrysolopha*) resulting in the latter's death. Much more parasitism was observed in the year 2000 as compared to 2001 and 2002. Parasitisation by above-mentioned fly seemed to be a major factor in regulation of the natural population of *G. chrysolopha.*

6.4. Life cycle of *C. chlorina*:

6.4.1. Egg: Eggs oblong, blackish green, measuring 1.95 mm in length and 0.50mm in breadth. Incubation time 3 or 4 days. Hatching success 95% in laboratory conditions (Plate 8a,Tables 4a, 4b).

6.4.2. Larva: The beetle passed through 4 larval instars. The instars showed similarity with one another (Plate 8b-8c).

6.4.3. First Instar: First instar larva very soft, black in colour, generally sluggish, about 1. 95± 0.198 mm in length. Head, antennae, legs, thorax and abdomen black in color. The first instar larvae nibble the green tissue of the leaf.

6.4.4. Second Instar: Body soft and black, larger than 1^{st} instar, 2.55 ± 0.174 mm in length. Stadial period 3 to 4 days. Active feeders of leaf tissue.

6.4.5. Third Instar: Body soft and black, active feeder, moved fast, 3.58 ± 0.214 mm in length. Stadial period 3 to 4 days.

Plate 8a. Eggs of *Chrysomela chlorina*

Plate 8b. Larvae of *C. chlorina* feeding on *A. nepalensis* leaf

Plate 8c. Different stages of *C. chlorina* (showing larvae and pupa)

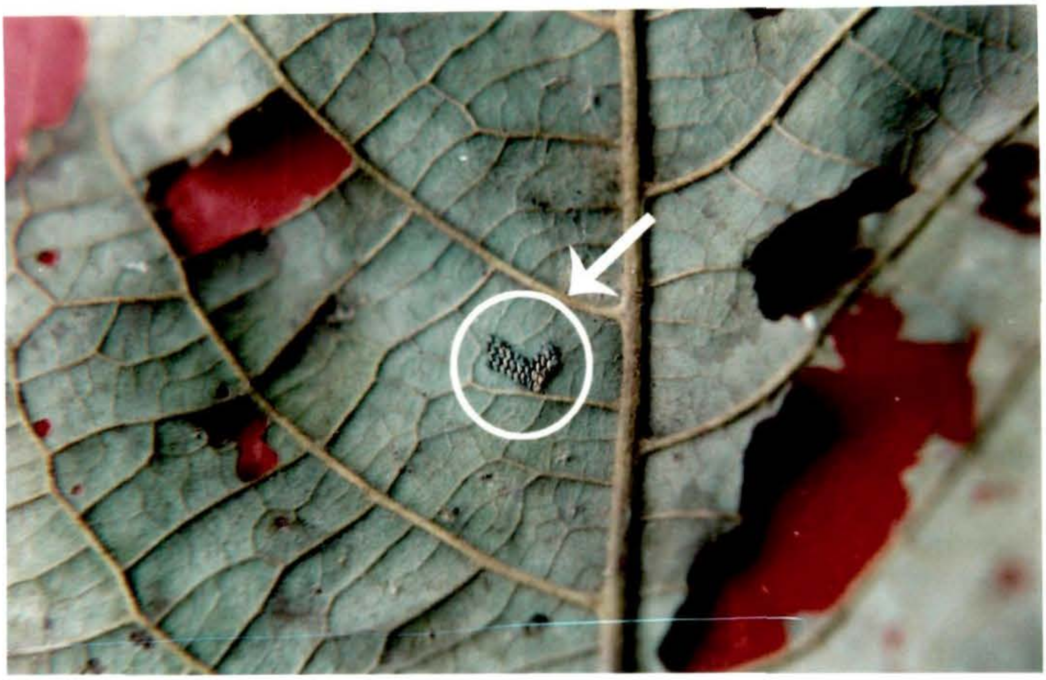


plate - 8a

plate - 8b

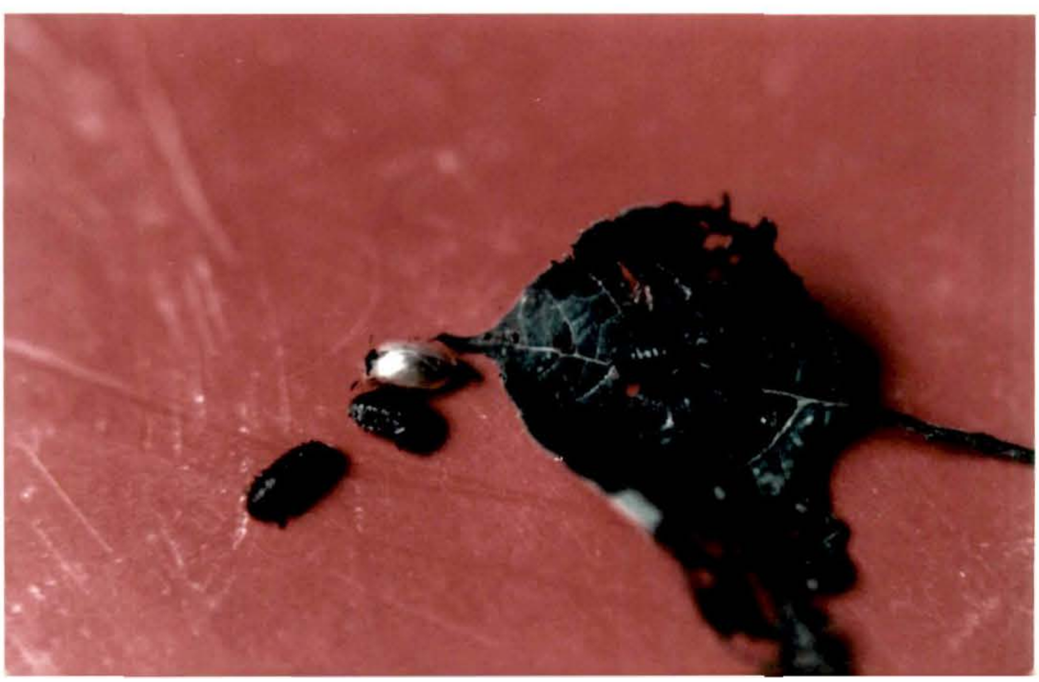


plate - 8c

Table: 4a. Morphometric data of *C. chlorina* on *A. nepalensis*

Particulars/Stages	Measurements (mm)
Egg	
(a) Length	1.95 ± 0.085
(b) Width	0.50 ± 0.055
1st instar larva	
(a) Length	1.59 ± 0.198
(b) Width	1.33 ± 0.112
(c)Width of the head capsule	0.5 ± 0.0090
2nd instar larva	
(a) Length	2.55 ± 0.174
(b) Width	1.61 ± 0.111
(c) Width of the head capsule	0.90 ± 0.096
3rd instar larva	
(a) Length	3.58 ± 0.214
(b) Width	1.70 ± 0.185
(c) Width of the head capsule	1.30 ± 0.019
4th instar larva	
(a) Length	5.50 ± 0.288
(b) Width	2.02 ± 0.085
(c) Width of the head capsule	1.80 ± 0.021
Pupa	
(a) Length	6.05 ± 0.315
(b) Width	1.90 ± 0.115
Adult Beetle	
1.Male	
(a) Length	6.32 ± 0.615
(b) Width	3.50 ± 0.239
2.Female	
(a) Length	6.50 ± 0.695
(b) Width	4.00 ± 0.316

Mean values of 10 samples with SD

6.4.6. Fourth Instar: Body black, very active, prominent abdominal segments, hard body. Feigned death by folding legs. 5.50 ± 0.288 mm in length, stadial period 4 to 5 days.

It was observed that the width of head capsule and the length of the larvae of *C. chlorina* showed a regular geometrical progression. The growth of head width of *C. chlorina* was observed to fall into four distinct classes each indicating an instar (Fig.5b).

6.4.7. Pupa: The fourth instar larva stopped feeding, became hard and inactive and formed pale white membranous puparium (Plate 8c). The length of the pupa measured 6.05 ± 0.315 mm.

6.4.8. Adult: There was no sharp diamorphism between the male and female beetle. Body oblong; broad posteriorly, elytra metallic green with bronzy purple sheen. Prothorax broader than long, pronotum brown with five small rounded spots. Scutellum with rounded apex. Head broad and depressed in the middle, clypeus well marked by two deeply impressed oblique lines meeting at a point in the depressed central area. Antennae short, shining brown black. Abdomen, legs light brown. Male smaller than female. Mating took place within three- four days of adult emergence. When disturbed, adult feigned death by folding legs and lying motionless for certain time. *C. chlorina* completed two to three generations in a year and underwent dormancy in cold winter months (Plate 8d).

Fig: 5b. Relation between progressing width of head capsule and length of the larvae of *C. chlorina*

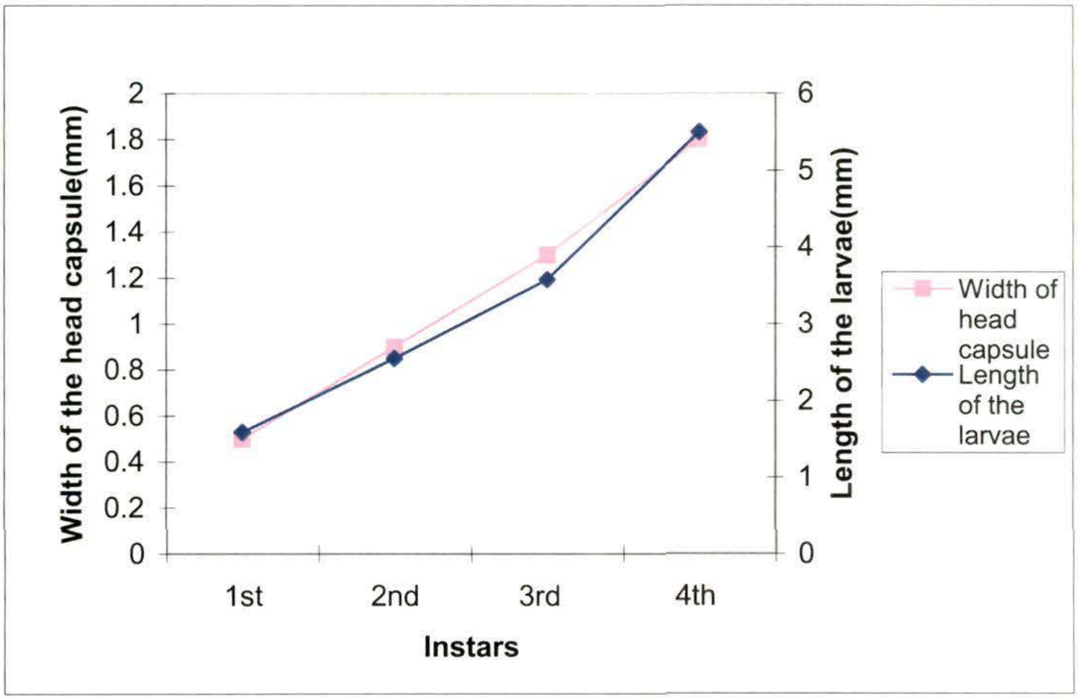


Plate 8d. Adult beetle of *C. chlorina*

plate - 8d

6.4.9. Fecundity and oviposition: Adult female started laying eggs within a few hours of mating. A single female laid up to twenty five to thirty eggs at a time. Female laid eggs two to three times during life time. Eggs were laid on the dorsal side of the leaf, on stem in a cluster. Duration of premating period, preovipositing and ovipositing periods are provided in Table 4 b. No significant difference was observed in the life cycle pattern and development- performance in all the three years of study.

6.4.10. Natural enemies associated with *C. chlorina*:

In the fields, mainly the pentatomid bugs attacked the eggs of *C. chlorina*. The first instar larvae of the coccinellid, *Aiolocaria hexaspilota,* were found feeding on the egg masses of the pest. The larvae of *C. chlorina* were predated by the adults and the late instar larvae of *A. hexaspilota* that occurred concurrently having a life cycle pattern coinciding with that of *C. chlorina.* It appeared that this predator was the main factor in controlling the pest population. Other predators, such as *Harmonia eucharis* and *H. sedecimnotata* were very few in number and only occasionally fed on the grubs. Both the above mentioned predators were found only at Pangthang in year 2000 and 2001. At Kabi they were seen attacking the pest only in the year 2000. In year 2002, they were not seen at either of these two altitudes.

Table: 4b. Duration (mean ±SD) of different stages of life cycle of *C. chlorina* on *A. nepalensis*

Particulars/Stages	Duration (days)
Pre mating period	3.50 ± 1.044
Oviposition period	5.50 ± 1.086
Incubation period	3.50 ± 2.150
Larval periods	
1st instar larva	3.50 ± 0.710
2nd instar larva	3.00 ± 0.425
3rd instar larva	4.50 ± 0.705
4th instar larva	4.50 ± 0.500
Total larval period	15.50 ± 2.540
Pupa	3.50 ± 0.555
Longevity of adults	
(a) Male	9.50 ± 1.450
(c) Female	8.50 ± 1.150
Total life cycle (Egg-Adult)	38.50 ± 2.250

Mean values of 10samples

6.5. Survivorship study of *G. chrysolopha* (Fig 6a):

The survivorship curve of *G. chrysolopha* showed no mortality in the first week followed by marginal mortality rate till 28th day. After that larvae, in general, had very less mortality till the 144th day. From 148th day (with some variations), death rate, in general, increased and it reached its maxima on the 160th day or in the last few days of its larval life. Generally the death took place during moulting. l_x value for larval survival ultimately showed that the number of larvae entering into pupation was quite high (Table 5a).

