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.