STUDIES ON BIOLOGY, PRODUCTIVITY AND HOST PLANT DIVERSITY OF *KERRIA LACCA* KERR AROUND KULDIHA WILDLIFE SANCTUARY, ODISHA

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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In partial fulfillment of the requirement of the Degree of Doctor of Philosophy in Forestry of Mizoram University, Aizawl.

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CERTIFICATE

This is to certify that the thesis entitled **"Studies on biology, productivity and host plant diversity of *Kerria lacca* Kerr around Kuldiha Wildlife Sanctuary, Odisha"** submitted by **GAYADHAR SHIAL** for the award of degree of **Doctor of Philosophy** in **Forestry** of Mizoram University, Aizawl, embodies the record of original investigation carried out by him under my supervision. He has duly registered and the thesis presented is worth of being considered for the award of the Ph.D. degree. The work has not been submitted for any degree to any other University.

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DECLARATION

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MAY, 2024

I **GAYADHAR SHIAL**, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to do the best of my knowledge to anybody else, and thatthe thesis has not been submitted by me for any research degree in any other University/Institute.

This is being submitted to the Mizoram University for the degree of **Doctor of Philosophy in Forestry**.

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Date:

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List of Abbreviation used

NTFPs	Non-timber forest products
TSP	Tribal sub-plan area
KWLS	Kuldiha Wildlife Sanctuary
G	Gram
Kg	Kilogram
Cm	Centimeter
Mm	Millimeter
RH	Relative humidity
Tmax	Maximum temperature;
Tmin	Minimum temperature
WV	Wind velocity
%	Percentage
Ha	Hectare
Vol.	Volume
pp.	Pages
sq. cm	Square centimetre
cm2	Square centimetre
=	Equal
-	Minus
+	Plus
AF	Agroforestry
VC	Village commons
SAR	Strips along road side
±	Standard deviation
A/F	Abundance Frequency ratio
>	Greater than
(H)	Shannon-Weiner index
SMW	Standard meteorological week

Chapter 1

General Introduction

Tropical forests are well known for the most species-diverse terrestrial ecosystems in the earth. Their immense biodiversity generates a variety of natural resources which help to sustain the livelihood of local communities (Mishra, 1968). Abundant kinds of economically important plants and animals yielding various non-timber forest products (NTFPs) are available in these forests. Non-Timber Forest Products (NTFPs) provide alternate source of food and income to sustain millions of tribes (Ajaz-ul-Islam *et al*., 2013). Globally, harvesting, storage and marketing of NTFP bring a pivotal role in subsistence of livelihood among the forest dependants particularly in rainfed areas. It is estimated that India earns more than 50 % of the forest revenues and 70 % of the forest export income comes from NTFPs (Shiva, 1993). There is a greater role of NTFPs in socio cultural and conventional culture of forest inhabitants, particularly the tribal, landless, women and other underprivileged rural people as perceived by Prasad (2011). In India it is found that 275 million (27 percent of the total population) poor people of the most disadvantaged section of society, for the forest dwelling communities depend on NTFPs for their subsistence and livelihoods (Malhotra & Bhattacharya, 2010). Among these products, resins and gums play an important group of products in the baskets of NTFPs that provide high price at national and international markets (Mulugeta *et al*., 2003). Lac is also generally stated as a Non-Timber Forest Produces (NTFPs) (Jaiswal *et al*., 2006). As per Forest Act 1927, lac also is stated as NTFP. Subsequently with the advancement of rural social structure, farmers initiated scientific cultivation of lac on various host trees. It is one of the most preferable NTFPs perceiving its lucrative price cultivated on various host trees that has potential to improve the livelihoods of households of small and marginal farmers and forest dwellers.

For the tropical countries like India these products are of great value for socio-economic and cultural importance of people who live in forest fringes (Yadav and Dugaya, 2013). Owing to bio-safety and pressure on natural products the future demand potential of lac is propitious. Shah *et al*., (2015) also stated that lac insect is one of the economically most important insects and produces lac, a valuable non-timber forest produce (NTFPs). It is a natural commercial resinous (polymer) substance secreted by a specialized group of tiny scale insects. Lac is only animal origin which is a biodegradable, non-poisonous and non-injurious to human beings. It is a composition of natural resins developed by scale insects (Mohanasundaram *et al*., 2022**)**. Moreover, it provides livelihood to millions of economically underprivileged populations especially tribals.

In several states lac cultivation is an efficient activity for enhancing livelihood of sub-forest, forest and rain fed areas (Jaiswal *et al*., 2012). Lac based farming is a low input natural resource-based enterprise provides additional income and enhanced the socio-economic conditions of lac farmers living in rural and tribal areas (Jaiswal *et al*., 2006; Pal *et al*., 2010). Now-a-days lac has attained more research recognition due to universal trend for safer use of natural products. Sharma (2013) reported that lac has substantial use in printing, paints and polishes, fruit coating, cosmetics, pharmaceuticals and various similar applications. Moreover, the extensive requirements for natural products in worldwide intensify numerous utilizations of lac products in food and related areas (Sharma and Ramani, 2011) due to its non-toxic, durability and magnificent adhesive characteristics (Srivastava and Jeet, 2020). Lac by-products are biodegradable, non-poisonous, environmentally sound, have versatile needs and attractive export opportunities (Chattopadyay, 2011). Sharma *et al*. (2006) also opined that promotion and influence for lac cultivation eliminates environmental degradation, build up the ecological balance and also conserve endangered lac insects, associated fauna and flora. According to him these lac insects and their wide host range association help for the conservation of biodiversity of different soil flora, fauna and soil microorganisms. In India available lac insect genetic resources are under threat due to loss of a large number of indigenous populations as many lac insects and associated fauna have been eliminated or its habitat destroyed (Mohanta *et al*., 2014). Hence, for promoting and strengthening lac culture will not only eliminate environmental deterioration but also sustain the associated fauna and flora for the future generations.

Lac is secreted as a protective covering throughout the body of lac insects except mouth, two brachial pores and anus. On an average about 300,000 insects can produce 1 kg of lac resin. The English word "lac" in Hindi is derivative of Sanskrit word, 'Laksha', meaning a lakh or hundred thousand due to innumerable number of insects in small patches indicating the gregarious habit of this insect involved in its production (Krishnaswami, 1962; Ogle *et al*., 2006). Vedic people of ancient India knew that the lac is obtained from numerous insects (Kerr, 1782) and exploited for different uses which are mentioned in 'Atherva Veda'. The uses of the excretions of the lac insect were known to mankind from the ancient time. Romans and Greeks were also well aware of the use of lac. Nearly 4000 years back China was more familiar with lac production and trade in addition to promotion of silk (Singh, 2006). The famous Indian epic 'Mahabharata' also described 'Laksha Griha', an inflammable house made up of lac, designed by 'Kauravas' along with their chief architect 'Purocha' with hostile intention of burning their rivals 'Pandavas' in alive condition. Lac insects are scattered in all zoogeographical provinces except Palearctic region. They prefer warm climate and are therefore distributed between 40° latitude above and below the equator on both hemispheres in tropical and subtropical regions (Varshney, 1977 and Sharma, 2018). Lac cultivation is confined to south, east, and Southeast Asian countries such as India, China, Bangladesh, Pakistan, Vietnam, Indonesia, Laos and Myanmar (Borah *et al*., 2020).

At present lac insects of the world are reported of 9 genera and 99 species of which 2 genera and 26 species are found in our country (Sharma and Ramani, 1999 and Ahmad *et al*., 2013). India, the premier lac producing country of the world is fortunate enough having abundant biodiversity of economically valuable lac insects and produces about 20,000 tons of lac annually. Lac of commerce is obtained from a few species of the genus *Kerria* and yielding three basic components of higher value of its products namely; resin, wax and dye. *Kerria lacca* (Kerr), a scale insect is the foremost commonly found and cultivated species of lac insects in India. *Kerria lacca* belonging to a bug family Tachardiidae, superfamily Coccoidea of the order Hemiptera is one of the most valuable gift of the nature to mankind (Pal, 2009; Mohanta *et al*., 2012; 2014). This family is reported in accordance with the sclerotized behaviors of an adult female (Rajgopal *et al*., 2021). India is pioneer country in lac production, processing and export and shares about 50-60% of the world's total lac production (Sharma *et al*., 2006).

In India, *Kerria lacca* (Kerr) is represented by two different strains, rangeeni and kusumi and both the strain produces two crops in a year (bivolatine). So, the lac production of our country can be ascertained as the summation of the contribution of four crops. Strains of lac insects have been distinguished on the basis of differences in lifecycle patterns, their respective host plant preference and the quality of lac produced. Kusmi has equi-durational life cycle (6 months each) whereas rangeeni is characterized by unequal duration of bivoltine life cycle per year namely katki (rainy season crop – 4 months) and baisakhi (summer season crop- 8 months) (Sharma *et al*., 2006; Sarvade *et al*., 2018). Rangeeni strain contributes about 90% of lac production and remaining 10% by kusumi crops. Due to their genetic differences in response to temperature variation these two forms of strains differ in lifecycle patterns. Kusumi strain is superior because of the lighter colour of resin, and it fetches better price (Kumar *et al*., 2002; Sharma *et al*., 2006) and it produces two crops, jethwi (summer season crop) from Jan-Feb. to June-July and aghani (winter season crop) from June-July to Jan-Feb (Chattopadhyay, 2011). Aghani crop of kusmi strain shares the maximum quantity to the total lac production (Sharma and Ramani, 1999). These lac crops are named after the name of Hindi months. Thus, the lac production in our country can be categorised as the summation of the providing four crops, contributed by two crops of each strain. Regarding share of different crops, katki-33.39% (rainy season crop of rangeeni) contributed the most in national lac production followed respectively by baisakhi- 27.35% (summer season crop of rangeeni), jethwi 19.50% (summer season crop of kusmi) and aghani 19.42% (winter season crop of kusmi) (Paul et al., 2013). Lac production of India was 16978 tonnes in 2014-15, where 32.31 % was contributed by aghani, 26.36% by jethwi, 23.57% by baisakhi, and 17.76% by katki crop (Yogi *et al*., 2017).

Owing to attractive price in the recent past, at current times and potential international demand for lac products, there is increased level of interest among farmers to carry on lac cultivation (Ramani and Baboo, 2011). Lac cultivation required low cost investment but returns are highly lucrative, particularly in extremities of climatic conditions when production of other major agricultural crops declined. Now-a-days lac is emphasizing more research recognition due to universal trend for safer use of natural products. These insects are phytosuccivorous and thrive well on specific plants for their survival and growth are called as lac hosts. They remain attached to the host plant across their lifespan apart from crawler and adult male stages**.** Lac culture is primarily a seasonal and part-time agroforestry-based activity which may be practiced on cultivated or existing wild host plants.

Lac insects survive on more than 400 plant species are reported as a host for lac insects from different parts of the country (Varshney and Teotia, 1967; Sharma *et al*., 1997). Some researchers have claimed that these sap suckers grow well on a range of 250 host plants (Mohanta *et al*., 2012; Shah *et al*., 2018). On the basis of preference of lac insect and utilization in the country, the lac host plants are placed under three categories (Srivastava, 2011), viz. (a) Common or major host plants, (b) Occasional host plants and rare host plants.Lac production and productivity depends upon distribution of suitable host plants, their sustainable management and quality of brood lac use, institutional linkages, climate change and extremist activities (Shah *et al*., 2015; Bharat, 2010), settlement of live lac insects in tender shoots (Khobragade *et al*., 2012; Rathore, 2011; Jhangel *et al*., 2013; Sharma *et al*., 2015; Ghugal *et al*., 2015;Namdev *et al*., 2015; Sahu, 2016) till the lac crops are harvested. Ghosal (2013) also described that lac insects vigorously thrive well on tender shoots of lac host plants. The most common commercial host species for lac cultivation are Palas (*Butea monosperma*), Ber (*Zyziphus mauritiana*), and Kusum (*Schleichera oleosa*) besides there are also numerous trees of regional importance (Sharma *et al*., 1997). In our country, prevalent conventional major host plants are *Butea monosperma* (Palas), *Schleichera oleosa* (Kusum) and *Ziziphus mauritania* (Ber) (Ghosh *et al*., 2014; 2016). *B. monosperma* provides principal sources of secondary income for tribals contributing to 46.9% followed by *S. oleosa* 32.3%, and *Z. mauritiana* 20.8% (Jaiswal *et al*., 2006). Owing to paucity of ample knowledge on lac culture only 5% of host plants of *S. Oleosa* and *Z. mauritiana*are utilised for producing kusmi strain of lac, whereas only 1% of plants of *B. monosperma* for lac cultivation (Das and

Kumar, 2013). *S. oleosa, B. monosperma, Ziziphus mauritiana, Ficus spp., Cajanus cajan* and *Flemingia semialata* are the major host plants of *K. lacca* (Sharma and Ramani, 2010; Monobrullah *et al*., 2016). Lakra (2005) also found that the lac cultivation was mainly practiced on palas and ber for rangeeni strain and on kusum for kusmi strain of host plants. Currently a new species of *F. semialata* as a bushy lac host plant has been introduced by progressive lac growers in Chhattisgarh. However, Pal and Yogi (2014) calculated that the host utilization percentage was more on Kusum (56.2 %) followed by Palas (44.6 %) and Ber (13.1%). From current lac production scenario, it was also evident that only less than 10% host trees are being used for lac cultivation and there are number of factors hindering the growth of the lac sector (Yogi *et al*., 2021).

Climate change including long-term shifts in rainfall patterns, persistent droughts and floods, raised intensity and frequency of extreme coldness, epidemic of insect pests and diseases area altering severely most of the biological systems (IPCC, 2007) and likewise lac sub-sector is also adversely affected. In India too during past few years lac production showed a retrograde trend which is greatly affected by biotic stress (predators and parasitoids) as well as abiotic (adverse climatic factors) causing hindrance in lac culture. Lac insect ecosystem is a complex multi-trophic web and maintains a variety of flora and fauna. It is characterised by a rich biodiversity of lac insects, lac host plants, several predators of lac insects, parasites, microbes and host plants pests. During the life cycle of the lac insect, due to complete sedentary habit of insects after settlement in host plants they are susceptible to be attacked by many insect predators and parasitoids, causing significant damage to the lac crop both qualitatively and quantitatively (Singh *et al*., 2011a). Like other agricultural crops lac is vulnerable to be infected by many insect pests such as predators, parasitoids and diseases promoting huge loss to the lac crops due to sedentary behaviour of lac insects (Varshney, 1976). Apart from lac host plant, *K. lacca* is associated with large pest complex comprising predatory and parasitic insects which influence lac production and quality. Various parasitoids such as *Aprostocetus purperous* (Cam.), *Trachidaephagus trachidae* (How.) are responsible for majority of crop loss. Among these parasitoids, *A. purperous* alone has acquired the most dreaded pest of lac insect (Mohanasundaram *et al*., 2016). Sharma *et al*. (2006) revealed that the major predators of lac insects are *Eublemma amabilis* Moore, *Psuedohypatopa pulverea* Meyr, *Chrysopa lacciperda* Kimmins and *Chrysopa madestes* Banks. During winter season predators of *Chrysopa lacciperda* and *C. madestes* appear most frequently and cause serious mortality in lac insects (Shah *et al*., 2015; Singh *et al*., 2011 a, b). In lac production 35 to 40 per cent losses are caused by predators (Glover,1937; Jaiswal *et al*., 2008) and 5 to 10 per cent damage by parasitoids (Varshney,1976).Among lac associated fauna, parasitoids alone represent 93 and 89 per cent population followed by predators and hyper parasitoid on ber in baisakhi crop during 2011-12 and 2012-13 (Mohanasundaram *et al*., 2016). Further the density of population of lac insects influenced the intensity of parasitisation by the Chalcid parasites correlated with lac (Chowdhury *et al*., 1971). Eben *et al*. (2000) described that the growth and development of parasitoids are determined by feeding of host plants by herbivores. In our country available genetic resources of lac insects are under threat as many lac insects and associated fauna have been abandoned or its habitat destroyed due to depletion of a substantial number of local populations (Mohanta *et al*., 2014).