The survivorship curve of *G. chrysolopha* appeared to stand between curves Type I and II as suggested by Pearl (1928).

6.6. Survivorship study of *C. chlorina* (Fig 6b):

Observations made on the survivorship of *C. chlorina,* revealed that there was a gradual increase in mortality of the grubs till the 4th day. Following this, an enhanced mortality but with some variations was observed. This trend continued till 21st day. An increase in the death rate was observed from 22nd day, which continued till all the larvae entered pupation (Table 5b). Generally, maximum death took place during moulting.

The survivorship curve of *C. chlorina* appeared to stand between curves Type I and II as suggested by Pearl (1928).

Table: 5a.Survivorship table of *G. chrysolopha*

X	l_x	d_x	L_X	T_X	e_x	1000 (q_x)
0	1000	0	1000.0	27433.0	27.433	0.000
4	1000	2	999.0	26433.0	26.433	2.000
8	998	0	998.0	25434.0	25.485	0.000
12	998	68	964.0	24436.0	24.485	68.136
16	930	2	929.0	23472.0	25.239	2.151
20	928	10	923.0	22543.0	24.292	10.776
24	918	8	914.0	21620.0	23.551	8.715
28	910	160	830.0	20706.0	22.754	175.824
32	750	20	740.0	19876.0	26.501	26.667
36	730	10	725.0	19136.0	26.214	13.699
40	720	2	719.0	18411.0	25.571	2.778
44	718	0	718.0	17692.0	24.641	0.000
48	718	13	711.5	16974.0	23.641	18.106
52	705	6	702.0	16262.5	23.067	8.511
56	699	29	684.5	15560.5	22.261	41.488
60	670	1	669.5	14876.0	22.203	1.493
64	669	9	664.5	14206.5	21.235	13.453
68	660	9	655.5	13542.0	20.518	13.636
72	651	11	645.5	12886.5	19.795	16.897
76	640	2	639.0	12241.0	19.127	3.125
80	638	2	637.0	11602.0	18.185	3.135
84	636	15	628.5	10965.0	17.241	23.585
88	621	1	620.5	10336.5	16.645	1.610
92	620	0	620.0	9716.0	15.671	0.000
96	620	2	619.0	9096.0	14.671	3.226
100	618	4	616.0	8477.0	13.717	6.472
104	614	0	614.0	7861.0	12.803	0.000
108	614	0	614.0	7247.0	11.803	0.000
112	614	4	612.0	6633.0	10.803	6.515
116	610	2	609.0	6021.0	9.870	3.279
120	608	0	608.0	5412.0	8.901	0.000
124	608	0	608.0	4804.0	7.901	0.000
128	608	2	607.0	4196.0	6.901	3.289
132	606	2	605.0	3589.0	5.922	3.300
136	604	0	604.0	2984.0	4.940	0.000
140	604	0	604.0	2380.0	3.940	0.000
144	604	72	568.0	1776.0	2.940	119.205
148	532	10	527.0	1208.0	2.271	18.797
152	522	202	421.0	681.0	1.305	386.973
156	320	220	210.0	260.0	0.813	687.500
160	100	100	50.0	50.0	0.500	1000.000

X= age in days, l_x = observed number of larvae surviving at start of X age interval, d_x =number dying during age interval x, L_X = number of individuals alive between ages x and x+1, T_X = individuals x time unit, e_x =expectation of life remaining for individuals of age x, q_x = mortality rate for an age interval.

Fig 6a. Survivorship curve of *G. chrysolopha*

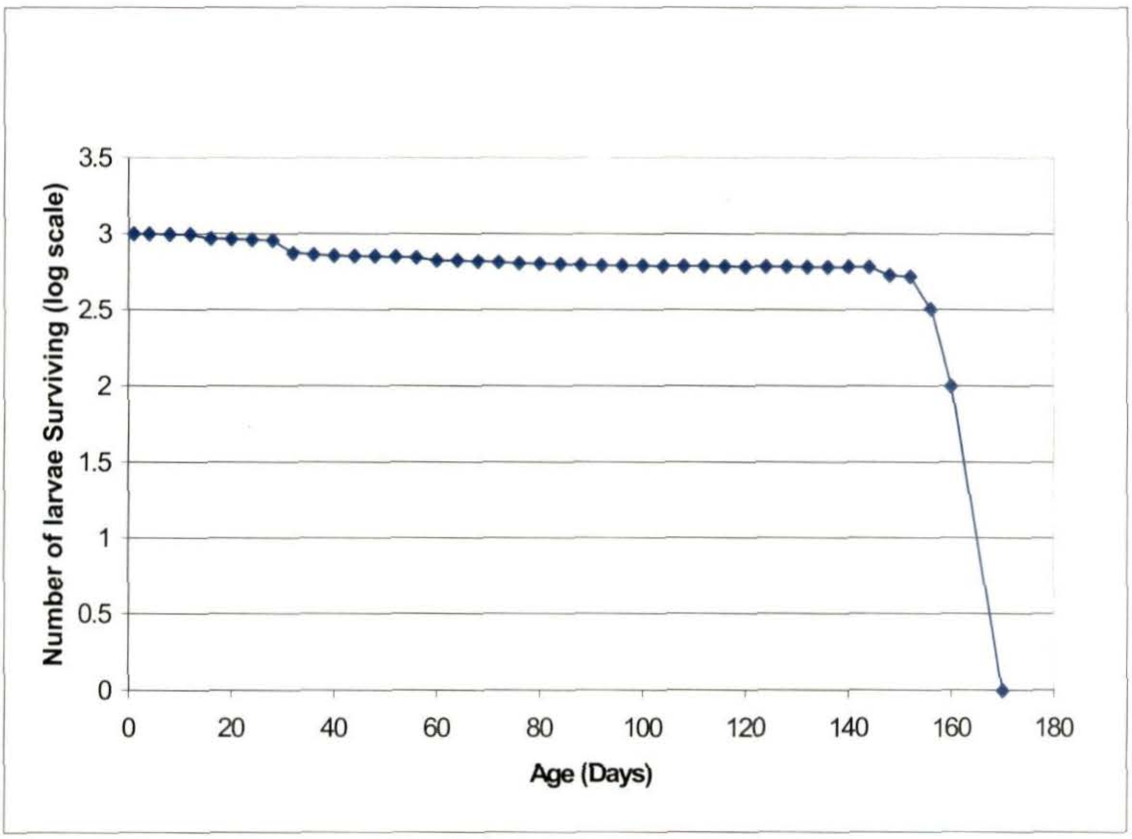
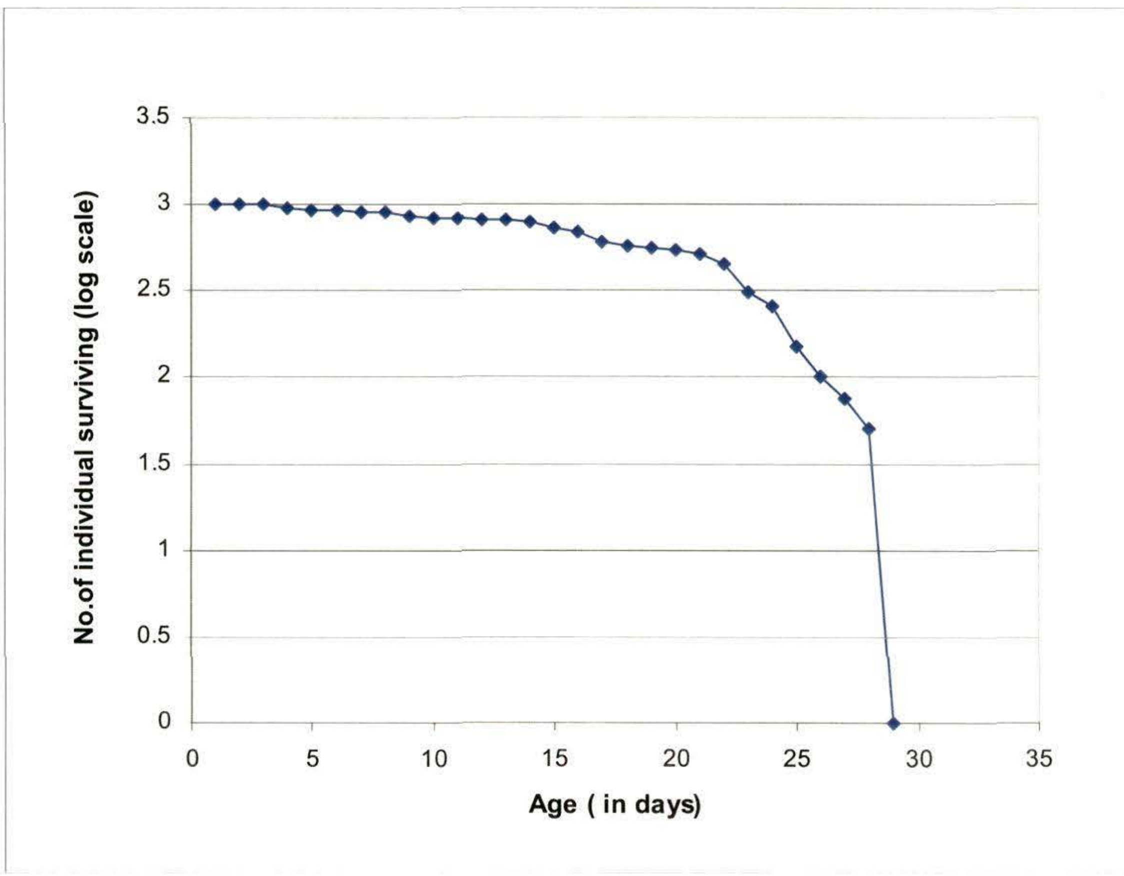


Table: 5b. Survivorship table of *C. chlorina*

X	l_x	d_x	L_X	T_X	e_x	$1000(q_x)$
0	1000.000	0	1000.000	18631.000	18.631	0.000
1	1000.000	2.000	999.000	17631.000	17.631	2.000
2	998.000	0.000	998.000	16632.000	16.665	0.000
3	998.000	48.000	974.000	15634.000	15.665	48.096
4	950.000	20.000	940.000	14660.000	15.432	21.053
5	930.000	12.000	924.000	13720.000	14.753	12.903
6	918.000	9.000	913.500	12796.000	13.939	9.804
7	909.000	11.000	903.500	11882.500	13.072	12.101
8	898.000	48.000	874.000	10979.000	12.226	53.452
9	850.000	10.000	845.000	10105.000	11.888	11.765
10	840.000	15.000	832.500	9260.000	11.024	17.857
11	825.000	6.000	822.000	8427.500	10.215	7.273
12	819.000	14.000	812.000	7605.500	9.286	17.094
13	805.000	20.000	795.000	6793.500	8.439	24.845
14	785.000	64.000	753.000	5998.500	7.641	81.529
15	721.000	32.000	705.000	5245.500	7.275	44.383
16	689.000	79.000	649.500	4540.500	6.590	114.659
17	610.000	35.000	592.500	3891.000	6.379	57.377
18	575.000	14.000	568.000	3298.500	5.737	24.348
19	561.000	11.000	555.500	2730.500	4.867	19.608
20	550.000	40.000	530.000	2175.000	3.955	72.727
21	510.000	60.000	480.000	1645.000	3.225	117.647
22	450.000	140.000	380.000	1165.000	2.589	311.111
23	310.000	55.000	282.500	785.000	2.532	177.419
24	255.000	105.000	202.500	502.500	1.971	411.765
25	150.000	50.000	125.000	300.000	2.000	333.333
26	100.000	25.000	87.500	175.000	1.750	250.000
27	75.000	25.000	62.500	87.500	1.167	333.333
28	50.000	50.000	25.000	25.000	0.500	1000.000

X= age in days, l_x = observed number of larvae surviving at start of X age interval, d_x =number dying during age interval x, L_X = number of individuals alive between ages x and x+1, T_X = individuals x time unit, e_x =expectation of life remaining for individuals of age x, q_x = mortality rate for an age interval.

Fig 6b. Survivorship curve of *C. chlorina*



6.7. Age distribution of *G. chrysolopha* and *C. chlorina*:

Using the information on morphometrics of the larvae, it was possible to analyze the age distribution of the natural population of *G. chrysolopha* and *C. chlorina* in different months of their occurrence. The changing age distribution of individuals, noted every fortnight for *G. chrysolopha,* showed different life stages in different months of their occurrence. It was found that the growing population had more number of younger age class i.e. III instar. As the time advanced and the population stabilized, more number of individuals from IV and V instars were found (Fig 7a). Therefore, it can be expected that the maximum injury (in terms of leaf consumed) done to the tree was by the larvae of the last two instars that dominated in the stable population for a longer time (Feb- April). Age distribution of *C. chlorina* in the present study, showed no clear period of dominance by a particular larval stage, although, in late June and early July, and again in the middle of August, IV instar larvae, were more frequent, showing partial dominance in the population. (Fig.7b).

6.8. Nutritional Indices of larvae of *G. chrysolopha*:

6.8.1. Feeding preference and quality of food consumed by *G. chrysolopha*:

The biochemical analysis of the quality of leaf consumed by *G. chrysolopha,* indicated that the larvae preferably consumed mature and senescent leaves having low percentage of basic nutrients (N: 1.500 ± 0.221, P: 0.055 ± 0.011, K: 0.753 ± 0.239 and C: 2.214 ± 0.389) with low water

Fig.7a. Age Distribution of larvae of *G. chrysolopha* in different months of their occurrence

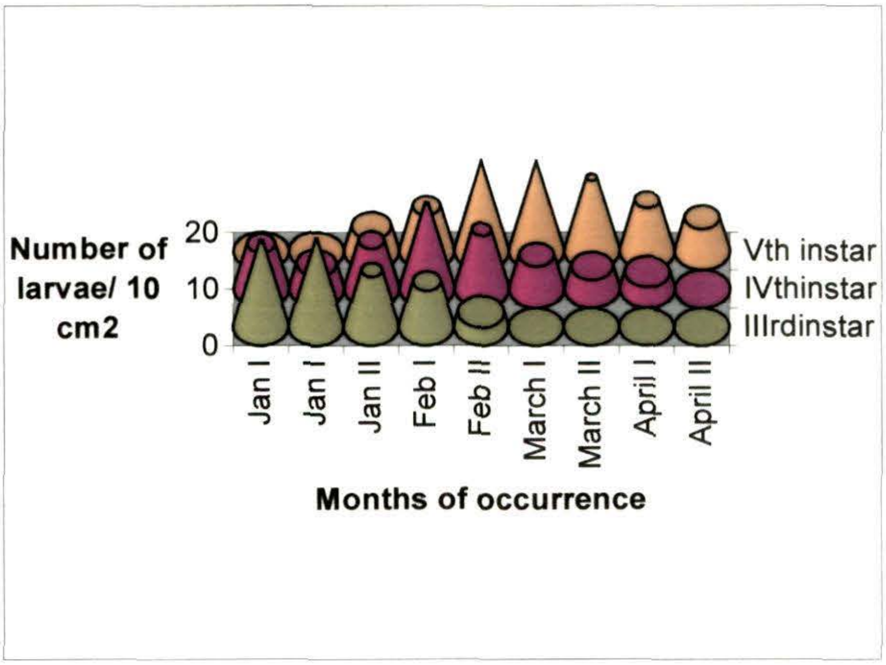
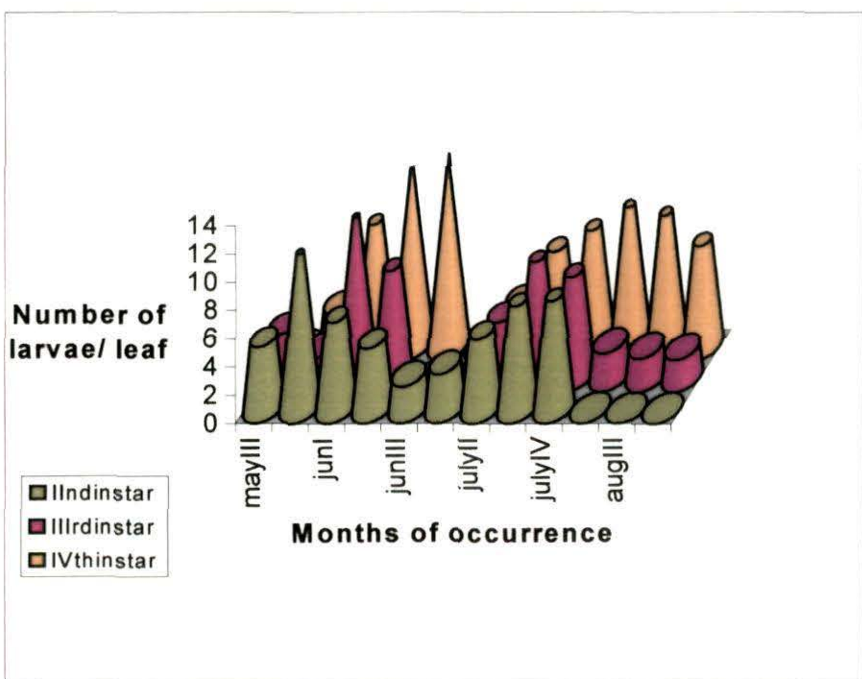


Fig. 7b. Age Distribution of larvae of *C. chlorina* in different months of their occurrence



content (60.5-65.2) % (Table: 6b). The analysis of P & K along with N & C was done with the objective to know its quantity present in the leaves and after the leaf is digested, the quantity present in the frass (faecal urine) as these are the essential components which determine the fertility of the soil (Weis and May, 1989).

6.8.2. Feeding behaviour:

In the field, the late instars larvae (3^{rd}, 4^{th}, 5^{th}) of *G. chrysolopha* showed nocturnal movement (migration) in procession. During the daytime, they rested in webs made by them at the base of the tree and at night they climbed tall trees reaching the canopy for food (foliage). When a larva encountered a leaf that was acceptable for feeding, it generally completely consumed it, starting from the margin leaving only the mid- rib. They fed only at night and returned to the base of the tree with the daybreak. It was observed that when the defoliation was severe, the tree took around two years to recover from the stress. In the laboratory, during the experimental period, most of the larvae were active feeders. In all the three stages, the larvae fed on host leaves from the margins. It was observed that larvae of *G. chrysolopha,* fed on senescent and mature leaves. Maximum feeding (18.845 gm/ larva /stadial period) was observed in the 5^{th} instar. Active feeding period for all the three instars, remained almost the same (Table 6c). Maximum feeding activity for all the three instar larvae was recorded at the middle of each stadial period and the larva stopped feeding before moulting (Fig 8).

Table: 6a. Comparison of basic nutrients (mean ± S.E) in leaves mainly consumed by *G. chrysolopha* and *C. chlorina*

	N (%)	P (%)	K (%)	Organic Carbon (%)
G. chrysolopha	$1.500^{a} \pm 0.221$	$0.055^{a} \pm 0.011$	$0.753^{a} \pm 0.239$	$2.214^{a} \pm 0.389$
C. chlorina	$2.877^{b} \pm 0.437$	$0.073^{b} \pm 0.010$	$1.205^{b} \pm 0.223$	$3.793^{b} \pm 0.308$

Values not followed by the same letter are significantly different ($p < .50$) using student's t test.

Table:6 b. Feeding preference of *G. chrysolopha* for shade tree leaves (*A. nepalensis*) of different maturity in relation to their moisture content

Leaf Type[1]	Mean leaf water content (%)	Mean leaf consumed(g) /day (mean ± S.E) / final instar larva
Type I	$75.151^{a} \pm 2.50$	Rejected
Type II	$72.855^{b} \pm 1.50$	$0.114^{a} \pm .051$
Type III	$70.206^{c} \pm 2.50$	$0.625^{b} \pm .199$
Type IV	$60.505^{d} \pm 3.50$	$0.615^{b} \pm .169$
CD (5%)	2.21	1.92

Means followed by same lower case letters are not significantly different at 5% level

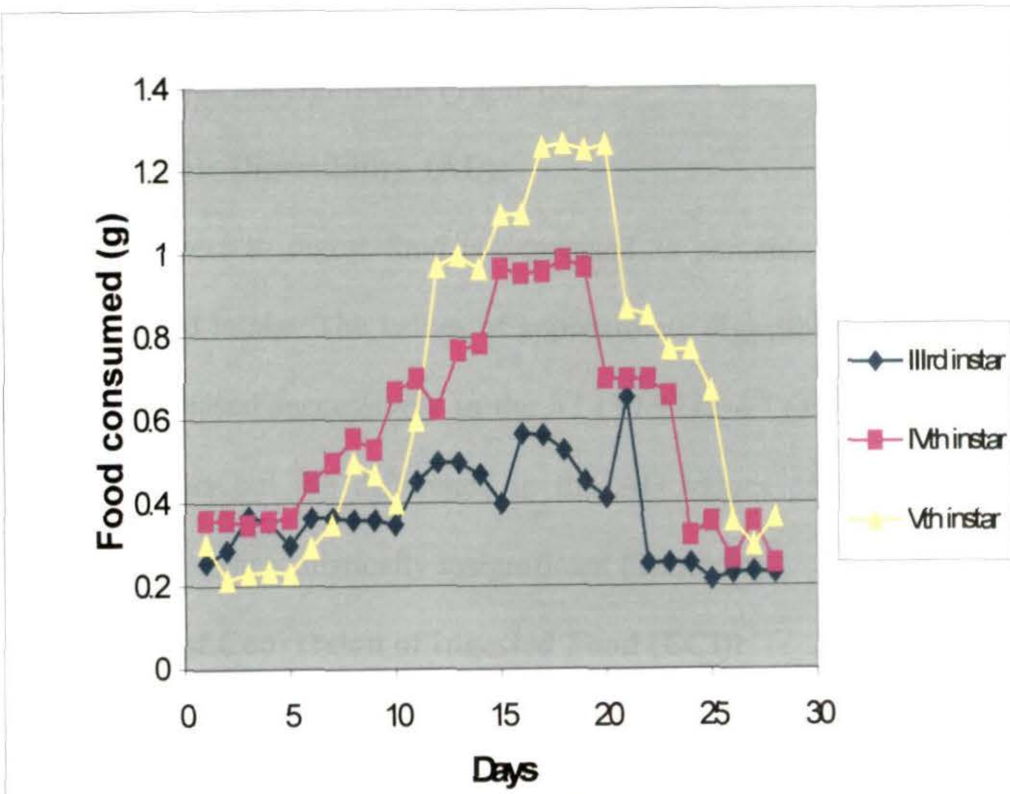
[1] Type I- Tender, Type II- Young, Type III- Mature, Type IV- Senescent

Table 6c. Food consumption (fresh weight), active feeding period and stadium (days) during development of *G. Chrysolopha* on leaves of *A. nepalensis* (Mean ± S.E)

Instar/ Stage	Stadial period	Active feeding period	Food Consumed (g)/ larva
III	$29.578^{a} \pm 3.454$	$25.050^{a} \pm 1.390$	$10.381^{a} \pm 1.024$
IV	$35.238^{b} \pm 3.624$	$25.500^{a} \pm 2.304$	$16.699^{b} \pm 1.262$
V	$34.750^{b} \pm 4.234$	$25.800^{a} \pm 2.409$	$18.845^{c} \pm 1.791$
CD (5%)	2.122	0.969	1.477

Means followed by same lower case letters are not significantly different at 5% level

Fig. 8. Food consumed by three larval stages of *G. chrysolopha* larvae during their stadial period



6.8.3. Consumption Index (CI): Consumption index (CI) indicates the rate of feeding in relation to the weight of the animal in a definite time interval. The data showed that CI value was highest in the 3^{rd} instar and it progressively declined in the 4^{th} and 5^{th} instars. The CI value found in the 3rd instar (1.490) was significantly different from that in the 4^{th} (1.187) and 5^{th} (1.116) instars. However, the difference in the CI values for the 4^{th} & 5^{th} instars, was not significant (Table 6d).

6.8.4. Approximate Digestibility (AD):

Ability of an insect to digest food is expressed as percentage of food digested over food intake. The values of approximate digestibility for *G. chrysolopha,* increased successively in the 3^{rd} (30.977), 4^{th} (33.462) and 5^{th} (34.983) instars but the difference in the AD values of the three instars, was found to be statistically insignificant (Table 6d).

6.8.5. Efficiency of Conversion of Ingested Food (ECI):

The efficiency, with which the ingested food is converted into body mass, is stated as percentage of weight gain over food intake. In this study, it was observed that ECI of the 3^{rd} instar (4.123%) was higher than that of 4^{th} (3.732%) and 5^{th} (2.450%) instars. Significant difference was evident in the ECI values of the 4^{th} and 5^{th} instars, whereas no significant difference was noted between ECI values of the 3^{rd} and the 4^{th} instars (Table 6d).