Major lac growing states of our country are Jharkhand, Chhattisgarh, Madhya Pradesh, Maharashtra and Odisha. These five states provide around 95% of the national lac production. Share of Jharkhand in national lac production is about 58 % followed by Chhattisgarh (16.1 %), Madhya Pradesh (11.9 %), Maharashtra (5.6 %) and Odisha (3.2 %) (Yogi *et al*., 2015; 2018). The economy of Odisha is predominantly an agrarian state and has only 41.16 % of total land under cultivation wherein almost 70% of population depends on agriculture and allied activities for their livelihood. Being a state with diverse agro-climatic conditions under which lac cultivation is carried out remarkably across areas. Odisha formerly called Orissa is the 8th largest state by area and 11th largest by population of the country. Fortunately, this state is blessed with ample of forest biodiversity and Non-Timber Forest Produces (NTFPs). Forest cover of the state is 51,619 sq. km which constitutes 33.15% of the state's geographic area (Forest Survey of India, Report 2019). However, natural existences of lac insect, locally called as Jau in Odisha is well established with bountiful of lac host plants particularly Palas, Ber and Kusum plants. In the recent past, Odisha was one of the major lac producing states of the country which contributed significantly to national lac production, but in the present circumstances its share is almost negligible. Lac production in some traditional lac production pockets of Odisha is decreasing due to effects of various parasites, predators and pathogens. Prevalence of enemy insect and diseases are the main causes of reduction in lac yield and on an average 30-40% total lac crops are destroyed by them (Malhotra and Katiyar, 1979).

However, lac culture is also practiced traditionally in some pockets of Balasore district of Odisha, indicating that agro-climatic condition of region is suited for lac cultivation. Nilagir block of Balasore is historically a major lac producing area in the North Eastern India. It is relevant to revealed that people of study site used to collect and sell it commercially. Most of the villages of this block have abundant host trees naturally growing on the on borders of paddy fields (bunds), road sides and barren lands in clusters. All three major host trees such as Ber, Kusum and Palas are found abundantly in these areas. Some of the households’ especially tribal people are having habitual access and interest to make use of host trees for lac cultivation and follow general lac cultivation process steps. Although lac is cultivated widely in different parts of Balasore district and can be better exploited for commercial production, but with improvement in agriculture, indiscriminate deforestation and vast industrialization, the naturally existing host trees are depleting more rapidly. Moreover, there is non-availability and scanty knowledge among lac cultivators about the conservation of these of their natural habitat; lac insect enemies’ interactions and causes for its occurrence are also unknown. There is no documented literature available about the availability of naturally occurring commercial lac host plants and the natural enemies of lac insect in the state of Odisha.

Due to overexploitation of medicinal plants, fuel wood collection, timber collection, illicit felling, uncontrolled grazing and forest fire causes diminishment of habitat and declining of plant diversity of site at an alarming pace. Among species of much ecological and economic importance to the forest fringes in the surroundings of Kuldiha Wildlife Sanctuary, Nilagir block in Balasore district of Odisha are

Kusum (*Schleichera oleosa* Lour*)*, Palas (*Butea monosperma* Lamk) and Ber (*Zizyphus mauritiana* Lam). Kusum (*Schleichera oleosa* Lour), plant is the best lac host species for production of kusumi lac strain. Palas (*Butea monosperma* Lamk) plant is very suitable for production of rangeeni lac strain within a period of 5-6 years of regeneration. Ber (*Zizyphus mauritiana* Lam) is also suitable for kusumi and rangeeni strains of lac within a period of 4-5 years of regeneration. Therefore, these species are subjected to much human disturbances for lac cultivation which in turn may lead to change in vegetation structure of this species. Lac host species which not only provides livelihood to millions of lac growers but also helps in conserving vast stretches of village commons need priorities for conservation and protection and also required to be monitored have also been highlighted. The data on distribution of plant communities are useful to describe the population dynamics of each species and how these major lac host species related to the other species in the same community are also studied. The present study will enunciate as a crucial component in view of surveillance and sustainable conservation of the plant diversity especially of the lac host species in and around Kuldiha wildlife sanctuary, Odisha.

Besides, an attempt has also been made under present investigation to record the naturally occurring commercial host plants and natural enemies (Predators and Parasitoids) of lac insect prevailing around the Kuldiha wildlife sanctuary, for future promotion of lac cultivation in the region. The seasonal incidence of the parasites and predators were studied during the period of investigation along with the flactuation in their population level and peak incidence period. Since, this information is required for developing a lac pest management programme, the study also aimed to find variation in emergence profile of lac associated fauna in relation to lac host plants and their crop seasons for future promotion of lac cultivation in the region. Lac associated fauna alters lac production extensively. In recent past, it has been perceived that those species which were not well-known as economically inimical have now become destructive. However, some of the new insect species which have not yet been previously reported are also found to be associated with lac insect fauna. Taking into account of severity of loss caused, the present study was taken up to estimate the population dynamics and seasonality emergence profile of lac associated biotic fauna to initiate information to formulate adequate management strategies for enriched lac production. Overall, a systematic study to record the biodiversity of the lac host pants is critically essential for their conservation and future exploitation for commercial lac cultivation. Similarly, the study on the biology and productivity of *Kerria lacca* on some major host plants at the natural forest ecosystem and manipulated agro-ecosystem under the influence of biotic and abiotic factors will provide a baseline database on the promising factors influencing the biology and productivity of lac insects

Objectives:

The present research work was aimed to study biology, productivity and host plant diversity of *Kerria lacca* Kerr around Kuldiha wildlife sanctuary, Odisha with the following objectives:

1. To study the biological attributes of lac insect in some lac host and their natural enemies (predators and parasitoids).
2. To study the host plant diversity of lac insect (*Kerria lacca* Kerr) around the Kuldiha Wildlife Sanctuary, Odisha.
3. To assess the productivity of lac insect in some of the major host plants both in the natural and modified ecosystems.

Chapter 2

Review of Literature

Loss of biodiversity is of great concern to India since many plant and animal species are severely threatened by a destruction of their natural habitat and an over-exploitation of resources. The disturbances created by these factors determine forest dynamics and species diversity at the local and regional scales and therefore, strategies actions required to protect this rich bio-wealth. Studies on *Kerria lacca* (Kerr) as an important non-timber forest product has gained significant importance among researchers and interest groups. Lac insect biology, lac crop productivity and host plant species diversity have been studied by many researchers in different parts of India and abroad. Investigations on current status of host plant species diversity, lac insects' natural enemies and lac insect biology help in generating baseline information to the forest department, policymakers and conservationists to develop management plans for conservation and sustainable utilization of this economically important species. Several researchers in India and abroad have also studied the biological attributes of lac insect in some lac hosts and their natural enemies (predators and parasitoids), the host plant diversity of lac insect and productivity of lac insect in some of the major host plants in different ecosystems. However, literature on the present study on the lac culture viz. lac insect biology, lac crop productivity and host plant species diversity in the studied area is limited. Therefore, several research articles have been reviewed for getting more information on various aspects of lac crops which have been outlined herewith.

2.1. Biological attributes of lac insects and their natural enemies

Singh *et al*. (2021) studied host preference of lac insect in Manipur during katki season. They have also stated that lac insect, *Kerria lacca* (Kerr) is a beneficial creature of nature to humankind. Lac insect produces resin, wax and dye and its productivity and quantity depend on the hosts on which it is nourished. The mean initial density of first instar nymph on hosts varied which ranged between 10-19, 10-20, 9-23 (crawlers per cm^2) in different portions of hosts. The mean initial mortality percentage ranged 10-19%, 10-20%, 9-23% (per cm^2). The mean final density of first instar nymph varied between 94-115, 94-115 and 93-114 (crawlers per cm^2). The density at maturity of female insects varied between 2-8, 2-9, 3-11 (cells per cm^2). However, the mean weight of cell ranged from 8-24, 9-24, 8-23 (mg). The mean fecundity of insect varied from 188-327, 197-317, 188-316 (eggs per cell). The mean scrapped lac yield ranged between 62-173, 66-170, 59-165 (g) respectively on upper, middle and lower portion. It was concluded that *Flemingia macrophylla* was the most favoured host species in Manipur during katki season.

Swami *et al*. (2021) studied productivity linked parameters of lac insect, *Kerria lacca* on different host plants found in Southern Rajasthan on rangeeni strain in baisakhi season at Rajasthan College of Agriculture, MPUAT, Udaipur. They inoculated with brood lac on seven species of various hosts such as ber, palas, custard apple, kikar, babool, *Flemingia macrophylla* and *Flemingia semialata*. Among all the host plants ber was the most suitable, preferred and excellent as compared to other hosts. Initial, final settlement and mature female cell density recorded was 116.50, 106.03 crawlers and 4.93 cells per sq.cm, respectively; while, settlement and mortality per cent was 90.55% and 8.84% followed by babool, palas, custard apple, *Flemingia macrophylla* and kikar. *Flemingia semialata* was the least selected host where initial, final settlement and mature female cell density recorded as 64.87, 54.70 crawlers and 2.80cells per sq.cm, respectively having 83.56 per cent settlement and 15.64 per cent mortality.

Mohanta *et al*. (2014) studied lac cultivation by non-conventional method in peripheral and buffer zones of Similipal Biosphere Reserve (SBR). The study revealed that the initial density of settlement of larva varied between 92.58-126.74 per cm^2 and 93.12-109.62 per cm^2 in kusmi strain on kusum and ber trees, respectively. However, for rangeeni strain that range varied from 82.67-118.32 no. /cm^2. Irrespective of all the crops, strains and host plants the sex ratio (male: female) was seen to be 1:3. Resin production per cell varied from 17.00-21.40 mg and 19.00-25.60 mg for winter and summer crop, respectively of kusmi strain on kusum and ber plants. However, it was 05.30-11.20 mg and 18.72 -23.00 mg for rainy and summer crop, respectively in rangeeni strain. Moreover, the life cycle, life span and resin production of this lac insect was influenced by the temperature. Lac cultivation also prevented deforestation and conserved the forest ecosystem. Lac insect possessed some vertebrate predators (woodpeckers, monkeys, squirrels, rats, lizards, birds) and insect predators of Lepidopterans (*Pseudohypatopa pulverea*, *Eublemma amabilis*) and Neuropterans (*Chrysopa madestes*, *C. lacciperda*). It was concluded that lac cultivation directly or indirectly played a key role in conservation of biodiversity.

Sharma *et al*. (2018) studied life cycle of rangeeni strain of lac insect on ber, pigeonpea and flemingia in the department of entomology, college of agriculture, MPUAT, Udaipur, Rajasthan. In that rangeeni strain the mean duration of pre-sexual periods prevailed 46.77, 47.53 and 48.93 days from the date of inoculation of brood lac. Mean duration of male emergence with 11.50, 12.73 and 13.27 days on ber, flemingia and pigeonpea, respectively. However, percentage of male population were 10.51, 11.02 and 11.17; 11.33, 13.23 and 13.59; 10.78, 11.17 and 11.86 per sq. cm of in upper, middle and lower portion of host plant in three sets of experiment, respectively on ber, flemingia and pigeon pea.

Swami *et al*. (2017) studied the biology of rangeeni strain of lac insect (*Kerria lacca* Kerr) on pigeon pea (*C. Cajan* Linn.) during katki season. They have calculated different biological parameters such as duration of pre-sexual periods (days), duration of male emergence (days), sex ratio (per cent male insect) and life period of female lac insect (days) on pigeon pea. The mean extent of pre-sexual stages continued for 48.36 days from the date of inoculation period of broodlac with 11.50 days mean duration of male emergence. Percentage of male population were 11.33, 7.33, 4.02; 17.75, 10.63, 6.23 and 17.75, 11.73, 11.56 in lower, middle and upper portion of plant respectively. In rangeeni strain of katki crop the total life period of lac insect on pigeon pea was 117 days.

Mishra *et al*. (1999) studied different productivity parameters of lac insect, *K. lacca* such as live cell, fecundity, fresh weight and dry weight of lac cell on *Flemingia semialata* and *F. macrophylla*. On *F. semialata* live cell weight, phunki (dry) cell weight and fecundity was varied from 13.16 to 38.33 mg, 8.00 to 19.00 mg and 253 to 565 eggs respectively. On *F. macrophylla* it was 16.83 to 31.67 mg, 9.33

to 18.83 mg and 297 to 477 eggs. They concluded that there was significant difference between fecundity and lac cells.

Sharma *et al*. (2005) revealed that each lac insect *K. lacca* has ability to multiply 250 times more in one descent and showed very less brood lac and yield ratio. In the laboratory condition each single lac cell on *F. macrophylla* yielded around 56-175 times more lac. However, in the field situations yield reduced to 45-50 times. When the infestation was done by mass inoculation and the extent of operation was increased, the yield was extremely reduced to 3, 4 and 7 times of the inoculation on *B. monosperma*, *F. macrophylla* and *Z. mauritiana*, respectively for rangeeni strain; and 5, 9 and 14 times, respectively on *F.macrophylla*, *Z. mauritiana* and *S. oleosa* for kusmi strain during rainy/winter season crop under field studies. With improved lac culture operations, damage due to pest infestations, quantitative and qualitative loss of brood lac, and management of lac insect population on the lac host plant became harsh and critical factors which affect the lac crop adversely.

Kumar *et al*. (2007) recorded 13 host plants of lac insect in the southern region of Rajasthan, among which palas and ber plants were found dominant in numbers as compared to other host plant. Different host plants such as palas (*B. monosperma*), ber (*Z. mauritiana*), pipal (*Ficus religiosa*), bargad (*F. bengalensis*), arhar (*Cajanus cajan*), bhalia (*F. semialata* and *F. macrophylla*) were inoculated with brood lac to calculate the lac yield and other biological parameters. Ber plant was found to be the good host for lac cultivation and produced maximum quantity of lac as (165.5 g per m). The maximum fecundity was calculated as (525.2 and 450.6 per female), female cell diameter (3.52 and 3.06 mm) and cell weight (14.21 and 10.12 mg) in both the crops viz. baisakhi (summer season) and katki (rainy season) crop.