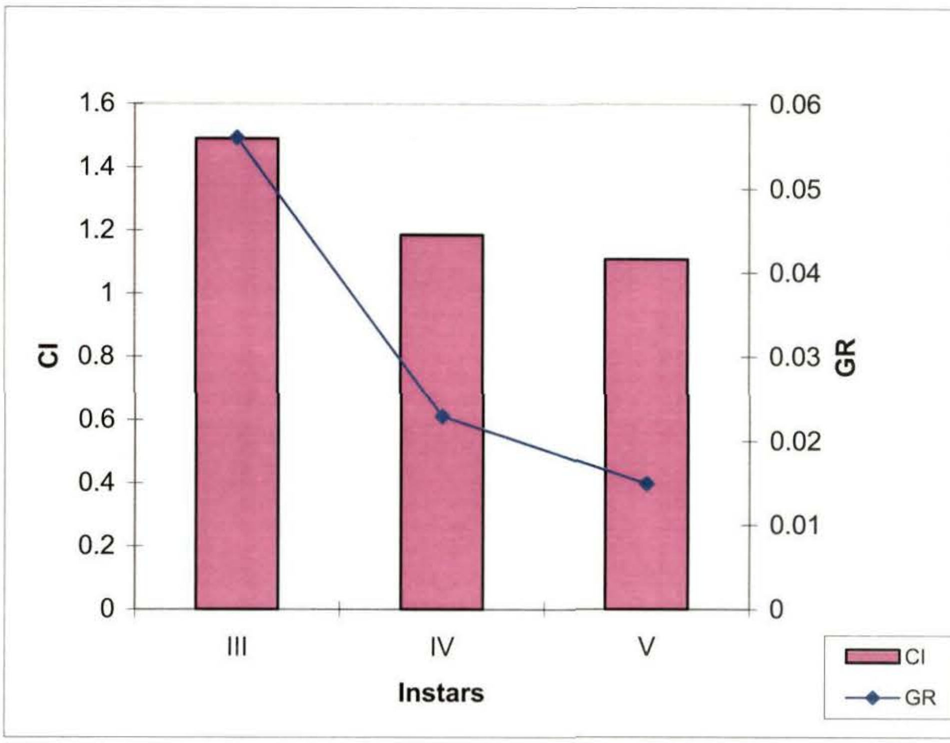
Table-6d. Nutritional & Growth indices of *G. chrysolopha* utilizing shade tree leaves *(A. nepalensis)* as food (Mean ± SE)

Instars	CI	GR	AD (%)	ECI (%)	ECD (%)
III	1.490[a] ± 0.091	0.056[a] ± 0.002	30.977[a] ± 1.342	4.123[a] ± 0.393	7.564[a] ± 0.413
IV	1.187[b] ± 0.068	0.023[b] ± 0.023	33.462[a] ± 2.451	3.732[a] ± 0.211	5.085[b] ± 0.319
V	1.116[b] ± 0.080	0.015[c] ± 0.001	34.983[a] ± 2.048	2.450[b] ± 0 .191	3.612[c] ± 0.220
CD (5%)	0.258	0.000	5.706	0.773	0.997

Means followed by same lower case letters are not significant at 5% level

CI = Consumption Index
GR = Growth Rate
AD = Approximate Digestibility
ECI = Efficiency of conversion of Ingested food
ECD= Efficiency of conversion of Digested food

Fig. 9a. Relation between GR and CI of *G. chrysolopha*



GR =Growth rate

CI = Consumption Index

6.8.6. Efficiency of Conversion of Digested Food (ECD):

The efficiency with which the digested food is converted into body mass, is presented as the percentage of weight gain over food digested. Highest value for it was observed in the 3^{rd} (7.564%) followed by 4^{th} (5.085%) and 5^{th} (3.612%) instars, all with a significant difference. (Table 6d).

6.8.7. Growth Rate (GR):

The growth rate indicates the rate at which digested food is available to the animal and, ultimately, the increase in per gram body weight per day. In the present study, the result of growth rate for *G. chrysolopha* reared on *A. nepalensis,* showed the highest value in the 3^{rd} instar (.056) followed by 4^{th} (.023) and 5^{th}(.015) instars (Table 6d). GR in all the three instars was found significantly different from each other. A positive relationship was observed between consumption index and growth rate (Fig 9a).

6.9. Nutritional Indices of larvae of *C. chlorina*:

6.9.1. Feeding preference and the quality of food consumed by *C. chlorina*:

The biochemical analysis of the quality of leaf consumed by *C. chlorina,* revealed that the larvae preferably consumed new leaves, rich in nutrient percentages (N: 2.877 ± 0.437, P: 0.073 ± 0.010, K: 1.205 ± 0.223 and C: 3.793 ± 0.308) (Table 6a) with high water content (75.15 ± 2.50%) (Table 7a).

Table: 7a.Feeding preference of *C. chlorina* larvae for shade tree leaves (*A. nepalensis*) of different maturity in relation to their moisture content

Leaf Type[2]	Mean leaf water content (%)	Mean leaf consumed/day (g ± S.E) / final instar larva
Type I	$75.457^{a} \pm 2.50$	$0.1045^{a} \pm 0.095$
Type II	$72.650^{b} \pm 1.22$	$0.0999^{b} \pm 0.071$
Type III	$70.055^{c} \pm 1.75$	$0.0499^{c} \pm 0.001$
Type IV	$65.451^{d} \pm 1.42$	Rejected
CD (5%)	2.552	0.000

Means followed by same lower case letters are not significant at 5% level

Table: 7b. Food consumption (fresh weight), active feeding period and stadium (days) during development of *C. chlorina* larvae on leaves of *A. nepalensis* (Mean ± S.E)

Instar/ Stage	Stadial period	Active feeding period	Food Consumed (g)/ larva/ day
II	$3.5^{a} \pm 0.051$	$3.5^{a} \pm 0.051$	$0.309^{a} \pm 0.075$
III	$3.5^{a} \pm 0.047$	$3.5^{a} \pm 0.047$	$0.451^{b} \pm 0.095$
IV	$4.5^{b} \pm 0.1950$	$4.5^{b} \pm 0.507$	$0.514^{c} \pm 0.102$
CD (5%)	0.109	0.110	0.000

Means followed by same lower case letters are not significant at 5% level

[2] Type I- Tender, Type II- Young, Typè III- Mature, Type IV- Senescent

6.9.2. Feeding behaviour:

First instar larvae showed gregarious/aggregate feeding habit. Larvae of the 2nd, 3rd and 4th instars, skeletonized whole leaf leaving only the mid- rib. (Plate 8b). Generally, the feeding was done during daytime. Maximum food (0.514 g/larvae) was consumed by the 4th instar of *C. chlorina.* All the three instars fed throughout the stadial period (Table 7b).

The adult behavior consisted of short feeding periods followed by extensive wandering. Nutritional parameters of the 1st instar larvae could not be studied because they nibbled very little amount of green matter of the leaves.

6.9.3. Consumption Index (CI):

The data obtained in the present study showed that the larvae of *C. chlorina* on *A. nepalensis* had short development time with significantly higher Consumption Index. The CI value was highest (0.935) in the 4th instar as compared to the values of the 3rd and 2nd instars. The values, however, were not significantly different (Table 7c).

6.9.4. Approximate Digestibility (AD):

Highest AD value was recorded in the 2nd instar (72.449%) that gradually declined in the subsequent instars. However, a significant difference was observed among the 3rd and 4th instars.

An overall high AD was observed in all the instars of *C. chlorina* on *A. nepalensis* (Table 7c).

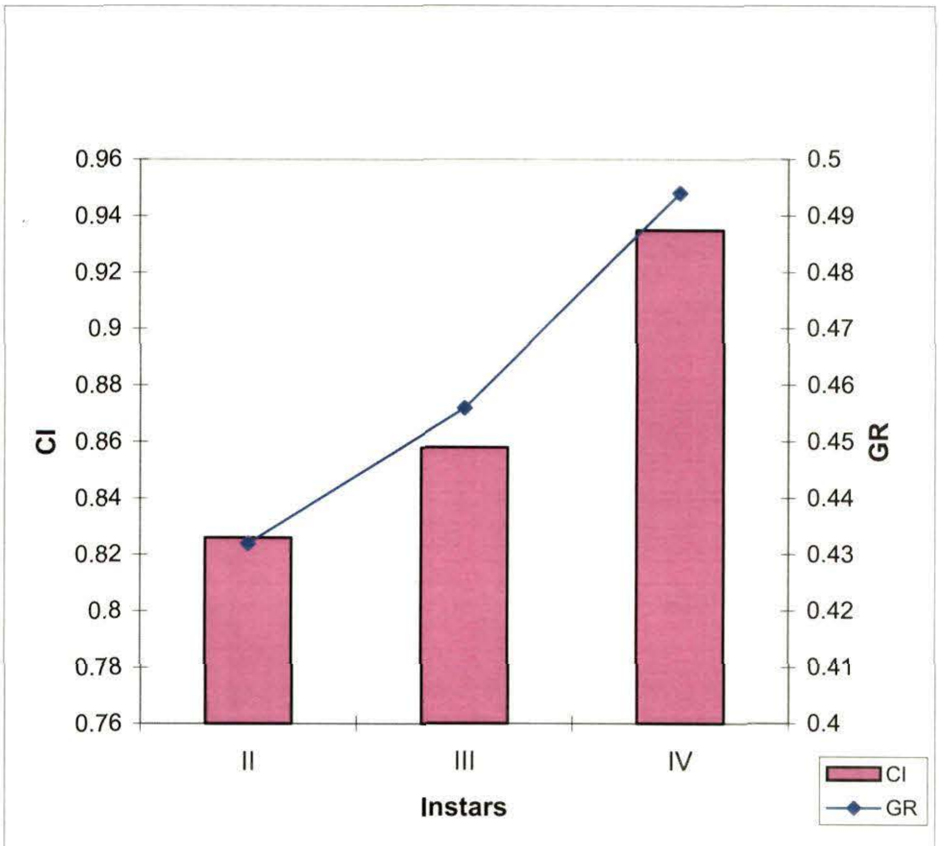
Table-7c. Nutritional & Growth Parameters in relation to food *(A. nepalensis)* utilization by *C. chlorina* (Mean ± SE)

Instars	CI	GR	AD (%)	ECI (%)	ECD (%)
II	0.826[a] ± .015	0.432[a] ± .011	72.449[a] ± 2.046	18.969[a] ± 0.135	38.961[a] ± 0.325
III	0.858[a] ± .028	0.456[a] ± .021	70.318[a] ± 2.141	17.985[b] ± 0.125	38.554[a] ± 0.342
IV	0.935[a] ± .041	0.494[a] ± .065	61.445[b] ± 2.182	17.978[b] ± 0.119	36.998[a] ± 0.314
CD (5%)	0.244	0.157	4.407	0.631	2.853

Means followed by same lower case letters are not significant at 5% level

CI = Consumption Index
GR = Growth Rate
AD = Approximate Digestibility
ECI = Efficiency of conversion of Ingested food
ECD= Efficiency of conversion of Digested food

Fig 9b. Relation between GR and CI of *C. chlorina* on *A. nepalensis*



GR =Growth rate

CI = Consumption Index

6.9.5. Efficiency of Conversion of Ingested Food (ECI):

ECI of *C. chlorina* decreased from the 2^{nd} to the 4^{th} instar. Significant difference was observed in the ECI values of the 2nd and 3^{rd} instar larvae (Table 7c).

6.9.6. Efficiency of Conversion of Digested Food (ECD):

ECD value was found to decrease with the advancing stages. ECD value was highest (38.961%) in the 2^{nd} instar but was not significantly different from that of the 3^{rd} and 4^{th} instars.

6.9.7. Growth Rate (GR):

Highest growth rate (0.494) was recorded in the 4^{th} instar larvae (Table 7c). No significant difference in GR was observed between the instars. A positive relationship was observed between consumption index and growth rate of the larvae (Fig 9b).

6.10. Evaluation of ecological role of the major folivores:

6.10.1. Positive role:

6.10.1.1. Analysis of faecal urine of *G. chrysolopha* and *C. chlorina* (Table 8):

Faecal- urine produced by the folivores usually fell to the soil below the shade tree. Soil mixed with faecal-urine was tested at monthly interval for three consecutive months for both the folivores, *G. chrysolopha* and *C. chlorina.*

It was observed that faecal-urine of both the larvae had very little percentage of nitrogen, phosphorous, potassium and organic carbon that

Table: 8. Comparison of basic fertility component present in faecal urine produced by *G. chrysolopha* and *C. chlorina*

	N (%)	P (%)	K (%)	Organic Carbon (%)
G. chrysolopha	0.00225	traces	.000240	0.0856
C. chlorina	0.0102	traces	.000754	1.0526

No significant difference in the values

Table: 9a. Variation in composition with time of the soil mixed up with the faecal urine of *G. chrysolopha*

Soil Samples	N (%)	P (%)	K (%)	Organic Carbon (%)
Control	0.256± 0.053	traces	traces	0.276± 0.0121
Month I	0.256± 0.053	traces	traces	0.276± 0.0121
Month II	0.295± 0.064	traces	traces	0.296± 0.0104
Month III	0.295± 0.047	traces	traces	0.295± 0.0155

No significant difference in the values in three consecutive months

Table: 9b. Variation in composition with time of the soil mixed up with the faecal urine of *C. chlorina*

Soil Samples	N (%)	P (%)	K (%)	Organic Carbon (%)
Control	0.292± 0.022	traces	traces	0.295± 0.0174
Month I	0.292± 0.022	traces	traces	0.295± 0.0174
Month II	0.301± 0.045	traces	traces	0.354± 0.0158
Month III	0.299 ± 0.095	traces	traces	0.355± 0.0104

No significant difference in the values in three consecutive months could add to soil fertility. Results of this study indicated that the composition of faecal urine being very low in the basic fertility components, were not contributing much as manure.

6.10.1.2. Analysis of soil mixed with faecal urine:

Assessment of the changes in soil fertility with time was done through soil analysis. The result showed very little changes in the fertility components (N.P, K and organic C) of the soil during the three months of observation. So, the basic fertility property of the soil remained unchanged (Table 9a and 9b). It can be inferred that faecal -urine of both the pests that dropped to the soil at the foot of the shade tree (*A. nepalensis*), did not contribute any organic fertility to the top soil, despite decomposition within the span of 3 months.

6.10.2. Negative role:

6.10.2.1. Estimation of the extent of injury done to the leaves by the major folivores:

The observations made to assess the extent of injury done to the leaves by the larvae of *G. chrysolopha* and *C. chlorina* showed that in all the three years, percentage of injury done to the leaf, by and large, remained similar. In general, the larvae of *G. chrysolopha* caused more injury to *A. nepalensis* than the larvae of *C. chlorina,* by consuming greater amount of leaves in terms of leaf area (Table 10a).

Table: 10a. Leaf area consumed (in %) by final instar larvae of *G. chrysolopha* and *C. chlorina* (n=10)

Years	Leaf area consumed (Mean ± S.E) /larva/day
G. chrysolopha	16.565[a] ± 0.185
C. chlorina	7.987[b] ± 0.095 *

* significant at $p < .05$ (student's t test)

Table: 10b. Efficiency of Growth and Food Utilization by *C. chlorina* on *Alnus nepalensis* (A) and *Amomum subulatum* (B)

Instars	CI	GR	AD (%)	ECI (%)	ECD (%)
			A		
III	0.826 ± .015	0.432 ± 0.011	72.449 ± 2.046	18.969 ± 0.135	38.961± 0.325
IV	0.858 ± .028	0.456 ± 0.021	70.318 ± 2.141	17.985 ± 0.125	38.554 ± 0.342
V	0.935 ± .041	0.494 ± 0.065	61.445 ± 2.182	17.978 ± 0.119	36.998 ± 0.314
			B		
III	0.795 ± .057	0.404 ± 0.002	70.535 ± 2.534	18.013 ± 0.247	38.564 ± 0.227
IV	0.729 ± .084	0.394 ± 0.001	65.235 ± 3.228	17.32 ± 0.241	35.355 ± 0.334
V	0.726 ± .098	0.384 ± 0.023	63.654 ± 2.156	16.245± 0.223	33.162 ± 0.292

6.10.2.2. Estimation of injury potential of *C. chlorina* utilizing cardamom leaves as alternate food:

As mentioned earlier, out of the two major folivores (*G. chrysolopha* and *C. chlorina)*, *C. chlorina* inflicted injuries to the leaves of cardamom plants also. Therefore, to assess the direct injury potential of *C. chlorina,* nutrition indices of the pest were calculated when it fed on cardamom leaves. The consumption and conversion values indicated that this pest could utilize both its host leaves with almost equal efficiency (Table 10b). The result obtained here suggested that *C. chlorina*, due to its polyphagous habit, could cause substantial injury to the cardamom leaves also. Such direct crop injury besides the injury caused to the shade tree leaves, establishes the negative role of *C. chlorina* in the cardamom agroforestry system.

7. Discussion

Sikkim, the northeastern hilly state of India having 83% of the geographical area as forest land, is one of the most important areas of plant diversity and richness. *Alnus nepalensis* is considered to be an important tree of the state and is a nature's endowment to it. Entomofauna associated with this tree showed not only richness at species level but also a fair representation of a large number of families under different orders through various seasons of the year. A few species were found common to both *Amomum subulatum* and its shade tree *A. nepalensis*, in the large cardamom agro forestry.

7.1. Entomofauna associated with *Alnus nepalensis*:

Host plant–insect relationship in a particular geographic area is a very complex interplay of biotic and abiotic factors. Most of the insects utilize the host tree as their nutrient source (Schopf and Hartl, 1997). Information available to quantify the relationship of *A. nepalensis* ('Utis' in local parlance) with its dependent entomofauna, especially from this region, is insufficient. Nevertheless, Pangtey and Thakur (1986) have mentioned about a few coleopteran and lepidopteran associations with the 'Utis' tree from Sikkim.

The present survey on the insect association with *A. nepalensis* revealed that the tree was exploited throughout the year, by various insect groups (Plate 9, in Annexure). Some reports of insect association with *A.*

nepalensis belonging to different orders are mainly available from Nepal (Quednau, 1973; Sabatinelli and Migliaccio, 1982; Moestrup, 1985; Mulder, 1983; Das and Raychaudhuri, 1983; Sharpe, 1983; Quednau and Chakrabarti, 1980 and Peter, 1990).

Three years observations, in the present study, showed a greater occurrence of the coleopterans followed by lepidopterans, homopterans, hemipterans, hymenopterans, orthopterans, neuropterans, thysanopterans and dipterans at both the altitudes, Pangthang (2160m amsl) and Kabi (1630m amsl). Almost similar trend of occurrence was observed for insect pests of forest trees from Pakistan, where 86% were coleopterans, 5.6% were lepidopterans, while 8.4 % were hymenopteran parasites (Rehman, 1993).

Trees of high altitudes and of low elevations encounter different growth conditions resulting in their suitability as host for different herbivorous insects (Erelli *et al.*, 1998). Host plant suitability at a particular elevation, influence community composition of herbivores (Erelli *et al.*, 1998), possibly more favourable to one community than other. *A. nepalensis,* a high elevation tree, influences dominance of coleopteran as compared to the other associated insect orders. This could be a good example of selection of particular community at high elevation.

The study on the seasonal occurrence of these insects revealed that their maximum occurrence was during spring followed by summer and winter seasons, with the major exception of defoliator *Gazalina chrysolopha* (Lepidoptera: Notodontidae), which appeared to be especially adapted for winter conditions.

Greater morphological complexities of host plant might offer greater diversity for potential pest niche (Strong and Levin, 1979). Different parts of the plant and the same plant parts under different conditions during different seasons, vary in biochemical compositions (Panda and Khush, 1995). Therefore, the seasonal changes in host plant can be a decisive factor in getting the insects of different guilds to utilize the tree. Lawton and Schroeder (1977) first showed the relationship between the structural diversity of the plant and the richness of their insect fauna. *A. nepalensis* is a semi deciduous tree, which is expected to have changes in its physical and biochemical profile with changing seasons. The biochemical composition and nutrient dynamics of *A. nepalensis* differ with seasonal changes and age stand (Sharma *et al.*, 2002). As a consequence, the tree (*A. nepalensis)* harbours different insect guilds during different seasons.

In spring season, with the sprouting of the fresh leaves, great number of plant chewers with their associated natural enemies, were found in abundance. This observation was similar to the one reported by Pangtey and Thakur (1986) and Phaloura and Singh (1991, 1992). They reported a few coccinellides and chrysomelid beetles to defoliate the young shoots of the 'Utis' (*A. nepalensis)* tree in the spring season. Herbivory in temperate forests is typically concentrated in the spring season, during leaf expansion (Fenny 1970, Hunter 1987) and most of the defoliation events are usually associated with young foliage (Coley and Aide, 1991 and Hunter, 1993). Generally, larval stages of many foliage chewers occur when leaf tissue is young and relatively nutrient-rich (Tabashinik and Slansky, 1987 and Mattson and Scriber, 1987). Fresh fronds in the spring season, on *Alnus* tree, are rich in their basic nutrients and therefore may invite greater number of insects in springtime. Similar example of maximum defoliation in spring season has been reported on *Quercus robur* (Oak tree) in Europe where, 95% of the total defoliation by insects took place in spring season with the bud burst of the tree (Hunter, 1993). Such an attack in the budding season may result in a general reduction in future performance of the tree unless it is able to compensate.

During the summer months, occurrence of lepidopterans and hemipterans increased on *A. nepalensis*. Thakur (1982) reported similar incidence on *Amomum subulatum,* with some of these insects commonly occurring on both host plants.

In winter months, insects generally occurred in less proportion. During this period, only sap feeders (homopterans) with few lepidopterans, coleopterans and orthopterans were found. In winter, *A. nepalensis* mostly had senescent leaves with less percentage of water content that could hardly be utilized by mandibulate herbivores; however the haustellate herbivores, which principally feed on sap of the plant, were able to utilize the tree to some extent during this time. Therefore, greater occurrence of homopterans population observed in winter months, on *A. nepalensis,* could be explained. A few species of lepidopterans, coleopterans and orthopterans that occurred in winter months, appeared to be especially adapted. High quantity of tannin may act as a good chemical defense against herbivores (Fenny 1976, Bernays, 1981). So, plants with high percentage of tannins are avoided by most feeders. In *A. nepalensis,* total soluble polyphenolics (including tannins), in senescent leaves is found high in dry weather (winter months) (Sharma *et al.*, 1997), as such, fewer occurrences of insect species during winter months on the tree are expected. In an agroforestry system, like that of *Alnus*- cardamom, the present finding may be helpful to take adequate measures in advance to check the defoliation of the shade tree by the insects in different seasons, so that an uninterrupted shade to the large cardamom plants is maintained.

7.2. Insect common to large cardamom plant and *Alnus nepalensis:*

For an insect, the host plant is not merely something to feed on but also something to live on (Kennedy, 1953). Thirteen insect species common to *Alnus* and cardamom in the present study, were also reported by Pangtey and Thakur (1986) on the cardamom plant. In an agroforestry system, alternate host plants are particularly important, where the cropping season is short and is followed by cold and dry season of fallow systems (Van Emden, 1981). Oligophagous and polyphagous species create potential for frequent host shifts (Strong *et al.*, 1977), possibly to fulfill their nutritional requirements. The insects common to large cardamom plant and *Alnus* tree, may be examples of 'host shift', or, cases of using alternative hosts. Many instances have been cited where insects were found to make a 'host shift' to compensate their unfulfilled nutritional needs or survive on a refuge/alternative host as a residual population. The present observation on insect-*Alnus*- cardamom relation may be one of the above situations and may be of some help in future management practices of "Utis" tree in large cardamom agroforestry.

7.3. Incidence of major folivores:

Objective of such a study was intended to know the period of occurrence of the major folivores on *A. nepalensis* that caused significant injury to the tree in different seasons.

Outbreak of *Gazalina chrysolopha* was reported in winter months of 1982, defoliating heavily the entire shade tree plantations and thus substantially reducing their shading effect to the large cardamom plantations (Pangtey and Thakur, 1986). As the tree recovered with new leaves in spring, a chrysomelid beetle, *Chrysomela chlorina* skeletonized them and created a crisis in terms of shade availability for the large cardamom (Pangtey and Thakur, 1986). In subsequent years, severe defoliation of *A.*

nepalensis by *C. chlorina,* from Garhwal (U.P) and Sikkim hills had also been reported by Phaloura and Singh (1992).

In the present study, during the three years of survey work and observation, similar attack and defoliation by *G. chrysolopha* and *C. chlorina* were observed, thus confirming these species as major defoliators of the shade tree for cardamom plantations from both the altitudes (Pangthang and Kabi) of Sikkim.

7.3.1. Incidence of *Gazalina chrysolopha:*

Incidence of the caterpillars of *G. chrysolopha* in Sikkim was recorded from November to May. A similar incidence of this species defoliating Oak tree in Jammu and Kashmir was observed by Rehman and Chaudhry, (1992). However, in eastern and central Bhutan, their incidence on *A. nepalensis,* was reported in April (Raman, 1998). This difference in the time of their occurrence could be due to the topographic and climatic conditions of Bhutan hills, which is located further east to Sikkim slopes, being different.

7.3.2. Incidence of *Chrysomela chlorina:*

Incidence of *C. chlorina* started in the month of May and continued till September. This finding was similar to that reported from Sikkim (Pangtey and Thakur, 1986) and Garhwal hills (Phaloura and Singh, 1992).

The information about the onset and level of incidence of both the folivores may help to control these insects at their initial stages and will be particularly important as the early instars of both the folivores do not cause much injury to the plants (as revealed in the present study).

7.4. Population changes of major folivores and their relation with weather parameters:

7.4.1. Population of *G. chrysolopha:*

The population of *G. chrysolopha* showed some variations during the three years of study. An exceptionally high population, in epidemic proportion, of *G. chrysolopha,* was observed in the year 2000, which was more pronounced at the peak population period. Population in the peak period (February to March) in this year, was nearly double than that in the years 2001 and 2002. A questionnaire- based survey and direct observation of the plantations did not reveal any change in the management practices (such as pruning/ planting of any new trees) by farmers in and around the areas of the *Alnus-* cardamom agroforestry, which could have possibly contributed to the anomalous population surge of this insect. Large cardamom based agroforestry is almost a self-sufficient system. Management of cardamom agroforestry with a rotation cycle of twenty years for both shade trees and cardamom is suggested for maintaining and increasing the yield (Sharma *et al.*, 2000). Therefore farmers usually do not intervene with the *Alnus*-cardamom agroforestry system in general. So occurrence of this anomalous population in the year 2000, may be due to some "Phenological reasons" such as synchrony between flushing time of the tree and the insect population growth phase which may be critical for better survival of the insects and the population outbreak. Similar case histories are evident in other forest lepidopterans (Embree, 1968; Wint, 1983; Hunter, 1993; Hunter and Elkinton, 2000 and Klemola *et al.*, 2003). Soma lepidopterans are known to exhibit long cycles of outbreaks with periods of 10 to 20 years due to different climatic and abiotic reasons (Price, 1997 and Koltunov and Andreeva, 1999). The population levels of insects may also fluctuate widely with long periods of low density and then a rapid increase to epidemic levels followed by sudden declines, such cases have been cited by Martineau (1984), Rose and Lindquist (1997). An epidemic level increase in population of *G. chrysolopha,* as observed in year 2000, was also reported in year 1982 (Pangtey and Thakuk, 1986) with sudden decline in successive years. Therefore, the reason of anomalous population increase of *G. chrysolopha* may be attributed either to the plant-phenology hypothesis or to a genetic program of the insect system, because no exceptional climatic influence appeared to have effected the population surge. However a long term study is required to give any convincing explanation to substantiate this anomalous incidence of the population.