Sharma and Ramani (2010) revealed that average brood lac requirement for inoculation differed on various host plants *viz*. on Palas (0.75 to 1 kg), Kusum (4 kg) and Ber (1.5 kg). Range of settlement of lac insect of different host plants showed (average 48- 131 per sq cm in rangeeni and 81-140 per sq cm in kusmi) determined by the quality of brood lac used for inoculation. Under optimum conditions average settlement of lac insect of rangeeni strain was significantly less than that of kusmi strain.

Jaiswal and Sharma (2011) reported that the prevalence of male lac insect in aghani crop of kusmi strain occurred 7-8 weeks after brood inoculation. However, in katki crop of rangeeni lac male insect emergence was 6-7 weeks after brood lac inoculation. In both the crops, the adult male survived for 2 days.

Monobrullah *et al*. (2016) evaluated the performance of different biological attributes based on the host and location mediated variations of *K. lacca* at two separate locations viz. IINRG, Ranchi and farmers field at Pudidih, West Bengal in rangeeni (summer). The initial mortality and sex ratio of the lac significantly differed, whereas initial settlement of lac insect revealed significant difference only between locations. A significant difference was noticed between host plants, locations and their interaction in survival of lac insect at maturity, whereas the fecundity and resin weight indicated significant variation between locations only. Initial mortality exhibited more difference between hosts, location and interaction between location and host whereas, brood lac yield and sex ratio characterised significant difference between hosts only.

Sahu (2016) studied the performance of survival and yield of rangeeni lac on *Butea monosperma* applied with different micro nutrients and humic acid. Average weight of brood lac used for inoculation ranged from 600 to 1200 g per plant. Among the treatments in 30 days after BLI, the mean population density per 2.5 sq cm varied from 44.95 to 50.28. However, during harvest at 84 days after BLI it was reduced to varied range from 20.86 to 26.05. Among the different treatments at 50 days after BLI the mean population density of live female lac insect per 2.5 sq cm ranged from 44.95 to 50.28. At crop maturity female insect ranged from 20.86 to 26.05 per 2.5 sq cm. The yield of brood lac per plant was varied from 2.80 to 4.59 kg and maximum in humic acid treatment and minimum in control. The average fresh weight of 100 matured cells varied from 6.36 to 11.14 g and maximum in humic acid treatment and lowest in control. Mean dry weight of 100 cells ranged from 4.95 to 8.21 g, it was highest in humic acid treatment and lowest in control.

Kumar *et al*. (2017) calculated comparative performance of the population density of lac insect on palas host tree per 2.5 sq cm on three different branches of separate positions such as upper, middle and lower at 50, 62, 76 and 94 days of BLI application of micronutrients in rangeeni strain. At 50 days of BLI it varied from 44.95 to 50.28 in different treatments. At 62 days of BLI it ranged from 37.05 to 39.34. At 76 days of BLI it varied from 28.37 to 33.46. At 94 days of BLI the mean population density per 2.5 sq cm varied from 20.86 to 26.05.

Sharma *et al*. (2007) noticed that during the rainy seasons the parasitoids of lac insect *Kerria lacca* were detrimental for the resin production and the fecundity of the insects. Due to parasitism mean reduction of resin production in rangeeni strain varied from 17.25- 39.80 per cent and in kusmi strain it was 25.24-37.91 per cent.

Narayanan (1962) found that super parasitism on larva occurs in single scale. The life span of parasitoids was found to be about one month, while for *Kerria lacca* it ws 4-8 months. In a year, *A. purpureus*, *T. tachardiae* and Coccophagus *tschirchii* passed about 10-12 generation on lac insect, and 9 generations for *Parechthrodryinus clavicarnis* Cameron. *A. purpureus* and *T. Tachardiae* were the most dominant parasitoids among lac insect associated fauna (Chattopadhyay, 2011).

Singh *et al*. (2011a) stated that in kusmi strain of the aghani crop the green lace wing, *Chrysopa sp.* predator of lac insects brought about severe damage and reduced the yield. A severe damage caused by the *Chrysopa sp*. was observed during (aghani crops) winter season and also faulty management practices led to the loss of entire crop.

Mohanasundaram *et al*. (2018) found that among the prevalent of parasitoids, *A. purpureus* was the most dominant species followed by *T. tachardiae* and *P. clavicarnis*. However, among the predators *E. amabilis* was seen more dominant in both the seasons of crops. Population of *B. greeni* was more in rainy/winter crops (katki and aghani) than summer (baisakhi and jethwi) crops.

Borah and Garkoti (2020) studied the traditional lac culture and forest-based livelihood of Karbi community living in West Karbi, Anglong district of Assam. A total of eight naturally growing host host plants except *Ziziphus mauritiana* and *Ficus religiosa* used by the community for lac cultivation. Lac has been used as natural dye, binding agents, medicine, and polishing earthen pots. Lac culture was providing one quarter of the family income among the Karbi people. Due to uncertainty in production, fluctuations in market price and unorganized market system were the alarming causes for this forest based indigenous income generation practices among local communities.

Jaiswal *et al*. (2012) stated that due to change of climatic pattern, lac production is one of the most suitable options for providing livelihood in sub-forest and forest areas. The state of Odisha provided around 2.5 % of the country production. The crop-wise lac production statistics witnessed that rangeeni crop of rainy season registered growth rate a positive trend (1.2 %), while summer crop found a major decline (-10.7 %) per annum. A positive growth rate (24.3 %) of rangeeni lac production was found only in Balasore district. However, in regards to lac production in kusmi positive growth rate was found in Mayurbhanj (12.1 %), Koraput (9.4 %), and while, Keonjhar, Sundargarh and other districts together (5.2 %). The author also commented that for sustainable lac production and secured livelihood promotion, some areas of the state may be identified where there is intermittent rainfall during summer season and also summer temperature should not exceed beyond $42^{o}C$ to fulfil the gap between demand and supply of brood lac.

Jaiswal *et al*. (2006) reported that Jharkhand and adjoining states were pioneer in lac production. Lac production played an important source of livelihood for tribal engaged in its cultivation and contributed around 28% of total agriculture income. Among the major lac host trees, ber 18%, palas 80% and kusum 2% was retained by 90, 80 and 52% families, respectively. The average shares of ber, palas and kusum was 117.2, 12.5 and 2.3 (nos.) and only 51, 70 and 62%, respectively of these trees were used for lac cultivation. Host wise contribution of income from lac host found that palas (46.9%) shared largest income followed by kusum (32.3%) and ber (20.8%).

Meena and Sharma (2018) studied species composition and richness of insect fauna related with lac insect in western plains of India. They found that 11 species of fauna from 8 families associated with *Kerria lacca* (Kerr.) describing 8 families and 3 predator species of *E. amabilis, P. pulverea, C. zastrowi.* Three species of primary parasitoids *viz*. *T. tachardiae*, *A. purpureus*, *T. clavicornis*, *E. dewitzi* and hyperparasitoids *A. fakhrulhajiae, E. tachardiae*, *B. greeni*, *B. tachardiae*. These represented different orders such as 8 represented to Hymenoptera, 2 Lepidoptera, and 1 Neuroptera. It was also reported that 27.27% of the genera (species) belonged to family Encyrtidae; 18.18% to Braconidae and 9.09% each to Eupelmidae, Chalcididae, Noctuidae, Blastobasidae, Chrysopidae and Eulophidae. Among all the associated fauna *E. dewitzi* was found to be the most abundant parasitoid. However, in eastern part of India *T. tachardiae* and *A. purpureus* were recorded as the most destructive parasitoids of lac insect.

Mohanasundaram *et al*. (2022) reported that electroantennography responses of adult male and female and behavioural studies of *Eublemma amabilis* (Moore) and *Pseudohypatopa pulverea* (Meyr) towards volatiles of lac insect (*Kerria lacca*) and its associated products found greater effects of predator male and female to lac insect whole body extract than resin, wax, crawler and lac insect female extracts.

Mohanasundaram *et al*. (2016) revealed that *Aprostocetus purpureus* of Indian lac insect, *Kerria lacca* (Coccoidea: Tachardiidae) was a major parasitoid during summer season (baisakhi) crops on ber and palas which constituted 71.56 per cent and 74.47 per cent respectively, during 2011-12 and 2012-13. Active periods of *A. purpureus* was mainly observed during the critical periods of 17 to 22 week after inoculation. Male lac insect was more susceptible towards parasitization as compared to female. The observations concluded that *A. purpureus* was the most harmful pest of lac insect and brought about enormous economic losses of lac crops.

Mohanasundaram *et al*. (2018) studied variations in lac insect associated fauna found in different lac host plants of kusmi and rangeeni strains of Indian lac insect, *Kerria lacca* (Kerr.).Among the parasitoids, *Tachardiaephagus tachardiae* (How.) and *Aprostocetus purpureus* (Cam.) population were significantly larger in the month of November (14.7 and 62.7 respectively) and in *Ziziphus mauritiana* (ber) (50.2) during katki crop. However, in baisakhi crop of rangeeni strain these two parasitoids were also significantly during the month of March (4.3 and 11.9, respectively). During baisakhi crop population of parasitization recorded which showed significantly greater (9.5) on *Butea monosperma* (palas) followed by ber and red gram and reported as major reason of lac insect mortality at sexual maturity period. Populations *T. tachardiae* and *Eublemma amabillis* of kusmi strain were also significantly higher in the month of August (12.5 and 8.6, respectively) during jethwi crop. Maximum population of *A. purpureus* was noticed during the month of August (10.6) on ber (*Ziziphus mauritiana*) followed by kusum (*Schleichera oleosa)*. It was evident that during the month of October population of T. *tachardiae* and *A. purpureus* were found maximum (17.0 & 20.0, respectively). In aghani crop, among the three commercial host plants such as ber, *Flemingia* and kusum, population of *T. tachardiae* (3.3), *A. purpureus* (12.6) and *E. amabillis* were found more on *Flemingia*. The findings of the study concluded that the prevalence of the parasitoids, predators and hyper parasitoids varied significantly depending on the types of the lac host plants, seasons of cropping and the strains of lac insect. During the period of crop maturity and the sexual maturity, parasitization was detrimental to the quality of brood lac and finally to crop failure.

Mohanasundaram *et al*. (2023) reported relative abundance, emergence period and parasitization of parasitoids and predators associated fauna of lac insect (*Kerria lacca*) in rangeeni summer season (baisakhi) and rainy season (katki) crops on ber and on palas under two separate ecological conditions. They found that three parasitoids viz. *Aprostocetus purpureus, Tachardiaephagus tachardiae, Tyndarichus clavicornis*) and one predator *Eublemma amabilis* were in more numbers in both of the lac crops. *A. purpureus* of the lac associated fauna was noticed in enormous numbers of both the crops. Peak period of parasitization was observed during sexual maturity period (19 to 22) weeks after inoculation (WAI)) in baisakhi but in katki, during crop maturity period (16 to 19 (WAI) on both ber and palas.

Mohanta *et al*. (2012) studied variation of lac resin production in conventional (tradional) and non-conventional (scientific) cultivation in the surroundings of Similipal Biosphere Reserve (SBR) Odisha. They found that in non-conventional practices 25-35% more resin production occurred and it was more in buffer zone than that of the peripheral. They also concluded that resin production is more in kusmi strain as compared to rangeeni strain.

Mohanta *et al*. (2014) observed that lac insect (*Kerria lacca*) survived well on commercial host plants like palas, kusum and ber. The initial density of settlement of lac larva in Kusmi strain varied between 92.58-126.74 per cm^2 and 93.12-109.62 cm^2 on kusum and ber trees, respectively. It was 82.67-118.32 cm^2 for rangeeni strain. The sex ratio of (male: female) for all the crops, strains and host plants was found to 1:3. Production of resin per cell varied between 17.00-21.40 mg for winter crop and 19.00-25.60 mg for summer crop of kusmi strain on kusum and ker plants, respectively. In palas plant for rangeeni strain it was 05.30-11.20 mg and 18.72 - 23.00 mg for rainy and summer crop, respectively. A number of vertebrate predators like rats, lizards, woodpeckers, monkeys, squirrels, birds and insect predators such as Lepidopterans (*Eublemma amabilis, Pseudohypatopa pulverea*) and Neuropterans (*Chrysopa madestes*, *C. lacciperda*) predate on lac insects.

Monobrullah *et al*. (2015) studied population dynamics and appearance profile of the major parasitoids and the common predators found in rangeeni lac insect at locations of two different climatic regions viz., Institute Research Farm (Namkum, Ranchi, Jharkhand) and Putidih (Jhalda, West Bengal). They found that three parasitoids (*Aprostocetus purpureus*, *Tachardiaephagus tachardiae* and *Parechthrodryinus clavicornis*) and two predators (*Eublemma amabilis* and *Pseudohypatopa pulverea*) were prevalent during summer season (baisakhi) crop of rangeeni strain. *A. purpureus* and *P. clavicornis* appeared in large numbers during months of March-April, whereas *T. tachardiae* was more active during June –July in summer (baisakhi) crop. However, prevalence of *A. purpureus* and *P. clavicornis* population was seen in larger scale during September-October and T. tachardiae was more in October-November during rainy season (katki) crop. During crop maturity period, predators' viz., *E. amabilis* and *P. pulverea* were more in both the crops.

Pandey *et al*. (2008) recorded the appearance of abundant number of faunas associated with lac insect *Kerria lacca* (Kerr.) in lac growing regions of Allahabad, Uttar Pradesh. They found that prevalence of various insects (Predators and parasitoids) was more in katki crop than baisakhi. The study was carried out in rangeeni lac growing host plants i.e. *Zizyphus mauritiana* (Lamak.) and *Butea monosperma* (Lamak.) with same ecological situations. Lac associated predators like *Eublema amabilis* Moore and *Pseudohypatopa pulverea* Mayrick. were recorded in all the study sites. Similarly, lac insect parasitoids viz. *Tachardiaephagus tachardiae* (How), *T. somervilli* (Mahd.), *Aprostocetus purpureus* (Cam.), were also seen in scanty numbers in Allahabad and Mirzapur district. It was found that the appearance of the parasites and predator varied greatly with the crops. It was also concluded that population of lac insect fauna was scarce even below the desired level in most of the areas.

Pal *et al*. (2010) estimated lac production and processing at national level based on primary data. The procedures for estimation of lac production and processing have been adopted by considering all the lac produced at lac growers' level to the market and the processing unit by developing separate questionnaires for different units. Chhattisgarh state ranked 1st position followed by Jharkhand, Madhya Pradesh, Maharashtra and West Bengal. These five states have contributed around 95 per cent of the national lac production. During the study periods eight districts have produced more than 1,000 tons of stick lac. The quantities of processed stick lac on an average were 29,345 tons including the quantities of imported lac in India.