7.4.1.1. Effect of abiotic factors on the population of *G. chrysolopha*:

In all the three years, i.e., 2000, 2001 and 2002, the maximum and minimum temperatures played a crucial role in regulating the population changes. A negatively significant correlation between the maximum and minimum temperature and the pest population was observed in all the three years. It was observed that the population declined with the rise in temperature (16 ^{0}C and above) indicating that these caterpillars had better survival and incidence at low temperatures. Every insect species optimally survives in a particular range of temperature and humidity and the tolerance level varies from species to species (Southwood, 1972). The threshold levels of thermal tolerance of certain insects have already been documented by a number of researches (Price, 1975; Nayar *et al.*, 1976; Varley *et al.*, 1980). Thriving in cold conditions has also been reported in case of gypsy moth, *Lymantria dispa*, a serious defoliator of oak tree in North America. In these lepidopterans it was observed that the starvation rate leading to death of these insects, increased fairly with the temperature above 10 ^{o} C (Speight *et al.*, 1999). A low temperature (2^{0}C) threshold was found suitable for development of the winter moth eggs and larvae (Miller and Cronhardt, 1982). Lyamtsev *et al.* (2000) observed that temperature was one of the major factors affecting the population dynamics of *L. dispar*. The caterpillars of *G. chrysolopha* also appeared to be better adapted to colder climatic conditions and their incidence was largely guided by the temperature changes.

Climate induced changes have fundamental consequences for the population dynamics (Wint, 1983). Development of insects proceeds by 'accumulating' day degrees. However, there is a base temperature below which accumulation does not take place (Hunter, 1993). Faster development process with rise in temperature for the lepidopteran living in winter conditions has been reported for the winter moth, *Operophtera brumata.* The eggs of *O. brumata* hatched more rapidly than normal with the rise in temperature (3^0 C above the normally required temperature) (Buse and Good, 1996). An overall faster development in the life cycle of winter moth due to rise in temperature, was also observed by Kimberling and Miller (1998). Therefore, decrease in population density of *G. chrysolopha* larvae with rise in temperature, can be related to a faster development of this univoltine species, which entered pupation and the larval population declined, as have been observed in above-mentioned cases. The negative correlation of the pest population with temperature observed in the present study further supports the above conclusion.

7.4.1.2. Natural enemies as mortality factor:

Among other factors responsible for decline of a pest population is its natural enemies. Predation has been widely viewed as a primary means of controlling prey population density (Ananthakrishnan, 1992). Predatory attack was observed on all stages of *G. chrysolopha* but the maximum attack by its natural enemies was observed on its larval stages. In the fields, the eggs of *G. chrysolopha* were predated mainly by lacewings and ants. Initial population collapse due to the egg predation by ants has also been noticed for *L. dispar* (Brown and Cameron, 1982, Villemant and Fravel, 1991,1992, Ramzi, 1991 and Villemant and Ramzi, 1995). In the field, a tachinid fly was found as the primary parasitoid of the larval population of *G. chrysolopha*. Similar example was that of a tachinid fly controlling the pest population of the winter moth (Embree, 1965, Roland, 1986) and of gypsy moth (Hoch *et al.*, 1999).

Therefore, it can be inferred that gradual rise in temperature, onset of rains and accompanying activity of the parasites and predators, might be collectively responsible for decline of population of *G. chrysolopha*.

7.4.2. Population of *C. chlorina*:

The population of *C. chlorina* showed two peaks each year during all the three years of observation at both the altitudes. *C. chlorina* also fed on the large cardamom where it occurred a little late; following its appearance on *A. nepalensis* (Pangtey and Thakur, 1986). The second peak in the population might be due to host shift from large cardamom crop to *Alnus* tree in the agroforestry system. Two peaks observed in the population of *C. chlorina* can also be a result of two different generations commonly found among the chrysomelid coleopterans (Hazarika *et al.* 1998).

The population abundance of *C. chlorina* showed variations from year to year during the three year of study. Population of *C. chlorina* was somewhat higher in the year 2000 as compared to 2001 and 2002. Such a situation of population fluctuation may be explained based on some other assumptions as is applicable for species that are tolerant to most environmental factors and as such their continuous population build-up may result in fluctuations of great magnitudes (Saxena, 1992).

7.4.2.1. Effect of abiotic factors on the population of *C. chlorina*:

Rainfall and cloud cover had significant positive correlation with the pest population of *C. chlorina* in all the three years. Seasonal rainfalls influence flushing of host plants, which in turn, provides food for the herbivores, and directly or indirectly influence the insect population (Wellington *et al.*, 1999). The incidence of *C. chlorina* coincided with the onset of rain in Sikkim. The shade tree, *A. nepalensis,* has its new flushes with onset of spring that continues till the rainy season providing abundance of food to larvae, resulting in build up of population of *C. chlorina.* So a positive correlation of population rise and the rainfall is evident. Cloud cover and rainfall are related. Therefore, a positive relation of cloud cover with the insect population observed in this study could be well understood.

7.4.2.2 Natural enemies as mortality factor:

All the stages of *C. chlorina* were attacked mainly, by coccinellid predators, leading to partial control of the folivore population. The most common among the coccinellid predators was *Aiolocaria hexaspilota,* whose incidence and the life cycle matched with that of its the prey, *C. chlorina.* This observation is corroborated by the finding of Phaloura and Singh (1992). Two more coccinellids, *Harmonia eucharis* and *H. sedecimnotata,* were found to be occasional predators in the present study, although, about a decade ago, Phaloura and Singh (1992) had reported them to be among the major predators of the larval stages of *C. chlorina.* So it appeared that the importance of predator species have changed with time.

The data available in the present study would help to improve our understanding of the population changes of both the folivores and would enable us to know about the amount of injury that would be inflicted on the large cardamom shade tree (foliage) during different seasons of the year, in the prevailing agroforestry system.

Moreover, the utilization of the shade tree by the two major folivorous insect species at two extreme weather conditions, winter and rainy summers, reflects special adaptive strategies of these herbivores to exploit the shade tree resource, almost round the year to the maximum. The findings shall be of interest to an insect eco- physiologist as well as to a pest- management strategist.

7.5. Biology of Major folivores on *A. nepalensis*:

7.5.1. Biology of *G. chrysolopha*:

There is very little work done on the biology of *G. chrysolopha,* specially, on its larval development period, morphometrics, life cycle and nutritional indices. Pangtey and Thakur (1986) had reported the wing expanse of adult moth of *G. chrysolopha* to be 45.0-52.5 mm. But, during observations made in the present study, wing expanse of the female and male moth measured 36.50mm and 36.00 mm respectively. This difference may be due to the changed environmental conditions over these years. Females of *G. chrysolopha* were found to possess hair in anal tuft with which they covered their egg masses. Similar observations were also made by Rothschild *et al.* (1970) for *Gazalina* and other notodontid species.

The larval developmental period of *G. chrysolopha* in the present study was found to be very long i.e. 165.50 days, which is similar to one reported by Rehman and Chaudhry (1992) from Pakistan. It has been observed that factors such as temperature and quality of food available, affect the duration of the insect's life cycle patterns which are otherwise species specific (Muthukrishnan and Pandian, 1987). Slow growth and extended development are the consequences of an insect's inability to adequately compensate for poorer food quality (Slansky, 1993), especially N (nitrogen) which an insect consumes (Scriber and Slansky, 1981 and Ohmart *et al.*, 1985). The food consumed by the caterpillars of *G. chrysolopha* was found to be low in basic nutrients (N, P, K and C). So, it may be assumed that long development period of *G. chrysolopha* can be a strategy to compensate for sub-optimal food (senescent leaves) it consumed. Similar cases were known for other insects which when fed on poor quality of food, had prolonged their life cycles, such as, the gypsy moth (Cambini and Magnoler, 1999) and the forest tent caterpillar (Hemming and Lindroth, 2000).

In the present study, a low fecundity of female of *G. chrysolopha* was observed when compared to the other forest lepidopteran like the gypsy and winter moths. Growth and fecundity of insect herbivores are largely dictated by the chemical composition and nutritive contents of the plant foliage (Ruuhola *et al.*, 2001). Quality and the age of the host plant leaves consumed, significantly affects the number of instars, frass production, head capsule-size, pupal weights, and fecundity of an insect (Cambini and Magnoler, 1999). Lower fecundity of the female of *G. chrysolopha,* observed in this case, might be attributed to poor food quality that its larvae consumed. A similar result of lower fecundity was observed in *L. dispar* when they were fed on older leaves with low nutrients (Cambini and Magnoler, 1999).

Studies on measurements of width of head capsule of *G. chrysolopha* larvae showed a regular geometrical progression. The growth of head width of *G. chrysolopha* was observed to fall into five groups each indicating an instar. The present observations on the growth of the stages of the caterpillars are consistent with Dyar's rule (1890).

7.5.2. Biology of *C. chlorina:*

The larval period of *C. chlorina* is completed within 16 to 17 days and the whole life cycle within 30 to 35 days. Short development period of larvae of *C. chlorina* was similar to its congener *C. scripta* using *Populus* tree as host (Burkot and Benjamin, 1979 and Harrel *et al.*, 1982). Fast development of *C. chlorina*, besides being the life cycle strategy of the species, can also be attributed to the quality of foliage they feed on. Insects perform well and grow faster on their preferred food (Barbosa and Capinera, 1977) having higher N concentration (Mc Neil and Southwood, 1979 and Mattson, 1980). *C. chlorina* fed on tender and young leaves of *A. nepalensis* which were high in N concentration and as a consequence, all its larval stages showed a faster growth with a shorter development period, completing its life- cycle in about a month.

Morphometrics of the head capsule of four instars of *C. chlorina* followed a geometric progression. In general, the head capsule measurements of *C. chlorina* obeyed Dyar's law (1890).

These morphometric studies may be of great importance in applied research while determining the age distribution in an insect population. The integrated methods based on age distribution of population are most appropriate for field based "Life-table" studies of insects having overlapping generations (Southwood, 1972). In the present context, the morphometric data has been applied to find the age distribution of the natural population of the defoliators in question.

7.6. Age distribution of *G. chrysolopha* and *C. chlorina*:

Age distribution of natural population of *G. chrysolopha*, in the present study, in different months of their occurrence, showed the dominance i.e. prolonged existence and appearency of last two instars for longer period of time with increased food consumption. Therefore, it can be expected that the maximum injury to the tree, *A. nepalensis* is caused by the last two instars of *G. chrysolopha*.

Age distribution of *C. chlorina* during period of its occurrence, showed no fix pattern of dominance of any particular larval stage at a particular point of time, although, the count of the IV instar was the highest at least twice (June- July and mid August). This changing age distribution in the natural population may be due to overlapping generations of *C. chlorina* found in the field. Therefore, it can be inferred that no single larval stage predominantly caused injury to the foliage of *A. nepalensis*. The control measures should, therefore, be taken in advance to check the foliar injury by these insects, as is apparent from the age distribution information.

7.7. Survivorship of *G. chrysolopha* and *C. chlorina:*

Survivorship table, is a convenient format for describing mortality schedule of a population. Such a table is age specific summary of the mortality rate operating in it (Krebs, 1978). From the basic figures of this table, a survivorship curves can be drawn which gives the same summary at a glance. Survivorship study of *G. chrysolopha* and *C. chlorina* was carried out in the laboratory where death due to the attack of any of the natural enemies was negligible. Study of life expectancy of the insects in the laboratory has been carried out by earlier workers (Birch, 1948, 1953a,b; Leslie and Park, 1949; Howe, 1953). The survivorship curves of *G.*

chrysolopha and *C. chlorina,* drawn as suggested by Pearl (1928), stood between Type I and Type II curves in the present study.

According to Pearl (1928), when population mortality rate is low until near the end of life span, it is described as Type I or convex type curve. Diagonal survivorship curve, Type II, implies a constant rate of mortality independent of age and Type III or concave curve indicates high loss in early life followed by a period of much lower and relatively constant loss. The survivorship curves of *G. chrysolopha* and *C. chlorina* indicated that there was a low and constant rate of mortality in both the insects, independent of age almost till pupation. In the present study, a constant death (d_x) rate was observed for both the insect species, each feeding on a different quality of leaf (Young/ senescent). Herbivorous insects attune their digestive system to the food they have been previously exposed (Muthukrishnan and Pandian, 1987). In spite of prolonged larval period of *G. chrysolopha,* a relatively low mortality possibly implies that some sort of compensatory mechanism is operative in these larvae to make up for the poor food quality which is not drastically affecting their survivorship.

Immature insects are particularly vulnerable to desiccation during moultings (ecdysis). It was observed that in both the insect species, maximum death occurred during moulting, possibly due to desiccation. This may be one of the reasons of more or less constant death rate in both the insect species.

Conversely, a high survival of both the folivorous species on *A. nepalensis,* established the latter as a suitable host. Krebs (1978) stated that Type I and II curves are ideal for large number of species and, by and large, all the survivorship studies fall between these two curves. The same author further indicated that man in developed nations, tends to have Type I survivorship curve which can be analogized with the survivorship of herbivore insects on nutritionally rich and suitable host. Although the survival performance of *G. chrysolopha* and *C. chlorina* did not conform exactly to Type I curve yet high egg hatchability and reasonably fair viability of the developmental stages, beyond doubt, establishes *A. nepalensis* to be one of their suitable hosts. A longer feeding and development period might have allowed *G. chrysolopha* larvae to make up for the nutritionally poor leaf quality.

7.8. Nutritional ecology of major folivores on *A. nepalensis*:

The consumption and utilization of food by the insects are dynamic processes that exhibit compensatory responses to the changes in the dietary quality.

The information acquired from this study on nutritional indices, will be of help in understanding the trophic strategy of *G. chrysolopha* and *C. chlorina* and the quantum of depredation of the shade tree leaves, resulting from attack of these pests. Further the knowledge of their nutritional ecology and physiology can be utilized, in future, in designing their laboratory/

insectory based mass culture on natural/ semi synthetic/ artificial diets. Such large-scale culture of the pest species is often helpful in planning its control strategy under integrated pest management programmes.

7.8.1. Nutritional ecology of *G. chrysolopha:*

7.8.1.1. Feeding preference and behavior:

Phytophagous insects can be highly selective about the plants they consume. The plant species and plant parts they identify as food may vary between insect species. In the present study, caterpillars of *G. chrysolopha* feeding on *A. nepalensis* showed feeding preference for mature leaves, which are low in water and nutrients. The season when these caterpillars climb up the tree for leaf- feeding, the leaves of *A. nepalensis* are generally senescent. Phytophagous insects have evolved mechanism to overcome multiple hurdles posed by host plants (Panda and Khush, 1995). Insect's natural physiological feedback mechanisms and environmental factors enable them to adapt to changing situations and nutritional hurdles (Slansky and Rodriguez, 1987). *G. chrysolopha* showing a preference for mature and old foliage, seemed to have adapted itself for a continuous nutritional hurdle, encountered in the form of nutritionally poor leaves, which the tree had offered to them over the years during colder seasons. Moreover, some insect herbivores prefer mature foliage (Cates, 1980) and *G. chrysolopha* appears to be one of these types.

G. chrysolopha showed a trend of maximum leaf-feeding at the middle of each stadial period. The larvae of *G. chrysolopha* did not feed for a considerable period before and after the process of ecdysis. Pre and post moulting fasts, lasting for a definite duration, has also been observed in 'tasar' silk moth larva *Antheria mylitta* (Mohanty & Mittra, 1991). This period may be required for the formation of peritropic membrane of the gut (where found) as well as to overcome the stress imposed by the process of moulting (Muthukrishnan and Pandian, 1987).

7.8.1.2. Food consumption:

Studies on food consumption and utilization of *G. chrysolopha* on *A. nepalensis,* revealed that the consumption index (CI) decreased in the advancing instars. Relative Consumption Rate (RCR) or consumption index (CI) may change both within and between the instars, presumably reflecting physiological changes during development. Generally, late instar lepidopteran larvae tend to have lower RCR values than earlier ones (Slansky and Scriber, 1985; Mohanty and Mitra 1991; Atluri *et al.,* 2002). A reduction in CI value may also be due to enhanced utilization of the energy required for development of body structure and spinning activity in the final instar larvae (Muthukrishnan and Pandian, 1987) of *G. chrysolopha*.

As stated earlier, quality of food consumed by *G. chrysolopha* was found low in basic nutrients. Insects that feed on foods of lower nutritional quality, often show higher rate of consumption to compensate for lower nutritional quality and to obtain sufficient nutrition for development (Farrar *et al.*, 1989 and Lindroth *et al.*, 1997). Handling of a greater amount of poor quality food results in increasing pressure to detoxify the allelochemicals present therein; an activity that requires utilization of stored energy of the larvae resulting in the reduction of their body weight (Muthukrishnan and Pandian, 1987) thereby reducing CI. The bulk of food consumed through long stadial periods by all the advanced instar larva of *G. chrysolopha,* could be another reason of reduction in CI observed in present study.

The overall CI value for *G. chrysolopha* was quite low. RCR is generally high in phytophagous caterpillars feeding on foliage having high percentage of nitrogen and water (Slansky and Scriber, 1985). Inverse of this condition seems to apply in case of larvae of *G. chrysolopha* that mainly consumed mature and senescent leaves low in nitrogen and water content and thus showed a low CI value.

Similar result of decreasing CI with the advancement of instar was also noted for other lepidopteran larvae (Mohanty and Mittra, 1991; Bailey and Tara, 1988 and Bora and Dutta, 1996).

7.8.1.3. Food utilization efficiencies:

It was observed that efficiency of conversion of digested food (ECD) and efficiency of conversion of ingested food (ECI), in the present study, were quite low in all the leaf feeding larval stage of *G. chrysolopha*.

Phytophagous insects, especially tree-feeders, are faced with low levels of plant nutrients, hence their success in growing and reproducing depends upon their ability to efficiently convert ingested and digested food, and to metabolize plant N (nitrogen) with optimal level of leaf water (Scriber and Slansky, 1981). Sub-optimal availability of a limiting nutrient, often nitrogen or water, reduces growth rate, increases maintenance cost and causes a lower metabolic efficiency (Schoonhoven *et al.*, 1998). Water content of food has a strong effect on efficiency of conversion of ingested food (ECI). Significantly better growth occurs on food (foliage) with high water content (Panda and Khush, 1995). Insects feeding on senescent leaves with low water content suffer considerable metabolic strain on account of producing metabolic water (Marian and Pandian, 1980). *G. chrysolopha,* as mentioned earlier, fed on senescent leaves low in basic nutrients and low water content. Therefore, low food quality and low water content of leaves consumed by the larvae of *G. chrysolopha* may be collectively reducing its utilization efficiencies. Similar low food utilization efficiency was noted for other lepidopteran larvae while feeding on senescent/ sub-optimal foliage (Marian and Pandian, 1980 and Sheppard and Friedman, 1990). Low dietary water impairing the conversion efficiencies, have also been reported in several lepidopteran larvae (House, 1965; Fenny, 1976; Sciber, 1977; Martin and Von't hof, 1988 and Deb *et al.*, 2000).

The ECD and ECI, in the present study, have been found to decline with advancement of instars. This may probably be due to internal changes and extra expenditure of energy prior to pupation as explained by Soo Hoo and Fraenkel (1966) for the last instar larva of the tree-feeder southern armyworm *Prodenia eridania.* Presumably, most of the ingested food in *G. chrysolopha,* went for basal metabolism, resulting in low utilization for growth of the insect.

Although found statistically insignificant, approximate digestibility (AD) of *G. chrysolopha* increased with advancement of instars.

It was further observed that AD of *G. chrysolopha,* in all the three instars, was quite low. Plant defense chemicals (e.g., Tannin) alter the performance of digestibility in herbivores (Muthukrishnan and Pandian, 1987). As mentioned earlier, *G. chrysolopha* consumed leaves of *A. nepalensis* having high percentage of tannins. Tannins are examples of substances that can block the availability of protein by forming less digestible complexes (Fenny, 1968). Rhodes and Cates (1976) classified plant defense chemical into "digestibility-reducing quantitative chemicals" (e.g., Tannin), that interfere with the metabolic process reducing digestibility in insects. Fenny (1968), in winter moth, *O. brumata* observed that leaf tannins markedly inhibited the growth of larvae because of formation of indigestible complexes, thus reducing the rate of assimilation through digestion. This digestibility-reducing quantitative chemicals increase in their concentration with plant age and their ability to bind protein renders plant tissues only partially digestible (Denno and Donnelly, 1981).This fact bears out that the presence of high percentage of tannins in food in older leaves consumed by *G. chrysolopha,* might be responsible for overall lowering of digestibility of this insect species.

7.8.1.4. Growth Rate (GR):

The present study revealed that the growth rate of *G. chrysolopha* decreased with advancement of age and stage. Growth rate decreases in value, as larvae get larger, due to the allometric relationship between body size and the rate of consumption, etc (Montgomery, 1982). The decreasing trend of GR observed in *G. chrysolopha* may be attributed to above proposition.

It was found that the general growth rate in all the three advanced instars of *G. chrysolopha* was quite low and was directly proportional to CI. Growth rate depends upon consumption index (Scriber and Slansky, 1981). In the present study, a low consumption index in advanced instar is reflected in a decreased growth rate. Growth rate of herbivorous insects is assumed to be nutrient-limited (Schoonhoven *et al.*, 1998). Factors such as nitrogen, water, mineral and toxin content of food, significantly influence the overall growth rate through feeding rate (Muthukrishnan and Pandian, 1987; Mattson, 1980; Slansky and Fenny, 1977). As the nitrogen content of food increases, insect becomes more efficient in converting plant material into body tissue (Schoonhoven *et al.,* 1998) and vice versa. *G. chrysolopha* fed preferably on senescent leaves that showed a lower concentration of N, C, minerals (K, P) and lower water content. Therefore, it stands to reason that low quality food might be affecting the efficiency of the insect to covert plant material into body tissue resulting in slow growth rate (GR) of *G. chrysolopha.* A reduced growth rate with an increase in larval duration was also observed in forest tent caterpillar when fed on low nutrient leaves (Hemming and Lindroth, 2000).

The amount and quality of food consumed by lepidopteran larvae, influence their growth rate, developmental time, final body weight, and survival (Slansky, 1982). There is enough evidence to support that the nitrogen, minerals and water content and allelochemicals of plants, exert a strong influences on the 'bioavailability ' of nutrients to phytophagous insects and, in turn, influence their nutritional indices (Barbosa and Greenblatt, 1979; Sheppard and Friedman, 1990; Panda and Khush, 1995). Consumption and utilization indices of *G. chrysolopha* in the present study, stand as a typical example of the insect's response to dietary component of food, where a low CI, GR, ECI, ECD, and AD are the reflections of utilization of a sub- optimal food quality low in N, C and minerals (K and P) that was available through mature and senescent leaves of *A. nepalensis* during the period of occurrence of the caterpillars.

7.8.2. Nutritional ecology of *C. chlorina:*

7.8.2.1. Feeding preference:

C. chlorina preferred to feed on most succulent young leaves of *A. nepalensis* with high water content. In the field, these beetles infested most of the leaves of *A. nepalensis* having water content more than 70%. Cates (1980) stated that 'specialist herbivores' could do well on young leaves because they had a better tolerance for toxins present in the leaves of their specific host. *C. chlorina* also appeared to be a 'specialist' on its host, *A. nepalensis* in this regard.

7.8.2.2. Food consumption:

Consumption index (CI) was very high in *C. chlorina* as compared to *G. chrysolopha.* Water content of food plays an important role in determining CI value of insects (Pandian *et al.*, 1978 and Muthukrishnan and Pandian, 1983, 1987). A high value of relative consumption rate RCR or CI, is generally found in early foliage feeders and this response can be associated with high water content in early- season foliage (Slansky, 1993). It is evident from the results that *C. chlorina* fed on fresh leaves of *A. nepalensis* having high water content while *G. chrysolopha* consumed relatively drier leaves (late-season foliage). Slansky (1993) observed that RCR in caterpillars feeding on "high water" foliage was 4-5 times greater than those feeding on drier leaves. In the present case, probably the water content was the key factor to cause such a difference in CI values for the two insect species in question. The contrasting feeding indices of the two species belonging to different feeding guilds, in this study was similar to that found for the lepidopteran, *Alsophila pometaria* feeding on early season and *Anisota senatoria* feeding on late season foliage of oak tree. RCR value for the former lepidopteran species was 1.3 fold greater than the latter species (Lawson *et al.*, 1984).

There are reports stating that interaction between the different constituents, especially C, N and minerals of food may determine the efficiencies of utilization of food, growth and reproduction (Muthukrishnan and Pandian, 1987). Certain minerals such as K and P are required at least in trace amounts and are essential for growth and reproduction of an insect (Dadd, 1970). Minerals of food consumed influence CI of an insect (Baker, 1974). The percentage of minerals present in the food of *C. chlorina* was higher than that of *G. chrysolopha*. Thus, an increased CI observed in *C. chlorina* may also be due to influence of higher mineral content of the consumed leaves.

CI increased from early to late instars larvae in *C. chlorina,* which is in agreement with the data available on another congener, *C. scripta* feeding on *Populus* tree (Ohmart *et al.*, 1985).

7.8.2.3. Food utilization efficiencies of *C. chlorina*:

Efficiency of conversion of digested food (ECD) and efficiency of conversion of ingested food (ECI) were found to get lower with advancement of instars in *C. chlorina*. This may be possibly due to internal changes and extra expenditure of energy prior to pupation (Soo Hoo and Fraenkel, 1966). The fact that food utilization efficiencies (ECD and ECI) are higher for early instars compared to late instar larvae, may also be due to presence of much lower level of detoxifying enzymes in the earlier instars than in the later instars (Ahmed, 1986). Therefore, the variations in the nutritive as well as secondary components of the food may have their greatest impact on early instars than later ones (Schoonhoven *et al.*, 1998). The result obtained for ECD and ECI in the present study corroborates the above propositions.