Rahaman *et al*. (2009) stated that *Eublemma amabilis* Moore was one of the most destructive to lac insect and lac encrustation. The newly hatched larva pierced the lac insect through opening in the cell or by tunnelling a hole through the encrustation. Prior to pupation stage a single larva damaged 42-50 matured cells. In a year, it completed six generations and brought about comparatively much damage to the katki crop than the baishaki crop.

Shah *et al*. (2015) assessed yield and net returns of kusmi lac production on *Zizyphus mauritiana* (Lamb.) in the district of Seoni, Madhya Pradesh and effects of application of different combinations of primary nutrients to host plant on kusmi lac production. It was found that the application of NPK economically beneficial for kusmi lac production.

Shah *et al*. (2018) also estimated the population density and survivability of kusmi lac insect *Kerria lacca* on *Zizyphus mauritiana* trees treated with basal utilisation of different doses of essential nutrients in lac grower's field of village Panwas Tolla, Block Barghat, District Seoni, Madhya Pradesh. They concluded that survival percentage at maturity of lac crop was significantly more in nutrient managed *Z. mauritiana* plants over control.

Sharma *et al*. (1997) studied seasonal occurrence and relative abundance of parasitoids related to lac Insect, *Kerria lacca* (Kerr.). They have revealed that 14 species of parasitoids belonging to 13 genera of 10 families were associated with lac insects. Among the total population of parasitoids the major species were *Aprostocetus* (*Tetrastichus*) *purpureus* (Cam.) and *Tachardiaephagus tachardiae* (How) represented 55.82 and 28.37%, respectively. There was no significant difference between relative abundance and appearance pattern owing to variety, host and the location. Sharma *et al*. (2002) stated that lac developed in kusum tree was better than that of palas due to its light colour. Large white moth and small black moth were noticed as dominant enemies of lac insects.

Swami *et al*. (2021) studied lac insect associated fauna in arid western plain of agro ecological regions of Haryana, Rajasthan, Gujarat and Dadar and Nagar Haveli. They identified 11 species of predators, primary parasitoids and hyper parasitoids belonging 8 families of 3 orders infested the populations of lac insect. Out of these, 8 species comprised of Hymenopetra, 2 to Lepidoptera and 1 to Neuroptera were noticed. Among the predators, dominant species were *Pseudohypatopa pulverea, Eublemma amabilis* and *Chrysopa zastrowi*. However, primary parasitoids were *Aprostocetus purpureus*, *Tachardiaephagus tachardiae*, *Tyndarichus clavicornis*, *Erencyrtus dewitzii* and Hyperparasitoids were *Eupelmus tachardiae*, *Apanteles fakhrulhajiae*, *Brachymeria tachardiae* and *Bracon greeni*.

2.2 Plant diversity of lac insect (*Kerria lacca*)

Gordon and Newton (2006) revealed that study of tropical plant diversity helped for the quantitative analysis of ecological pattern. The rapid investigation of tropical plant biodiversity has considered an essential tool for the quantitative analysis of regional scale (between location) ecological patterns. But in the study they have presented local scale (within location) variation in a Mexican tropical dry forest and recommended that a major part of regional scale variation may be an artefact of the under sampling of sites within locations. It is recommended that before the plant diversity within each location of several sites required sampling at those locations can be properly compared. They also stated that the outcomes of such analysis provide greatest understanding of biodiversity supremacy at any given time and are being practiced as a foundation for targeting conservation resources.

Ao. *et al*. (2020) studied the plant species composition and diversity of the forest ecosystems in Fakim Wildlife Sanctuary, Nagaland. A total of 60 tree species of 40 genera and 27 families were recorded. Lauraceae and Rosaceae presented as dominant families. The total tree density was 432.5 individuals ha^{-1} and basal area 42.8 m^2 per hectare. *Betula alnoides* occupied highest IVI 17.13, highest density of girth class of 30-60 cm, basal area with 280 individuals' ha^{-1} and 20.7 m^2 ha^{-1}. Ecological diversity indices like Shannon-Wiener index (3.90), Simpson index (0.93), Pielou evenness index (0.92) and Margalef species richness index (11.59) were also calculated.

Rawat (1997) studied the ecology of the Eastern Ghats (EGs), which contains a series of ancient low hills in Andhra Pradesh very adjacent the east coast of India and comprising tropical forests which sustain large human populations. The ecological status such as plant species richness, and density of shrubs and trees were also analysed both within and outside of the PAs (core, buffer and fringe situations). A random plot sizes of 10m radius for trees, and 5m radius plots for shrubs and saplings were used. Due to the existing status of PAs, Srivenkateshwara National Park, Gundlabrahmeshwaram Sanctuary and some parts of Srisailam-Nagarjunasagar Tiger Reserve, experienced the minimum area of degraded forests. Forest fringes were harvested NTFPs, bamboo and livestock grazing from all areas irrespective of legal status. All bamboo sites have been severely worked but it is suggested that bamboo working to be completely closed in core areas of the PAs. It was recommended that a combined approach to conservation biodiversity as well as to adopt better agricultural practice in that area. Regions having the primary and virgin forests to be located, mapped and assigned immediate protection measures, awaiting a scientifically-based management plan was generated.

Ahmed and Sharma (2014) studied the species diversity, spatial pattern, phytosociology of woody plants and phytosociological attributes in two different landuse classes of agricultural and forest area in Ponda Watershed, Rajouri, Jamu and Kashmir. In all, 40 sampled plots of different sizes of 20 m × 20 m size for trees and 5m x 5m size for shrubs in forest areas were enumerated. However, in in agricultural fields the size of plots were 50m x 50m size plots for trees and 10m x 10m size for shrubs. From the study site a total of 72 plant species were found consisting of 46 number of tree and 26 shrub. In the forest area the dominant tree species was *Pinus roxburghii* having IVI of 150.65 and in agriculture field *Ziziphus mauritiana* revealed the dominant plant with IVI of 44.98. In case of shrubs *Carissa opaca* was most dominant in both landuse classes having IVI of 140.46 and 65.27 in forest and agriculture field respectively. Contagious distribution was same for plant species of trees and shrubs in the study site. phytosociological studies concluded that IVI, density and basal area were high in forest area but species richness and diversity found high in agriculture area having Shannon-Wiener's, Margalef's and Menhinick's index value of 3.25, 7.13 and 2.16 for trees followed by 2.53, 3.13 and 0.86 for shrubs respectively. Simpson's index of dominance value was also high in forest area.

Al-Amin *et al*. (2004) used stratified random quadrat method to study the composition and development of undergrowth (shrubs, herbs and grasses) in a declined and deforested area of Chittagong (South) forest division, Chittagong, Bangladesh. As a whole undergrowth composed of 45 species of 31 families. Shrubs have 14 species of 12 families. Herbs and grasses consist of 31 species of 19 families. Among the shrubs the highest density (94 plants/100 m^2) and the lowest density (8 plants/100 m^2) were found in *Clerodendrum viscosum* and *Cassia alata*, respectively. *Clerodendrum viscusum* occupies highest frequency of (50%) and *Corcorus capsularis* have lowest frequency of (5%). Abundance frequency ratio of each shrub, herbs and grasses are >0.05 indicating the contagious nature of each species distribution.

Anandan *et al*. (2014) commented that the tree species richness in locality promoted the opportunity to emerge for the other living organism as they have very long life span, good crown cover to take shelter, breed and food to eat etc. They studied tree species diversity in four different sites and estimated richness of trees, dominant trees, tree Diversity Index using Simpson's Diversity Index separately in each site. It was concluded that Thanthai Hans Roever College had the highest tree species diversity with the D value of 0.057809222.Among the all the tree species coconut dominated all the species in richness followed by Drumstick trees.

Arul and Parthasarathy (2010) evaluated the plant species diversity, stem density and stand structure of six larger tropical hill forests namely, Bodamalai (BM), Chitteri (CH), Kalrayan (KA), Kolli hills (KO), Pachaimalai (PM) and Shervarayan hills (SH) of southern Eastern Ghats, India. They recorded 272 tree species (≥30 cm gbh) of 181 genera and 62 families from the enumerated total area of 60 ha area. Similarity indices like Jaccard and Sørensen indicated that areas of CH and KA were more similar regarding to species composition. From the studied six sites of the entire 60 ha area the total stand density and basal area were 27,412 stems (457 stems ha−1) and 1012.12 m2 (16.9 m2 ha−1), respectively. The stand density and basal area ranged from 290 (in site BM) to 527 stems ha−1 (in site KA) and from 5.6 (in site BM) to 24.4 m2 ha−1 (in site KO), respectively. Among the six hill complexes there was a significant variation of stand density and basal area of tree species {$F(5,823) = 4.85$, $p < 0.0002$ and $F(5,823) = 2.71$, $p < 0.02$, respectively}. Only in PM sites ($rs = 0.65$, $p < 0.05$) and SH ($rs = 0.67$, $p < 0.05$) between stand density and species richness a positive correlation was found but not in other sites.

Austin *et al*. (1996) studied patterns of tree species richness in with reference to environment of south eastern New South Wales, Australia. They showed species richness for entire tree species, two growth forms, rainforest trees (broadleaf evergreens) and eucalypts (sclerophylls), and two numbers of subgenera of *Eucalyptus*. High temperatures, moderate rainfall and radiation circumstances on ridges with a seasonal rainfall and intermediate nutrient levels favours maximum species richness of eucalypts occurs. Maximum richness of rainforest species occurs at high temperatures, intermediate rainfall and low radiation in gullies with summer rainfall and high nutrient levels.

Bajpai *et al*. (2016) documented important species of trees used by Tharu tribe in the Himalayan Terai region of India. They recorded 204 tree species of 143 genera and 50 families. Most commonly used by tribal people of the area were 29 leguminous species of 16 genera. The study also recommended for imparting training to local people for sustainable utilization and proper conservation of these plant resources.

Bajpai *et al*. (2017) studied ecological inventory in the Kuwana forest of Gonda forest division in Uttar Pradesh. Phytosociological parameters such as frequency, density and abundance were calculated for the estimation of importance value index (IVI) by using random stratified sampling techniques. Three forest communities named as *Syzygium* Lowland Forest (SLF), *Shorea* Miscellaneous Forest (SMF) and *Mallotus* Miscellaneous Forest (MMF) were selected on the basis of principal component analysis (PCA) plot. MMF forest contained maximum 39 tree species and SLF minimum of 18 species growing in it. Higher variation of tree diversity in SMF community recognised by lower Dominance index (0.088) and higher Simpson index (0.912). The diversity indices (Shannon & Fisher alpha) was found as maximum (2.797 & 11.960 respectively) for MMF community and implied the presence of better tree diversity in this forest community. For SMF community, the higher values of Evenness & Equitability indices were 0.646 & 0.859, respectively indicated the more evenly distribution of tree species in this community.

Behura *et al*. (2015) analysed phytosociological diversity of herbs species at two different reclaimed sites of Sukinda Chromite mining region of Odisha, India. A total of 62 herb species were found from these reclaimed sites, out of which 34 species were present at 1-year and 18-year old dump sites. On east aspect at both the sites higher number of species was recorded. 18 year old site possessed 28 families as compared to 24 families in one year old site. Herbaceous species of family Poaceae, Fabaceae and Euphorbiaceae represented more in number than other families. *Cynodon dactylon* and *Mimosa pudica* represented dominant species among the all aspects of both the sites.

Behura *et al*. (2016) conducted vegetation analysis by quadrat method at two over burden dump sites of Sukinda, Jajpur, Odisha from which one site was one year old and other 18-year-old. Phytosociological study done on these both sites to find out differences in structural growth pattern of tree species after reclamation of those sites. They assessed the impact of aspect and age on different parameters such as density, basal area and Importance Value Index (IVI) of these two dump sites. From one year old site a total of 18 species were calculated comprising 14 families whereas 29 species at 18-year-old site representing 16 families were recorded. Pioneer species such as *Holarrhena pubescens*, *Mallotus philippinensis* and *Trema orientalis* were found in compact at 18-year-old site. At drier sites of west and south aspects exotic species like *Acacia auriculiformis* and *Cassia siamea* dominated but in north and east aspects indigenous species were found at one year old site.

Dash *et al*. (2020) made floristic diversity assessment following the standard ecological methods in semi evergreen forests around the peripheral site of Hadagarh Sanctuary, Odisha. They reported 68 plant species belonging 30 families from 14 species of tree, 42 species of shrubs and saplings and 12 species of herbs and seedlings. Among the tree species *Azadirachta indica* was most dominant with Importance Value Index (IVI) value of 61.45 followed by *Shroea robusta* (46) and *Schleichera oleosa* (37). Among the shrubs and herbs, most common plant species were *Ageratum conyzoides* L. (IVI-40.08) and *Mimosa pudica* L. (IVI-45.67) respectively. The study concluded that an adequate and long-term management intervention promote overall ecological and aesthetic value of the forests of the sanctuary area.

Bora and Kumar (2003) assessed the floristic diversity of the *Pabitora wildlife sanctuary* Assam and recorded 724 plant species belonging to 492 genera and 142 families of vascular plants. They also enumerated the floristic diversity pattern, phenology of some common plants including fodder plants, medicinal, rare and endemic plants etc of the region.

Das and Mohanty (2021) documented a total of 130 plant species belongs to 65 families out of which 32 trees, 36 shrubs and 15 of herbs, 20 of climbers, 16 hydrophytes, 01 epiphyte and 10 ptreidophytes species were present in the core zone of Bhubaneswar smart city, Odisha. *Mangifera indica* was the dominant species which occupied the highest value of IVI (61.6) followed by *Neolamarckia cadamba* (Roxb.) Bosser (39.0), *Butea monosperma* (Lam.) Taub. (23.6), *Ficus benghalensis* L. var. bengalensis (19.5). However, IVI value among the shrubs was maximum in *Ageratum conyzoides* L. (40.0) and in *Cynodon dactylon* (*L.*) Pers. (65.7) among herbs. Phyto-sociological assessment concluded that there is a much gap between the values of different ecological parameters such as Frequency, Density, Abundance, IVI etc and also more attention to be given for growth of immature tree species and trees having low IVI value to grow in that study area.

Shalini (2021) enumerated plant diversity from three study sites such as site I (foot hill), a protected area, site II (mid- hill), gentle disturbed and site III (hill top), a moderately disturbed area of sub-tropical forest of Langol hills, Manipur. Dominated species were *Lithocarpus fenestrata* Roxb., *Schima wallichii* (DC) Korthals and *Quercus serrata* Thunb. From the study sites a total number of 282 plant species of 210 genera and 82 families comprising of 81 tree, 38 shrub, 123 herb, 25 climber and 15 fern species. Species richness was recorded highest value in site II (26) followed by site I (25) and Site III (18) of tree layer. In shrub layer, it was highest in site III (14) followed by site I (13) and site II (10). However, in herb layer, species richness of maximum value was found in site III (21) followed by site II (18) and site I (16). The Shannon and Wiener diversity index for tree, shrub and herb layers varied between 2.37-3.77, 2.68-3.15 and 2.51-2.85 respectively. The study concluded that the mid-hill of gentle disturbed forest site has more tree species diversity compared to that of protected and moderately disturbed forest sites.