In the present observation on *C. chlorina,* it was found that approximate digestibility (AD) decreased, as the larvae grew older. Duncan and Kelekowski (1975) stated that efficiency of assimilation is maximum during the initial periods of an individual's life and shows a steady fall with the advancing age. A number of workers have also reported a decline in AD with larval maturity (Mordue and Hill, 1970; Mehrotra *et al.*, 1972; Mackey, 1978; Yadav *et al.*, 1979; and Shantibala *et al.*, 2002). This is probably related to increased feeding rate and increased gut size, as the larva grew older. Shorter retention time and larger food mass, probably, make enzymatic degradation and nutrients absorption through the gut wall, less efficient and this may have important consequences on insect's ability to utilize the food (Schoonhoven *et al.*, 1998). Therefore, the above suggestion may help to explain the results observed in the case of larvae of *C. chlorina.* The overall AD was high for the coleopteran *C. chlorina* as compared to lepidopteran *G. chrysolopha.* Food quality, water and toxin contents of plant food of herbivores are some of the factors responsible for influencing the assimilation efficiency (Muthukrishnan and Pandian, 1987). The value of approximate digestibility and efficiencies of food conversion, are, generally highest among the larvae feeding on foliage having high N content (Barbosa and Greenblatt, 1979, Lateef and Harcourt, 1972; Shantibala *et al.*, 2002). Higher AD observed in *C. chlorina,* which preferred nitrogen rich food with high percent of water, conforms to above propositions. However, this performance may also be attributed to the high tolerance of coleopteran larvae to "digestibility-reducing quantitative chemicals" present in the leaves (Fox and Macauley, 1977, Bernays, 1978) that helps in efficient assimilation of food.

The results presented here, suggest that leaf water content and some other leaf constituents (e.g., N and minerals) have an important influence on food consumption and utilization of *C. chlorina* and is another example of insect's response to dietary component of food

7.8.2.4. Growth Rate (GR):

Growth rate of *C. chlorina* increased with the advancement of instars of the grubs. It was observed that *C. chlorina* showed high growth rate within a short development period- a result contrasting to that of *G. chrysolopha,* which took a very long development time and showed much lower GR. There are quite a few contributions highlighting the role of the moisture content (e.g. Sciber, 1977, 1979; Tabashnik, 1982) and nitrogen content of foliage (Fox and Macauley, 1977; Slansky and Fenny, 1977; Tabashnik, 1982) in regulating insects' growth rate. A fairly high growth rate of *C. chlorina* may be attributed to above facts, since it fed on leaves having high percentage of water and nitrogen.

7.9. Ecological role of major folivores in the cardamom agroforestry:

7.9.1. Assaying the contribution of the folivores in production of faecal-urine rich ground litter (manure):

Egesta of defoliators which feed and defecate at faster rates, is likely to enrich the mineral content of soil and influence its primary productivity (Delvi, 1985). In temperate areas (like Sikkim) this is even more important because frass is one of the few mid-summer sources of nutrients for the plants themselves (Weis and May, 1989). Lovett and Ruesink (1995) and Lovett et al (2002) found that frass from gypsy moth caterpillars increased microbial immobilization of N, thereby reducing, at least temporarily, the possibility of N losses from ecosystem.

The present study has taken stock of the possible contribution of the folivores (in an outbreak, large quantity of frass dropped to the forest floor), in terms of soil fertility, through their faecal droppings in the large cardamom agroforestry. Besides the major components C and N of the leaf, certain inorganic elements such as K and P are also required for growth and development of the insects (Dadd, 1970). These are normally found in the excreta of insects (Larsson and Tenow, 1979) and, therefore, when mixed with the soil, possibly add to its fertility.

No significant difference in the soil constitution and chemical composition, could however be observed on analysing the soil samples containing faecal-urine of *G. chrysolopha* and *C. chlorina* and that without it. This indicated that the quantity of the faecal-urine added to the soil did not contribute to the soil fertility as manure in the present study. As evident from the data on the chemical composition of food and faeces of these larvae, they appeared to have totally absorbed the different nutrients present in the eaten leaves. In *G. chrysolopha,* where basic foliar nutrients were in low percentage, a poor contribution to the soil fertility through addition of frass (faecal urine) as manure was expected. *C. chlorina* showed a high utilization efficiency of ingested and digested food (ECD and ECI). The faecal urine poor in nutrient may be due to very high absorption of food components by the insects. Low concentration of nutrient components in faeces as compared to their concentration in the food eaten was also observed in lepidopteran larvae of *Hyalophora cecropia* (Schroeder, 1971) and of *O. brumata* (Axelsson *et al.*, 1975) which was possibly due to high absoption of food.

So in the present study the analysis of chemical composition of frass and the food eaten, gives inkling that the folivores are not contributing much to the soil fertility during the period of study (3-years). But a long term study may help to establish the contribution of frass in forest floor fertility of *Alnus*- cardamom agroforestry.

7.9.2. Negative role of the major folivores in large cardamom agroforestry:

Recently, much attention has been given to the herbivore- plant relationship, and to its ecological impacts (Denno and Mc clure, 1983). The quantitative assessment of actual consumption of host plant by its pest may help to assess the impact of the pest on the growth of the plant (George and Ipe, 2000) and thereby to specify the status of the pest causing stress to the plant.

It was observed that the final instar larvae of both the insects caused maximum injury to the tree, *A. nepalensis*. Assessment was made of such injury in the present study. Depredation of leaves by advanced instar grubs of the beetle, *Linaeidea aenea* was also observed on leaves of *Alnus glutinosa* by (Urban, 2000). Estimation of leaf damage by larvae in terms of leaf area consumed has been done by many workers (Simmonds, 1949; Manjunatha *et al.*, 1987 and George and Ipe, 2000).

Comparison of injury inflicted in terms of leaf area consumption, by major folivores, indicated that *G. chrysolopha* consumed more leaf area than *C. chlorina* and as a consequence, caused greater injury to *A. nepalensis*. Low and moderate levels of herbivory, stimulates plant productivity, whereas severe herbivory results in mortality or decrease in the fitness of the plant (Marquis, 1984). In this case however mortality due to defoliation was never recorded; nevertheless, if the defoliation was high an indirect damage of the cardamom plants was quite possible due to non-availability of shade.

In field, the shade tree *A. nepalensis,* experienced severe herbivory by both the major folivores *G. chrysolopha* and *C. chlorina.* The caterpillars of *G. chrysolopha* were found to be voracious eaters. The infestation of leaves of the shade tree, *A. nepalensis* ranged from young tender ones to old mature ones in different seasons. The grubs of *C. chlorina* generally defoliated young leaves, whereas the caterpillars of by *G. chrysolopha* preferred old and mature ones, thereby leaving no part of the foliage unattacked, and thus substantially reducing the shade areas. At a high incidence or overlapping of escalated populations of the above folivores, the injury symptoms of the foliage were apparent with partially or fully eaten or skeletonized leaves (Plate 8b). Severely injured leaves got dried up and were usually shed giving the tree a denuded appearance (Plate 3) and exposing the under growing cardamom plantation to excess sunshine, frost and other weather conditions. *G. chrysolopha* caterpillar has been found to defoliate the tree so severely that it almost took two years to get back to its normal foliage. Pangtey and Thakur (1986) have reported similar defoliation by *G. chrysolopha* and consequent loss of the shading effect. The same authors, and Phaloura and Singh (1992) have also mentioned about the severity of defoliation caused by *C. chlorina.*

C. chlorina was found to defoliate both *A. nepalensis* and *Amomum subulatum* (large cardamom) with almost equal propensity, a situation also observed years back by Pangtey and Thakur (1986). Observations on food utilization efficiencies of *C. chlorina* on *A. nepalensis* and *Amomum subulatum* supports the comparable nature of depredation of the two hosts. So, one can be justifiably apprehensive that a beetle like *C. chlorina,* can cause havoc in the large cardamom agroforestry by depredating both the shade tree as well as cardamom crop, if they occur in fair numbers.

Defoliation of *A. nepalensis* by these major folivores, may result in reduced leaf litter fall, causing an indirect effect on the soil fertility of the cardamom agroforestry. Litter falling to the forest floor is normally regarded as the main route by which nutrients of the soil are largely replenished through their direct movement from the canopy to the soil (Sharma *et al.*, 1998).

Finally, judging by the above facts if one tries to assess the role of these major folivores *in situ,* the balance tends to negative one. Large cardamom needs shade in the winter month (Nov- March) to avoid damage due to frost and hail storm. The folivore, *G. chrysolopha* cause the injury to the "Utis" tree in this critical period and cause indirect damage to the large cardamom plant.

So, these major folivores need to be kept under control, in order to ensure stable shading by *A. nepalensis* foliage and thereby ensuring a better growth of the large cardamom crop with a greater productivity. It is expected that the present study on the incidence, population, biology and natural enemies of the major defoliators will surely help in evolving strategies of management of these "pests" especially under IPM programmes of *Alnus*-cardamom agroforestry system.

8. Summary

1. Study on insect association of *Alnus nepalensis* ('Utis' tree) from Sikkim indicated that the tree harboured insects of different taxonomic and feeding guilds throughout the year.
2. Taxonomic analysis of the entomofauna showed the dominance of morpho-species (Recognizable Taxonomic Unit =RTU) coleopterans followed by lepidopterans, homopterans, hemipterans, hymenopterans, orthopterans, neuropterans, thysanopterans and dipterans at both the altitudes [Pangthang (2160m amsl) and Kabi (1630m amsl] and during three years (2000-2002) study period.
3. Excepting some of the haustillates (sap suckers) and a few lepidopterans, most of the insects occurred during spring and rainy-summer seasons. The tree had minimum entomofaunal association (diversity) in winters.
4. Abundance of insects in the spring and rainy seasons seemed to be due to sprouting of new leaves of *A. nepalensis.*
5. Low occurrence of insects in winter season, appeared to be mainly because of presence of mature and senescent leaves with low nutrient and moisture levels.
6. About 13 insects' species were known to commonly occur on *A. nepalensis* tree and *Amomum subulatum* (large cardamom) crop. Of

these, the folivorous beetle *Chrysomela chlorina* severely attacked both.

7. The lepidopteran, *Gazalina chrysolopha* belonging to family Notodontidae and the coleopteran, *Chrysomela chlorina* belonging to family Chrysomelidae, caused regular defoliation of *A. nepalensis* during the three years of observation and, therefore, appeared to be major folivores.
8. The caterpillars of *G. chrysolopha* appeared in winters from November till May, whereas the grubs of *C. chlorina* were active from May till August.
9. The populations of both the folivores were found higher in year 2000 than 2001 and 2002. This may be due to 'phenological reasons' or the genetic programme of these insects.
10. A tachinid fly mainly infested the caterpillars of *G. chrysolopha* and a coccinellid, *Aiolocaria hexaspilota* was recorded as the major predator of *C. chlorina* in nature.
11. Temperature and rainfall were found to have significant negative correlation with the population of *G. chrysolopha,* whereas rainfall and cloud cover had significant positive correlation with the population of *C. chlorina.*

12. Males of *G. chrysolopha* lived longer than females; the female oviposited once or twice. Females of *C. chlorina* oviposited 2-3 times in one generation.

13. *G. chrysolopha* took about 10 to 11 months to complete its life cycle, showing only one generation in a year while the life cycle of C. *chlorina* was completed within 3 months and it completed two to three generations in a year.

14. Length and head-width of larvae of both the major folivores grew in geometric progression. *G. chrysolopha* had five larval instars while *C. chlorina* had four.

15. Age distribution of natural population of *G. chrysolopha*, showed dominance of the last two instars for longer period. Therefore, it can be expected that the maximum injury to the tree, *A. nepalensis* was done by last two instars of *G. chrysolopha.* Age distribution of *C. chlorina,* however, showed no fixed patterns of dominance of any larval stage at a particular point of time. Therefore, it can be inferred that no particular larval stage, predominantly, caused injury to the tree foliage of *A. nepalensis*.

16. Survivorship curves of both the major folivores showed similar trends. Despite the fact that *G. chrysolopha* fed on nutritionally poor quality food, it had good survival rate on its host *A. nepalensis.* This

may presumably be due to an efficacious adaptation of *G. chrysolopha* to its principal host during colder period of the year.

17. Feeding preference tests of *G. chrysolopha* and *C. chlorina* was done using four types of leaves having different percentages of water content. *G. chrysolopha* showed preference for mature and senescent leaves with low water content while *C. chlorina* showed a clear choice for new succulent leaves with high moisture content.
18. Analysis of the food consumed by the major folivores showed that *C. chlorina* consumed nutritionally much superior food than *G. chrysolopha.*
19. The higher nutritional quality of food consumed by *C. chlorina* was reflected in its better growth and food utilization efficiencies. An overall slow growth rate and low utilization efficiencies of *G. chrysolopha* was most possibly due to poor quality of food available for its consumption.
20. Study on the aspect of positive contribution of these folivores was conducted by considering the value of their faecal urine as manure. In both the cases, no significant change in the fertility of the soil was observed after natural mixing with the faecal urine of these folivores.
21. Study on the injury inflicted by these herbivores indicated that *G. chrysolopha* caused more depredation to its host *A. nepalensis* in terms of leaf area consumed as compared to *C. chlorina.* Since *C.*

chlorina attacked both *Alnus* tree and large cardamom plant, it was doubly destructive to large cardamom agroforestry system.

22. In order to save *A. nepalensis* as a shade tree, as well as multi - purpose tree, on the slopes of Sikkim, a preventive cum control measure against the major folivorous insects species (*G. chrysolopha* and *C. chlorina*) has to be designed using the information generated on their bioecology in the present research work.

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10. Annexure

Plate 9. A few representatives of a vast diversity of insects associated with *A. nepalensis*

PLATE - 9