Dangwal *et al*. (2012) studied the diversity of plants based on the disturbance effects in subtropical Chirpine forest of Rajouri district, J&K, India. The highest vegetation diversity of trees, shrubs and herbs was located in the base of the hill as compared to hill slope and hill top. It was also observed that in Chirpine forest, *Pinus roxburghii* was the most dominant species and that forest is under risk and will be lost soon if not managed properly. Due to more anthropological disturbances in hill slope on trees, resulted decreasing in the number of seedling and sapling but encourages the greater number of shrubs and herbs mainly *Parthenium hysterophorus* and *Cynodon dactylon* in that site. They concluded that opening of canopy and anthropological pressure favours growth of these shrubs and herbs.

Deka *et al*. ((2012) observed phytosociological characteristics of naturally grown sal forests of Kamrup district, Assam. A total of 71 plant species were enumerated from the selected sal forest wherein Leguminosae and Asteraceae were the most dominant families. *Shorea robusta* occupied around 90% of the total stand density (2559 individual ha^{-1}) whereas species like *Erythrina suberosa, Delonix regia* and *Pterospermum acerifolium* were reported as single stem. In case of stand density, sal occupied the maximum basal area of the forest. Total density of shrubs and herbs was found 2 individuals m^{-2} and 63 individuals m^{-2}, respectively. *Shorea robusta occupied* highest dominance followed by *Zizyphus rugosus.* Diversity index was recorded as for tree (1.43), shrub (2.30) and herb (3.28). Around 84% of the plant species were found to have contagious distribution pattern but not a single species revealed regular pattern of distribution.

Ekka and Behera (2011) assessed species richness and diversity of herbaceous and woody vegetation which showed an increasing trend for non-grass species with increasing age of mining spoil dumps of different ages in an open cast coal field in Odisha. The results revealed that during initial stages of vegetation development, there was more appearance of grass species. They have also recorded four indigenous woody forest species in addition to five planted species and one weeds, namely *Lantana camara*. Importance Value Index (IVI) of this weed increased with the age of the mine spoil which indicates invasiveness of this species and is indicated for the poor performance of majority of the planted woody species.

Khan *et al*. (1986) studied species composition, regeneration state and survival percentage of seedlings and sprouts of tree species in tropical and subtropical forests of Meghalaya, northeast India. At Upper Shillong and Mawphlang the subtropical humid semi-evergreen forests were dominated by *Manglietia insignis followed by Pinus kesiya, Quercus dealbata, Q. griffithii, Rhododendron arboreum, Schima khasiana* and *Prunus undulate.* At lower altitude of Burnihat, the tropical deciduous forests were dominated by *Artocarpus chaplasa, Duabanga sonneratoides* and *Shorea robusta*. There was also difference of the species composition of the tree community between the periphery and at the centre the forest stand. Survival of seedlings and sprouts was more in the forest periphery as compare to under the dense canopy, indicating the function of light in forest regeneration.

Kumar *et al*. (2010) studied the tree species diversity and soil nutrient status in three different sites of tropical dry deciduous forest of western India. They have enumerated a total number of 93 tree species of 85 genera associated with 24 families. Tree stand density of the site differed from 458-728 individuals ha^{-1} and the average basal area varied from 5.96 - 19.31 m2 ha-1. Shannon-Weiner Index (H') also ranged from 0.67 - 0.79. The Simpson Index of dominance was from 0.08 - 0.16, the Margalef's Species Richness Index ranged from 21.41 - 23.71, Equitability or evenness index ranged from 0.02 - 0.05, the species heterogeneity index was from 2.53 - 3.61 and beta diversity varied from 2.05 - 4.87. A larger number of tree individuals represented in 41 - 50 cm DBH followed by 21 - 30 cm, 0 - 10 cm diameter class. A few numbers of tree species were found in above 100 cm diameter class. Combretaceae family represented the maximum 9 number of species followed by Rutaceae with 7 families.

Lalfakawma *et al*. (2009) studied species composition, diversity, dominance, density, importance value index and tree population structure of tropical semi-evergreen forest in disturbed and undisturbed stand in Lunglei district, Mizoram, North-East India. In the undisturbed stand a total number of species 67 recorded while in the disturbed stand it was 63 species. In the undisturbed stand a total number of tree (32) and shrub (18) species were more as compared to the disturbed stand (17 and 16) respectively. In the disturbed stand the number of herbaceous species represented greater (30) than that of the undisturbed stand (17). However, *Castanopsis tribuloides* (Smith) showed as common species in both the stands of disturbed and undisturbed stand, and represented dominance in the undisturbed stand having a density of 90 individuals' ha-1. In the disturbed stand, *Schima wallichii* (DC.) Korth Choicy was dominant species having a density of 125 individuals' ha^{-1}. Higher dbh classes of both stands indicated lower density as compared to the lower and intermediate girth classes. The study concluded that the anthropogenic disturbance encouraged deterioration of forest structure and changes of species composition which finally leads to havoc loss of tree species population structure.

Malik and Bhatt (2016) studied the regeneration value of tree species and survival of naturally appeared seedlings in a protected area of Western Himalaya, India. They counted a total number of 44 tree species belonging 36 genera and 25 families from the study site. Seedling density and Shannon-Wiener diversity index (H) varied from 1670 to 7485 individuals ha^{-1} and 1.91 to 3.32, respectively. However, sapling density and Shannon-Wiener diversity index (H) ranged from 1850 to 5600 individuals ha^{-1} and 1.23 to 2.57 respectively. Diameter density distribution indicated that smaller diameter classes having the highest frequency and formed an inverse-J curve which indicates of good regeneration status. In different forests mortality of seedlings varied from 12-100% (survival varied from 0-88%).

Malik *et al*. (2014) estimated species richness, diversity and distribution pattern of tree species along varying disturbance gradient such as highly disturbed (HD), moderately disturbed (MD) and least disturbed (LD) in f mixed broad leaved forests. A total of 34 tree species from 30 genera and 21 families were found along the disturbance gradient. Along the disturbance gradient from LD to HD forests tree species richness and diversity reduced. LD forest represented maximum species richness (20) but from HD it was minimum (11). Similarly, Shannon Wiener index (2.30 -3.34), Margalef's index (2.59- 4.11) Menheink's index (1.60-1.99) also represented maximum in LD and minimum in HD forests. Species richness and diversity indices indicated significant negative relation with disturbance. More than 90% of tree species had contagious distribution pattern i.e. the most common distribution pattern in nature. The study concluded that anthropogenic disturbance enhanced disturbance of forest structure and changes species composition, which brings about reduction of tree species richness and diversity.

Mandal and Joshi (2014) studied the vegetation dynamics and plant diversity of the dry deciduous forestsin Doon Valley of Uttarakhand. *Shorea robusta* was the main dominant species, and *Mallotus philippensis, Syzygium cumini* and *Ehretia laevis* as co-dominant tree species in all communities. The species richness and diversity rates were increased with the decrease in tree density and basal area. Maximum Importance Value Index (>150) calculated in Thano site signified that the *S.robusta* forest was developing towards the culmination stage, whereas the lower IVI values (100 and 150) in the other two sites (Selaquie Jhajra and Asarori) indicated the heavy disturbance and further development of alien invasive species like *Cassia tora, Cassia occidentalis, Lantana camara, Urenalobata, Ipomoea carnea, Sida acuta, and Solanum torvum*.

Mehra *et al*. (2014) studied biological diversity of Kumaun Himalaya and recorded 58 species of ethno-medicinal plants belonging to 38 families among which 11 species trees, 30 herbs, 14 shrubs and 02 climbers were recorded. They suggested that necessary measures should be taken for conservation and protection of these plants for sustained fuel wood, fodder, medicine, fruits etc. supply to the local communities.

Mishra *et al*. (2008) carried out vegetation analysis of the forest ecosystem of Similipal Biosphere Reserve (SBR) to find out structure and composition changes in plant community widespread in the core (undisturbed) and buffer (disturbed) regions of the reserve forest. The study found greater number of herbs and shrubs and a lesser number of trees in buffer area attributing to higher degree of anthropogenic disruption. Total tree basal area ranged from 48.7 to 78.61 m^2 ha^{-1} and 81.4 to 104.9 m^2 ha^{-1} in the buffer and the core area respectively. In the buffer area greater herb diversity (2.14 - 3.50) and lower tree diversity (2.14 - 2.98) was due to environmental openings creating more opportunity for the appearance of herbs and shrubs

Mishra *et al*. (2012) suggested that rapid deforestation and forest fragmentation were the main cause for elimination of plant population and less diverse from tropical moist deciduous forest of Similipal biosphere reserve, Odisha. Most of the tree species have represented that low ecological importance values due to rarity of most of species diversity. They also studied different structural parameters in analysis to know the present state of ecological features of the ecosystem. Due to various forms of human disturbances such as logging, illegal hunting, and other activities (mining in periphery, etc.) the habitat was destroyed. The authors also opined that paucity of data base as well as structural and functional attributes of the ecosystem at fixed intervals did not help to promote a long-term strategic action plan for sustainable development of ecosystem. Therefore, it was recommended to collect data continuously for the success of such plan.

Panda *et al*. (2013) analysed plant diversity and population inventory data in dry deciduous and moist deciduous forests of eastern Ghat region of India. Diversity and density of different species of herbs, shrubs, lianas and regeneration of tree species were enumerated from 5 x 5 m size plots. A total of 882 species of 532 genera and 129 families were studied out of which 263 tree, 78 shrub, 138 climber/twinner and 403 herb species found. Most important tree species found were *Shorea robusta, Lannea coromandelica, Madhuca indica* and *Diospyros melanoxylon* while members of Euphorbiaceae, Rubiaceae, Fabaceae and Combretaceae contributed to maximum species richness, stand density and basal area. The stand density and basal area varied in the range of 268 to 655 stems ha^{-1} and 6.65 to 22.28 m^2 ha^{-1}, respectively. The tree density and species richness reduced with increasing of girth class; maximum number of species and highest density was documented for 30 to 60 cm girth class. The values of Shannon-Weiner Index and Simpson Index differed in the range of 1.85-2.05 and 0.013-0.018, respectively.

Pausas *et al*. (2001) analysed patterns of plant species richness due to availability of resources and variables which had direct physiological influence on plant growth or availability of resources. Along the environmental gradients various the patterns of species richness were also documented. For understanding species richness patterns, they emphasized the importance of: (1) using variables that were applied to the growth of plants; (2) using multivariate gradients, instead of single variables; (3) comparing patterns for different life forms; and (4) checking for different shapes in the species richness response.

Pradhan and Rahman (2015) analysed floristic diversity of Birbhum district of West Bengal. During field survey specimens were collected, and identified and authenticated after referring to the different floras. During the study for the first time a total of six angiospermic taxa such as *Careya arborea* Roxb. (Lecythidaceae), *Celastrus paniculata* Willd. (Celastraceae), *Coffea benghalensis* Heyne ex Roem. & Schult. (Rubiaceae), *Crotalaria verrucosa* L. (Fabacaeae), *Erycibe paniculata* Roxb. (Convolvulaceae), *Eulophia explanata* Lindl. (Orchidacaeae) were collected from the district.

Reddy *et al*. (2007) studied the quantitative floristic assessment of three tropical forest types in Similipal Biosphere Reserve of Odisha. These forest types were dissimilar in field and varied in dominance, composition, diversity and structure from each other. The study recorded 549 species of flowering plants wherein a total of 4819 stems of ≥30cm gbh pertaining to 185 tree species were identified and analysed. Tree stand density ranged from 527 to 665 ha^{-1} having average basal area of 43.51 m^2 ha^{-1}. Shannon–Wiener index (H') varied from 4.3 to 5.46. Similarity index revealed that only 25% of floristic composition of semi-evergreen forest was same as moist deciduous forest. However, population density of tree species across girth class interval indicated that around 48.9% of individuals belong to 30-60 cm gbh. Present study provided baseline information for phytodiversity analysis of tropical forests particularly in the Similipal Biosphere Reserve and Eastern Ghats of Odisha in general.

Rout *et al*. (2018) studied the outcomes of phytosociological attributes in tropical moist deciduous forest of Kuldiha Wildlife Sanctuary, Odisha. They documented 108 plant species of 38 families representing 38 species of trees, 38 species of shrubs and 32 species of herbs. Based on the research findings the most common plants based on importance value index (IVI) and Relative value index (RVI) in tree, shrub and herb species were *Terminalia tomentosa* (IVI-292.27), *Shorea robusta* (RVI-50.89) and *Croton roxburghii* (RVI- 17.11), respectively. Euphorbiaceae represented as most dominant family. The authors also reported that the anthropogenic disturbance, the occurrence of fire and livestock grazing caused depletion of the old and uneven age structure of forest.

Sahoo and Panda (2015) studied comparative assessment of plant species diversity and community structure of tree species from 5 m × 5 m sub-plots in 12 ha of tropical moist deciduous forests in three forest ranges of Nayagarh Forest Division, Odisha, India along a human induced disturbance gradient. A total of 5451 trees belonging to 101 species, 78 genera and 37 families were recorded in the study site. It was concluded that higher level of disturbance promoted a declining trend in the density of trees and basal area. The stand density differed between 185.50 in HD stands to 744 stems ha^{-1} in UD stands and basal area from 12.54 in HD to 36.95 m^2 ha^{-1}in UD stands. Among the three stands Shannon, Simpson, Fisher's alpha and Margaleff's indices varied significantly. The authors also found that Shannon's Index ranged between 3.20 and 3.42 and Simpson Index varied from 0.09 to 0.12. However, the range of variation in Evenness index, Fisher's alpha index and Margaleff's index were documented between 0.75–0.79, 14.45–16.10and 29.65–34.83, respectively.

Sahu *et al*. (2012) recorded tree species diversity, distribution and population structure of tropical forests of Malyagiri hill ranges, Eastern Ghats, Odisha. A total of 1063 trees of 57 species were enumerated from 2.4 ha sampling plots from 60 quadrats, each 20 m x 20 m in size. Mean density and basal area were 443 trees ha^{-1} and 13.73 m^2 ha^{-1}, respectively. *Shorea robusta* was the most dominant tree species having an Importance Value Index (IVI) of 44.67 followed by *Terminalia alata* (31.98), *Madhuca indica* (17.3), *Anogeissus latifolia* (15.64) and *Diospyros melanoxylon* (13.41). Stem density and species richness showed a declining trend with increase in girth class of trees. The Shannon-Wiener index (H′) 3.38 and Simpson's index (C) 1.0 signified high tree species diversity forest.

Sobuj and Rahman (2011) studied the diversity of plant species in Khadimnagar National Park of Bangladesh by stratified random quadrat method. A total of 74 plant species (26 tree species, 17 shrubs and 31 herbs) were documented. Among the tree species, *Tectona grandis* represented the highest density (3.03/100m^2), frequency (76.67%), relative density (17.7%), relative frequency (11.3%) and relative dominance (37.3%). However, *Alstonia scholaris* showed the lowest density (0.07/100m^2), frequency (6.67%), relative density (0.39%) and relative frequency (0.99%). *Sterculia villosa* showed the lowest relative dominance (0.14%) and the highest abundance in *Chickrassia tabularis (4.58).* However, the lowest abundance was found in *Alstonia scholaris*, *Cynometra polyandra*, *Sterculia villosa* (1). For trees, shrubs and herbs Shannon-Wiener diversity index were computed as 2.76, 2.56 and 3.27, respectively.

Sundarapandian *et al*. (2000) studied forest ecosystem structure and composition along an altitudinal gradient (250-1150 m) in the Western Ghats, South India. A total of 58, 77, 125 and 105 plant species of 30, 28, 52 and 45 families were enumerated in different sites of moist deciduous forests (MDF, sites I & II), an evergreen forest (EF, site III) and a forest at higher elevation (HEF, site IV) respectively. Shannon index of tree species from four sites were 2.20, 2.37, 2.65 and 2.48, respectively. Dominant species recorded in the moist deciduous forests were the *Terminalia paniculata*, *Pterocarpus marsupium* and *Aporosa lindleyana*.However, in the evergreen forest dominant species were *Hopea parviflora*, *Vateria indica* and *Xanthophyllum flavescens.*

Thakur (2015) studied floristic composition of tropical dry deciduous forest in Baraytha forest of Sagar District, Madhya Pradesh. During the analysis of vegetation, total 82 species of 72 genera and 33 families of angiosperm were documented. According to priority different life-forms were Phanerophytes (55%), Therophytes (32.5%), Chamaephytes (6.25%), Geophytes (3.75%), Hemicryptophytes and Epiphytes both (1.25%).

Vinayaka and Krishnamurthy (2016) inventoried the forest ecosystem of Hulikal forest of Shimoga district, Karnataka. The dominant tree species identified in the study site were *Litsea floribunda*, *Garcinia gummi-gutta*, *Cinnamomum verum*, *Myristica malabarica* etc. Dominant shrubs like *Carissa carandas*, *Croton* *malabaricus*, *Memecylon malabaricum*, *Maesa indica*, *Leea indica* etc. From 30 quadrats belonged to 2172 samples were estimated. A total of 231 species of 60 families, among which 53 herb, 51 shrubs, 31 climbers and 96 were trees species. Due to closed canopy of trees lower diversity of herbaceous plants found in the forest. *Fahrenheitia zeylanica* was one of the most important species having Impotence Value Index (IVI) of 10.4 and basal area of 0.7. The Shannon diversity index value was represented as in the herbaceous species (3.6) , climbers (3.8) and tree species(4.3).Vegetative analysis of the forest indicated that the region is very abundant in species composition.

Visalakshi (1995) studied the floristic composition of *Dipterocarpus tuberculatus* dominated forest of Manipur, north-eastern India. They reported a total of 123 species and 48 families, where the diversity index of shrubs and herbs were greater than that of the tree species. Further, the author concluded that the presence of smaller number of larger girth class of tree species and higher number of the saplings and seedlings represented that the existing forest was characterised with persistent regeneration.

2.3 Productivity of lac insect in host plants

Green (1995) observed that the yield of stick lac was depened upon various factors such as insect strain, the host plant and the management practices of lac cultivation. In Bihar yields of stick lac in each plant was 6-10 kg per annum on kusum (*S. oleosa*), 1-4 kg on palas (*B. monosperma*) and 1.5-6 kg on ber (*Z. mauritiana*).

Choudhary *et al*. (1982) reported more than 400 species of host plants for the nourishment of lac insect. Various biological characteristics viz. survival of lac insects, fecundity and resin production differed greatly with the host species. Ghosal *et al*. (2002) revealed that the mean yield of brood lac (6350 g) and stick lac (33.0 g) was maximum in the middle portion of inoculated plant. 40 per cent coverage of inoculated tender shoot length produced maximum yield for brood lac cultivation and harvesting of stick lac increased with increased in shoot length coverage up to 80 per cent.

Sharma *et al*. (2007) revealed that the resin production of *rangeeni* and *kusmi* strains on number of host plants and for *kusmi* strain maximum yield was recorded in *S. oleosa* (22.84 mg), followed by *Acacia auriculiformis* (18.9 mg), *F. macrophylla* (9.43 mg) and *Cucurbita moschata* fruits (6.11 mg). Besides, it was found that *rangeeni* strain of *A. auriculiformis* produced 9.09 mg of resin, followed by *B. monosperma* (8.76 mg). *F. macrophylla* (7.49 mg) and *C. moschata* fruits (6 mg). A positive correlation was observed between the cell size and weight of resin yield. *Schleichera oleosa* plant for kusumi strain produced a maximum resin weight to cell size ratio of 6.452 and in *Acacia auriculiformis* it was 2.932 for rangeeni strain. Bhargava *et al.* (2008) calculated the stick lac yield of different host plants and found that annual lac yield ranged from 6 to 10 kg on kusum *(S. oleosa),* 1.5 to 6 kg on ber (Z. *mauritiana)* and 1 to 4 kg on palas *(B. monosperma).*

Patel (2013) studied the relative performance of ber (*Z. mouritiana*) in both the strains of kusmi and rangeeni. The mean brood lac requirement for inoculation ranged from 500- 700 g per plants. Number of lac insect settlement per 2.5 sq. cm in 30 days after BLI was 87.00, 79.30. 79.20 and 79.60 in kusmi strain. In rangeeni strain the settlement per 2.5 sq. cm was 32.02, 29.40, 22.44 and 20.28 at harvest. Mean number of male insects per 2.5 sq. cm ranged from 48.06 to 49.56 in kusmi and 29.28 to 35.32 in rangeeni. Average number of females per 2.5 sq. cm varied from 29.40 to 32.02 in kusmi and 20.28 to 22.44 in rangeeni. Mean fresh weight of 100 mature lac cells was 3.07 to 5.74 g in kusmi and 2.35 to 4.14 g in case of rangeeni lac. Dry weight of 100 cells was 2.56 to 5.40 g in kusmi lac and 1.79 to 3.42 g in rangeeni lac. The yield of raw lac ranged from 4.55 to 5.70 kg per tree in kusmi and 3.20 to 4.00 kg per plant in rangeeni. However, overall yield attribute was recorded significantly higher in kusmi than rangeeni over control.

Patel *et al*. (2014) studied the relative performance of kusmi and rangeeni strain. Yield of kusmi strain crop was higher than that of rangeeni strain crop. The mean fresh weight of 100 mature lac cells was maximum in kusmi 4.88 g followed by 3.61 g. In rangeeni strain it ranged from 2.97 to 3.38 g. There was 20.17 % more yield per plant in kusmi than that of rangeeni lac.

Namdev (2014) evaluated the performance of aghani crop in kusmi strain and nutrient management in *Z mauritiana* host plant in heavy rainfall region. The average brood lac used for inoculation ranged from 400-500 g. In 30 days after BLI in different treatments, the mean number of lac insect settlement per 2.5 sq. cm ranged from 79.93 to 90.02. During harvest after 172 days of BLI it ranged from 15.57 to 18.43 per 2.5 sq. cm. As compared to control, there was a significantly increased in number of settlement lac insect per 2.5 sq. cm. Besides, the mean number of stick lac ranged from 13.16 to 18.00. Mean fresh weight of 100 cells also ranged from 6.14 to 80.2 g and dry weight of 100 cells ranged from 4.25 to 7.90. The mean yield of stick lac ranged from 3.83 to 5.08 kg per plant at harvest. It was maximum on (NPK) followed by N, NP and control.

Namdev *et al*. (2015) calculated the performance of lac yield of *B. monosperma* and *Z mauritiana*. Yield of lac was low due to lack of nutrient treatment of the host plants. The average weight of 100 fresh cells of lac at harvest and dry cell weight increased significantly in nutrient management of *Z. mauritiana* plant vis-a-vis to control. Among the different treatments, production of kusmi lac in *B.monosperma* and *Z mauritiana* was 5.08. 4.54. 5.33 and 3.33 kg respectively per plant. Nutrient application in *Z. mauritiana* for lac crop significantly increased lac production. Mean weight of 100 fresh cells varied from 6.14 to 8.02 g in various treatments of nutrients.

Meshram *et al*. (2018) calculated productivity parameters of the host plant for commercial lac production. The host plant of kusum (*S. oleosa*) for kusmi strain of aghani (winter) crop produced maximum number of stick lac 237.91 per plant, mean length of 52.14 cm per stick lac, maximum fresh weight of stick lac 47.68 g per 30 cm stick, highest weight of scraped lac 23.96 g per 30 cm stick, total weight of stick lac 54.94 kg per plant, maximum weight of fresh and dry 100 cell 7.31 and 6.86 g. Among the various commercial host plants kusum (*S. oleosa*) for kusumi strain was found to be the best host for the lac cultivation followed by ber (*Z. mauritiana*) for rangeeni strain of baisakhi (summer) crop.

Sharma *et al*. (2005) revealed that each lac insect *K. lacca* has ability to multiply 250 times more in one descent and showed very less brood lac and yield ratio. In the laboratory condition each single lac cell on *F. macrophylla* yielded around 56-175 times more lac. However, in the field situations yield reduced to 45-50 times. When the infestation was done by mass inoculation and the extent of operation was increased, the yield was extremely reduced to 3, 4 and 7 times of the inoculation on *B. monosperma*, *F. macrophylla* and *Z. mauritiana*, respectively for rangeeni strain; and 5, 9 and 14 times, respectively, on *F.macrophylla*, *Z.mauritiana* and *S.oleosa* for kusmi strain during rainy/winter season crop under field studies. With improved lac culture operations, damage due to pests, quantitative and qualitative loss of brood lac, and management of lac insect population on the lac host plant became harsh and critical factors by affecting the lac crop adversely.

Sahu (2016) studied the performance of survival and yield of rangeeni lac on *B. monosperma* applied with different micro nutrients and humic acid. Average weight of brood lac used for inoculation ranged from 600 to 1200 g per plant. Among the treatments in 30 days after BLI, the mean population density per 2.5 sq. cm varied from 44.95 to 50.28. However, during harvest at 84 days after BLI it was reduced to varied range from 20.86 to 26.05. Among the different treatments at 50 days after BLI the mean population density of live female lac insect per 2.5 sq. cm ranged from 44.95 to 50.28. At crop maturity female insect ranged from 20.86 to 26.05 per 2.5 sq. cm. The yield of brood lac per plant was varied from 2.80 to 4.59 kg and maximum in humic acid treatment and minimum in control. The average fresh weight of 100 matured cells varied from 6.36 to 11.14 g and maximum in humic acid treatment and lowest in control. Mean dry weight of 100 cells ranged from 4.95 to 8.21 g, it was the highest in humic acid treatment and the lowest was in control.

Shah *et al*. (2015) stated that lac crop served as a subsidiary cash crop of forest dependents particularly for rainfed and resource poor farmers. They found that *K. lacca* inoculated in *Zizyphus mauritiana* (Lamb.) treated with NPK promoted increase in both the survivability of *K. lacca* insects as well as resin production by it. During maturity of the lac crop the mean percentage survivability of lac insect was the highest (17.21%) over control for the plants treated with NPK. Similarly, the mean fresh weight (g) of 100 cells of lac insect was also maximum in case of NPK (21.39%) over control, followed by N and NP treatments (15.84% and 14.25%, respectively). The mean dry weight (g) of 100 cell of lac insects was the highest in case of NPK (19.71%) followed by NP (14.50%) and N (13.57%).

The above literature review clearly reveals limited information on the biological attributes of lac insect and their natural enemies (predators and parasitoids), host plant diversity and the productivity of lac insect in major host plants in Odisha in general and in particularly in the peripheral regions of Kuldiha Wildlife Sanctuary (KWS) in Balasore district. Depletion of forest resources due to anthropological disturbances, lack of knowledge on species diversity study and seasonal incidence of natural enemies of lac insect hinders the production of lac production. Thus, the present study is designed not only in order to fill in knowledge gap in the existing information of vegetation diversity, variation in emergence profile of lac associated fauna and production of lac but also for future promotion of lac cultivation and eco-restoration strategies in different regions of Odisha, and the country as well.

3.1 Study site

The present study was undertaken in periphery areas of Kuldiha wildlife sanctuary, Nilagiri block of Balasore district under North Eastern Coastal Plain Agro-climatic Zone of Odisha. Nilagiri block of Balasore district is known as Tribal Sub-Plan (TSP) area. Kuldiha Wildlife Sanctuary is a part of mega-habitat surrounded by the trijunction of Balasore, Mayurbhanj and Keonjhar districts. It is situated in the south-western part of Balasore district under Nilagiri Civil Sub-Division in the State of Odisha. It is one among the 12 blocks of Balasore district. It is located 25 KM towards west from district head quarter Balasore and 193 kms from state capital Bhubaneswar towards south. The wildlife sanctuary is found in the 15 m elevation (average altitude) and lies between 21° 25' to 21° 30' north latitude and 86° 35' to 86° 40' east longitude **(Figure 3.1).** The area mainly comprises of hills and plateau inhabited by tribal dwellers. Geographical area of study site is approximately 290 Km^2. It is surrounded by Remuna, Udala, Kaptipada and Oupada blocks in east, west, south directions, respectively. The hills of Nilagiri has the highest peak of 543 metres (1,781 ft.) above sea level. The periphery of the sanctuary is 150.5 kms. Kuldiha wildlife sanctuary has features of all the four biotic provinces viz. Eastern Plateau, Chhotanagpur, Lower gangetic Plain and Coastline. In the Nilagir block, out of 138 villages of 25 Panchayats, only in 15 villages of Garadihi, K. C. Pur and Pithahata Gram Panchayats, the village community have been practising lac cultivation as their means of sustenance, whereas in each village 5-10 households have been engaged in lac rearing.

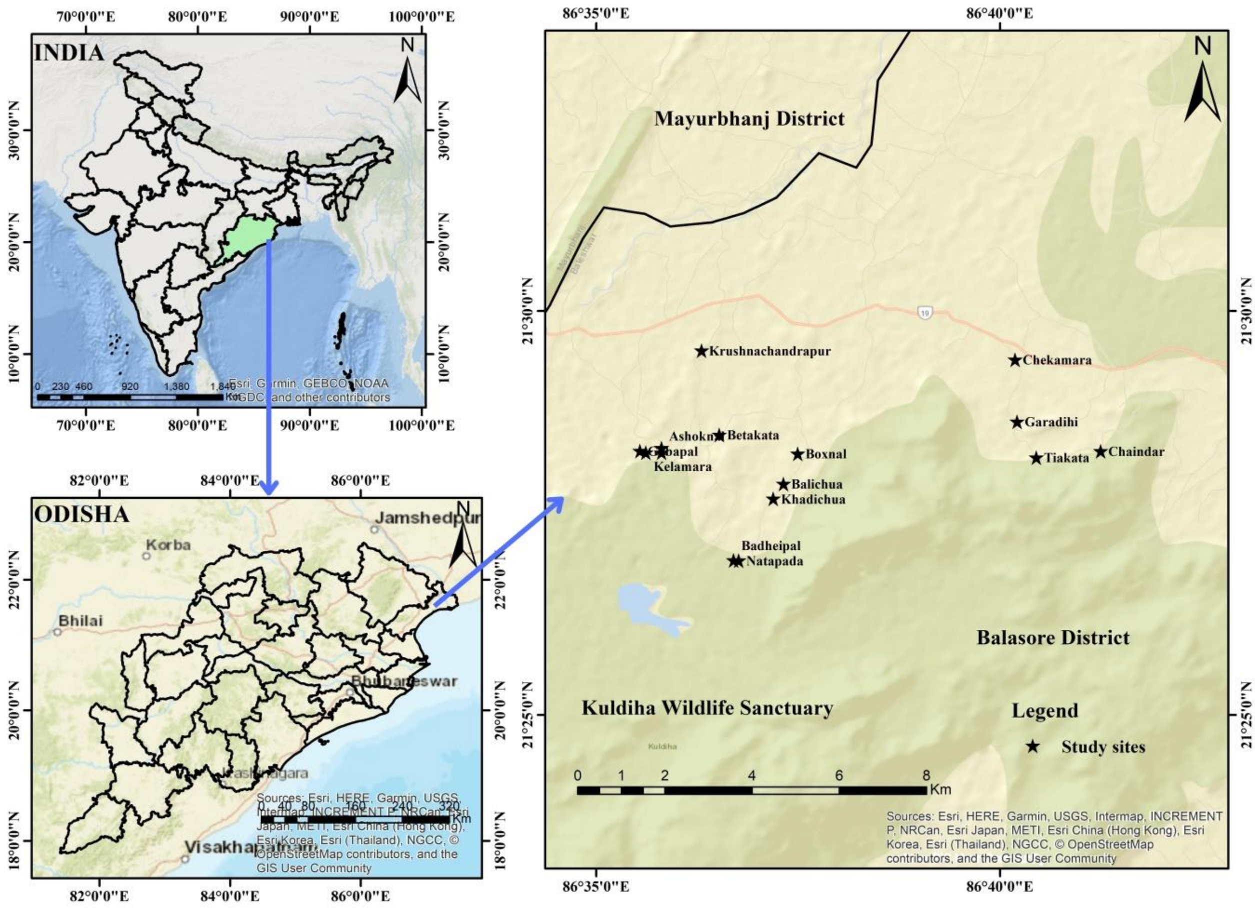


Figure 3.1 Map showing study site.

3.1.1 Geology

Kuldiha wildlife sanctuary predominantly represents mountain system covered by some small plains and valleys particularly in the south west boundary. The area consists mainly of formations of Archaean system comprising of laterite stone, basic granulites and intermediate to acid chornockic veins. They have been converted into sub-recent & recent deposits, such as laterties and alluvial soil. Based on field evidence, the rock formation consists of Khondolites are represented by quartz, garnet, sillemanite, schist and garnetiferous quartzites. They are greyish to purple or reddish brown in colours. The constituent minerals are quartz feldspar, garnet, sillemanite and occasionally graphite. Basic pyroxene granites rocks are dark coloured and are generally fine to medium grained. Acid & Intermediate Charnockite rocks are fine to medium grained, greenish grey in colour. Garnet ferrous granite gneisses and granulites rocks are medium grained, grey in colour. A good exposure of laterite is found in this area of the south western portion. This is an alteration product of khondolites.

3.1.2 Soil Characteristics

Soils of study area are mainly gravelly and lateritic with low fertility status. However, soils derived from granite gneisses are much fertile. Recent deposits of alluvial soils are primarily found in the bank of nala, river, perennial stream, seasonal springs, dam and other water bodies which are much limited in this area. In course of time, khondolites are usually deeply weathered producing a soil varying from sandy to heavy red loam. The red colour of soil is due to presence of hydrated oxides of iron. Due to its presence of more iron content, this type of soil is not suitable for agricultural purpose.

3.1.3 Climate

The climate of the study site is generally hot with high humidity, characterised by extremely warm in summer and moderately cold during winter. Usually, May is the hottest month whereas December is the coldest month of this district. Monsoon season generally spans from the month of June. During June to October the rainfall constitutes around 75% of the actual rainfall of this district. The area is characterised with a subtropical climate having three distinct cropping seasons i.e. summer, monsoon and winter. Winter season starts from November to February, whereas March-April-May forms the summer months. The monsoon generally prevails during June-July- August-September; and October constitutes the post monsoon period. The mean annual rain fall is about 1630 mm and enjoys a tropical climate. Because of its proximity to Bay of Bengal, climatically this tract is comparatively humid- hot. The mean maximum temperature is 38° C during April – May and minimum 8° C during November – January. The maximum temperature at times reaches beyond 42°C (**Figure 3.2**). Kuldiha sanctuary stands as water tower for the southern part of Balasore, northern part of Bhadrak and for a narrow strip in the southern part Mayurbhanj which are proximity of Balasore. Kuldiha acts as the inner land parallel to Bay of Bengal. Thus, this hill range gets comparatively more rainfall due to the coastal effect (Bay of Bengal) and monsoonal flow of wind from Bay of Bengal.

3.1.4 Vegetation and land use

The forests of Kuldiha are having sub-tropical vegetation, which is broadly divided into four forest types viz. i) Northern tropical semi evergreen forests, ii) Peninsular (Coastal) Sal forests, iii) Moist mixed deciduous forests and iv) Mixed dry deciduous forests. Agriculture is the main occupation of tribal people, whereas collection of Non-Timber Forest Produces (NTFPs) is the next important occupation. During lean periods, the tribals mostly collect these produces from the forest areas. They collect firewood, timbers, medicinal plants, leaves etc. are from the forests.

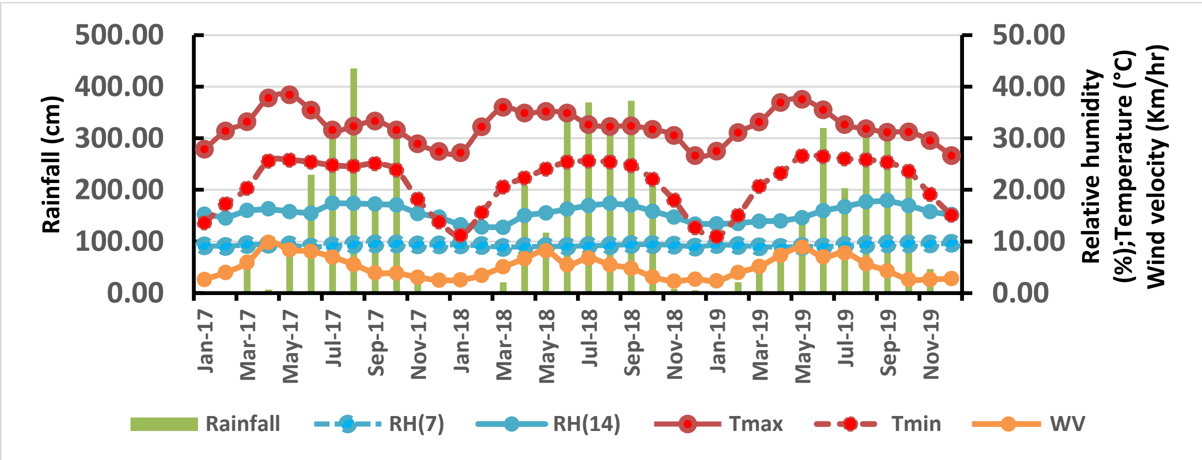


Figure 3.2 Climatogram of the study site during 2017 to 2019. RH (7) = Relative humidity at 7am; RH (14) = Relative humidity at 2 pm; Tmax = Maximum temperature; Tmin = Minimum temperature; WV = Wind velocity)

Villagers residing at close proximity allows cattle into the sanctuary for open grazing, which is a common practice in the area. Lac cultivation is also a subsidiary source of income of forest fringes. The lac host trees, namely Kusum (*Schleichera oleosa)*, Palas (*Butea monosperma)* and Ber (*Zizyphus mauritiana*) are commercially exploited for lac cultivation which are known as common or major host plants or excellent host plants. Diversified topography and unique geological formation spread out a wide range of different habitats for growth of many types of plant species. The common species of these regions are *Acacia nilotica*, *Adina cordifolia*, *Aegle marmelos*, *Albizia lebbeck*, *Albizia procera*, *Alstonia scholaris*, *Anogeissus* *acuminata Anthocephalus chinensis, Azadirachta indica, Bombax ceiba, Boraassus flabellifer, Buchanania lanzan, Cassia fistula, Cassia siamea, Protium serratum, Pterocarpus marsupium, Shorea robusta, Syzygium cerasoides, Syzygium cumini, Tamarindus indica, Dalbergia latifolia, Dalbergia sissoo* etc. Generally, original forest in some patches has been destroyed by illicit felling, shifting cultivation in the past and other anthropological activities. Tree growth is slow and getting re-established. Gregarious prevalance of Sal in hills and plains in the study area constitute 80 percent of vegetation.So, the site is considered as natural abode of lac insect, *Kerria lacca* (Kerr). Increase in human and livestock population has been exerting more pressure on the declining of forest resources. The average land holding size of the farmers in the district is only 0.78 ha and considered the lowest in the state due to higher population density. The marginal farmers dominate the farming communities (83.76 %) and occupy 57.50 % of the cultivable area. Small and semi-medium farmers covered only 15.91 % of the total farming community and occupy 39.40 % of the cultivable area. Percentage of large and medium farmers (>4 ha) are very less in the district. Fragmented landholding sizes are major factors for hindering improved agriculture practices as well as farm mechanisation.

3.2 Lac species description

Lac, the only natural resin of animal origin is secreted by a specialized group of insects called lac insects. There are 19 species of lac insects found in India among which *Kerria lacca*, Tachardiidae: Hemiptera species is most widely exploited for commercial lac production. At present our country is the largest producer of lac accounting for 50-60 percent of total world's lac production.

The first scientific information of the lac insect was given by J. Kerr in 1782, which was published in Philosophical Transaction of Royal Society of London (Vol. 71,pp 374-382). The first scientific name given to it was *Tachardia lacca* following the name of French Missionary Father 'Tachardia'. The systematic positions of Indian common lac insect revealed that the generic name Laccifer Oken is invalid and rejected. Kerria appears to be the oldest and the valid name for this genus and this change has been approved by the Intrenational Commission on Zoological

Nomenclature. The names of the family and other supra-generic taxa have also been changed according to article – 36 of the International Code of Zoological Nomenclature .Thus, the systematic position of this insect is as follows:

Phyllum-Athropoda

Class—Insecta

Order—Hemiptera

Sub order—Homoptera

Super Family – Coccoidea

Family – Tachardiidae

Subfamily ---Tachardinae

3.2.1 Morphology and Anatomy of Lac insect

Lac insects are unisexual in nature. Sexual dimorphism is distinctly found in this insect. The morphology and anatomy of adult male, female and crawler (larva) are described as below.

3.2.1.1 Adult female

Morphology

A sexually mature female lac insect has a disc-like body structure with wavy sub-circular outline (**Figure 3.3**). During post-sexual period the insect develops into a pyriform or globular structure measuring about 5.0 mm in length and about 3.0 mm in width (Kapur, 1962; Ramani,2002). The female does not have segmentation, whereas anterior and posterior ends of this insect cannot be clearly distinguished due to distorted growth in adults. Its oral aspect is attached to the host plant and the opposite aboral aspect bears the branchia, dorsal spine and anal tubercle. The body is covered with a thick resinous covering with three openings – two for branchia (respiratory openings) and one for the anal tubercle that bears the reproductive as well as excretory openings. The legs are absent and the vestigial antennae are present in the oral end. The mouth parts consist of four stylets (maxillae and mandibles) projecting through a short conical labium.

At the tip of the anal tubercle the anal opening is found and surrounded by a circlet of ten anal setae. To minimise the blocking of openings for the anal tubercle a large number of wax glands opened in between the anal setae which produce waxy filaments continuously. Towards the anterior end of aboral aspect there are two stigmatic processes known as branchia, whose tips are highly chitinous forming the branchial plate. A bunch of wax glands opened on branchial plate found to prevent choking of the branchial opening on the resinous covering and produces thick waxy filaments. At the base of branchium, the anterior spiracle is present. A triangular area is formed by anal tubercle and branchia. There is a pointed pedicellate structure located in the center of the area known as dorsal spine. The presence of six marginal pore clusters which forms a girdle around the body and each cluster has a W-like pattern (Ramani, 2002).

Anatomy

i. **Digestive system**

The stylets themselves formed a sucking tube. This tube opens into a short pharynx which leads into a long and thin oesophagus. The oesophagus leads into a long convoluted ventriculus located inside the distal part of the colorectum. The ventriculus leaves the colorectum as intestine. A pair of Malpighian tubules opens at the junction of mid- and hind-intestines through a short duct called as ampulla. The hind intestine re-enters the colorectum and remains closely associated with the ventriculus. The colorectum is club-shaped structure which opens through anal opening on the anal tubercle.

ii. **Respiratory system**

The respiratory system consists of four main tracheae which arise from anterior and posterior spiracles that branched out to permeate inside the body.

iii. **Nervous system**

Anterior to the mouth parts there is a partially fused cerebral ganglia, which connected to club-shaped ventral ganglion through a pair of connectives. The ventral nerve cord is short and terminally has divided into two branches. Five pairs of nerves arise from the ventral ganglion which supplies various organs.

iv. Reproductive system

The acrotropical type of ovaries consists of an elaborately branched system of ovaries filling practically the entire body, in which the embryos develop. The oviducts unite to from the uterus which leads to vagina. The vagina opens out through vulva located at about the middle of the anal tubercle, on the ventral side. The club shaped seminal receptacle opens into the uterus through a narrow duct. The ovariole is composed of a germarium a viellarium and a pedicel. The nurse cells,4-5 in numbers of the vitellarium provide the nutrition to the developing embryos. The ova are fertilized when still inside the ovarioles and eggs continue to develop within the ovarioles. The fully developed embryos are encased within a chorion. As the anal tubercle retracts during oviposition, a larval chamber is formed underneath the resinous covering into which the embryos are laid.

v. Resinous and non-resinous glands

The insect possesses different types of epidermal glands, distributed throughout the body which produced both resinous and non-resinous (mostly waxy) materials. The resin glands are unicellular epidermal glands and distributed throughout the body. The resin is secreted in the form of tiny droplets which coalesce to form a continuous covering. The wax secreting glands are also unicellular epidermal glands. These are distributed in groups in different parts of the body

(Ramani, 2002).

Figure 3.3 Adult female Lac insect

3.2.1.2 Adult Male

Morphology

The adult male is about 1.5 mm in length. The males may be alate or apeterous with a pair of wings from mesothorax. The spread of the wing is about 1.4 mm **(Figure 3.4)**. The alate hardly fly even though they are capable of active flight. Out of two pairs of ocelli, one pair on the dorsal and another on the ventral side of the head are present.

Figure 3.4 Adult male Lac insect

The antennae (~ 0.9 mm in length) are normally seven segmented in apterous male and eight segmented in alate male. The thorax is differentiated into protharacic, mesothoracic and metathoracic segments. There are two pairs of spiracles and three pairs of legs. The abdomen consists of nine or ten segments. The pairs are pointed, curved and highly chitinous structure enclosed partly by the genital sheath. A pair of caudal pits are located at the terminal abdominal segments. The wax secreting glands in these pits produce thin and long waxy filaments, sometimes referred as caudal setae (Ramani,2002).

Anatomy

The male insects do not feed as adults but an alimentary system similar to that of larva and female is present. The respiratory system consists of mesothoracic, metathoracic spiracles and system of trachea which supply to different parts of the body. The muscular system is well developed, especially in the thorax. The nervous system consists of cerebral ganglion and ventral ganglion joined by cricumoesophageal connectives. The cerebral ganglion is composed of four lobes. The reproductive system consists of long ovate testes extending up to thoracic region. The vasa deferentia join to form the ductus ejaculators which ends at penis. The resin secreting glands are absent in the adult male. Two prominent waxy filaments from the posterior end is seen after emergence. These filaments are produced from wax secreting glands opening into a pair of depression, located on either side of ninth and tenth segments.

3.2.1.2 Crawler

Morphology

The first instar larva – the crawler, is sub -ovate in outline with a narrow posterior end. It measures about 0.6 mm in length and 0.2 mm across the thoracic region. Usual colour of the crawler is crimson, but they may be yellow, cream or white in colour (**Figure 3.4**). Body is divided into head, thorax and abdomen, without clear demarcation. The head bears a pair of six-segmented antennae, a pair of ocelli and ventrally the mouth parts. It has piercing and sucking type of mouth parts. The oral stylets are extreamly long and lie looped occupying most of the abdominal cavity. In this crawler paired prothoracic and mesothoracic spiracles are present. The leg consists of caxa, trochanter, femur, tarsus and claw. (Kapur, 1962; Ramani, 2002).

Anatomy

The resin secreting glands are distributed throughout the body. There are also epidermal wax glands. These glands are concentrated in the branchial plate region near protharacic spiracles and aroud the anal opening. The salivary glands are situated on either side of the mouth parts, each glands resembles a compact bunch of grapes. They are opened through a common duct. The nervous system consists of the cerebral ganalion connected to an elongated ventral ganalionic mass, through cicumoesophageal connectives. There are two pairs of spiracles in ventral side. Three tracheal trunks arose from each of these openings and form an interconnected network throughout the body (Ramani, 2002).

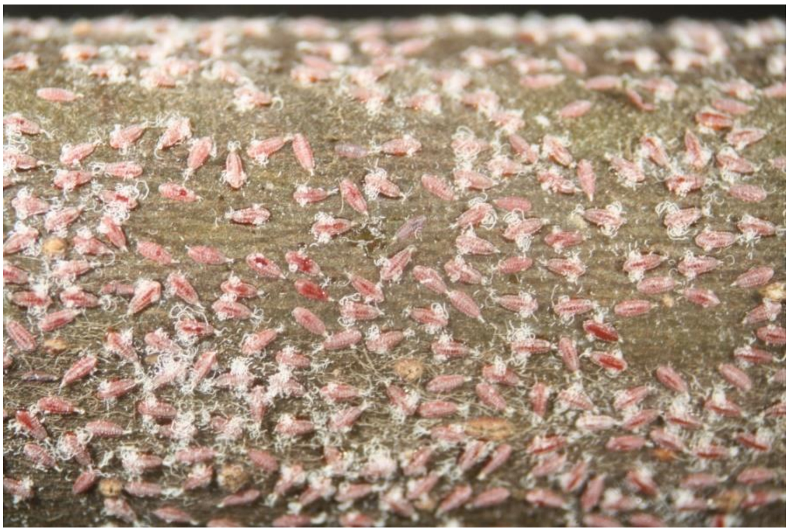


Figure 3.5 Crawler of Lac insect

3.2.2 Life Cycle of Lac insect

The life cycle of lac insect starts with first instar larval stage, the crawlers. The crawlers after settlement undergo three successive moulting to become the adult insects. The following descriptions are based on the studies of Indian lac insect, *Kerria lacca* which is commonly used for commercial lac production in our country (**Figure 3.5**).

The first instar is mobile and crawls over the shoot of host trees. It settles and feeds on phloem sap by piercing its proboscis into phloem region of shoot. Normally 200-300 young lac insect crawlers settle in one square inch area (Mishra et al., 2000). The males and females cannot be distinguished at this stage. The crawlers start secreting resin in minute quantity after 2-3 days of settlement. Except three body openings (Anal tubercle and two respiratory pores), the lac insect covers itself completely by its secretion of the lac resin. To avoid covering of these holes by resin, the lac insect secretes wax, which is white thread-like structure (Sharma and Ramani, 2002).

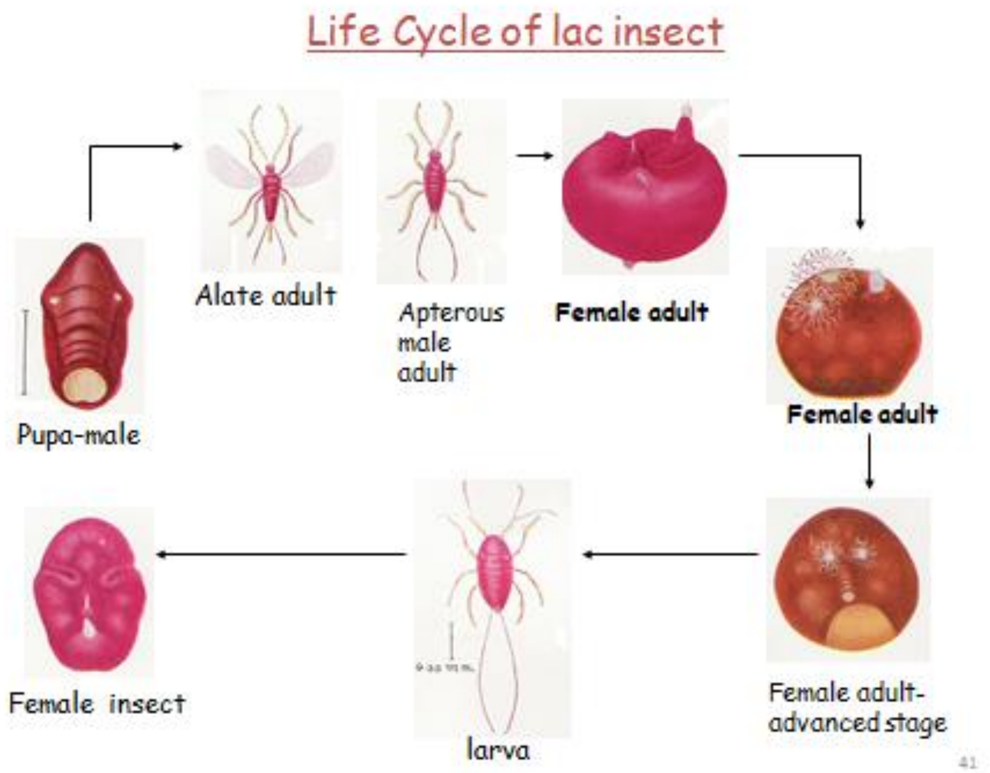


Figure 3.6 Life Cycle of Lac Insect

3.2.2.1 Metamorphosis

Metamorphosis in male and female insects is different. Complete metamorphosis occurs in male insect. There is a resting stage (Pupa) between young lac insect and adult stage. Incomplete metamorphosis occurs in female insect with absent of pupal stage (Jaiswal and Sharma, 2002). Before reaching the adult stage, lac insect moults thrice. The duration of each stage depends on the host tree species on which it feeds, lac crop and prevailing environmental conditions. The young lac insect larvae emerged from matured female cell, moulted and reached second stage. The male is elongated and cigar-shaped while female is round in shape. The lac cell grows more along the longitudinal axis and vertical axis, in case of male and female insects respectively.

The male and female larvae lose their legs, antennae and eyes after first moult to become second instar. The second instar male insect transforms into pre-pupa which later on metamorphoses into pupa and the pupa stage is a non-feeding resting stage. The pupa remains inside the outer covering of second instar, which does not shed. The internal organs of adult male insect are formed inside the pupa, as the larval internal organs degenerate by histolysis and adult internal organs are formed by histogenesis. The mouth parts of adult male insect are non-functional; hence it is non-feeding stage.

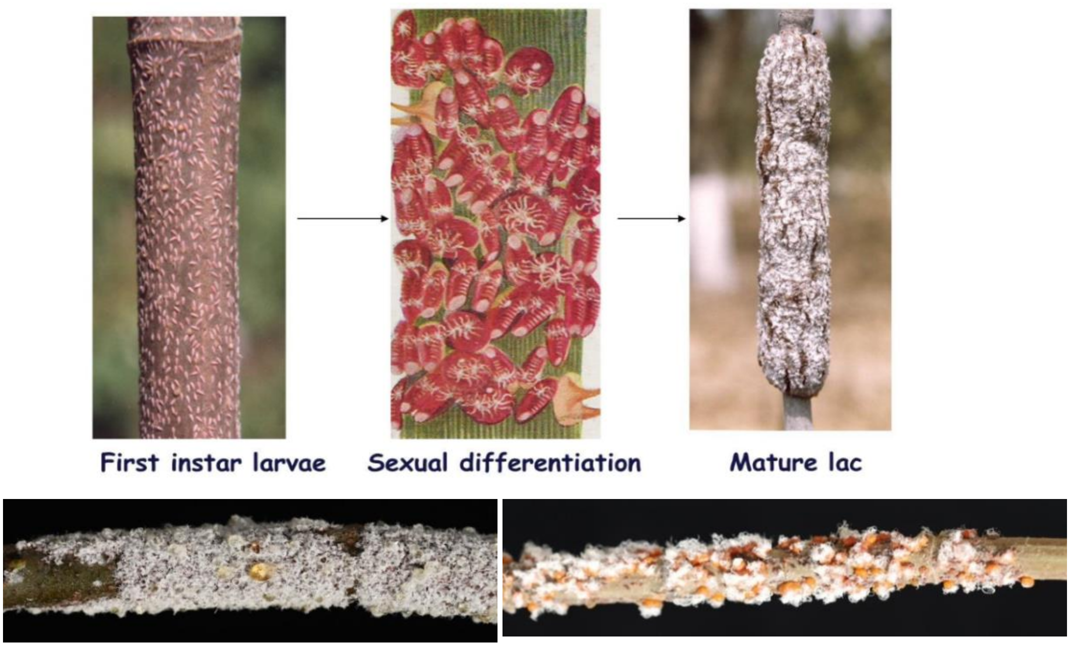
The adult male emerges out of pupa by pushing the operculum with the abdominal end of body. Within hours it starts mating with mature female insect. In the second instar female insect, the legs become atrophied and size of the antennae is reduced. Numbers of anal ring plates which are six in first instar become ten in second instar. By the time male insect reaches maturity and female insect also matures sexually. The duration of different stages depends on the strain and season of crop along with host tree and location (Jaiswal and Sharma, 2002).

3.2.2.2 Fertilization

When sexually mature, the male and female insects mate. It has been found that one male insect is capable of mating with 40-45 females and vice versa (multiple coitus). The life span of adult male is only 2-4 days after its emergence. They die after mating while female insects survive up to crop maturity. The female insect secretes lac resin in large quantities rapidly only after fertilization. The unfertilized female secretes resin in vary small quantity. Resin secreted by fertilized female protects mother insect as well as its young ones at later stages. The rate of secretion of wax filaments and honey-dew also increases after fertilization. The ova are fertilized by the spermatozoa inside the ovarioles and eggs continue to develop within the ovarioles (Jaiswal and Sharma, 2002).

3.2.2.3 Oviposition

After fertilization, the female insect prepares itself for oviposition inside the lac cell after long interval of time which differs from crop to crop. In katki and baisakhi crops it requires 7-8 and 18-20 weeks, respectively (**Table 3.1**). A mature female insect oviposits on an average of 300-400 eggs. When female is ready to oviposit, it contracts its body, thus creating space between insect and resin wall. Simultaneously some powdery wax and its filaments are secreted and shed in vacated space before egg lying in order to avoid injury to larvae. The anal tubercle is withdrawn inside the lac cell and eggs are laid in this space. The lac insect is ovo-viviparous i.e., it lays eggs which hatch immediately but the young larvae remain inside the resinous cell till environmental condition outside is not favourable for them. The young larvae come out through a pore one by one in large numbers over the lac encrustation. This crawling of first instar larvae in large number is called "swarming" (Kapur, 1962; Jaiswal and Sharma, 2002).



Swarming in lac Brood lac for inoculation

Figure 3.7 Stages of Lac insect development

Table 3.1 Strains of lac insect associated with different hosts in different seasons and their duration of maturity

Strains of lac and lac crops								
Sl. No.	**Inoculation with Lac Swarming larva**	**Lac Host Plant**	**Weather**	**Seed Inoculation**	**Emergence of male insects**	**Crop harvested**	**Female insects mature and give rise to swarming larvae**	**Period of maturity (In month)**
A.	**Rangeeni Crops**							
i	Katki crop	Palas	Rainy Season	June-July	Aug-Sept	Oct-Nov	Oct-Nov	4
ii	Baisakhi crop	Palas	Summer	Oct - Nov	Feb-March	April-May	June-July	6-8
		Ber	Summer	Oct-Nov	Feb-March	May-June	July-Aug	6
B.	**Kusumi Crops**							
i	Aghani crop	Ber	Winter	June-July	Sept.	Dec-Jan	Jan-Feb	6
ii	Jethwi crop	Kusum	Summer	Jan-Feb	March - April	June –July	June –July	6

3.3 Lac Hosts

3.3.1 Specific features of major lac hosts

Lac is produced by two strains, i.e., kusmi and rangeeni of lac insect in India. The lac insects thrive on the sap of certain plants called lac hosts that occur wild in nature. Based on the degree of preference of lac insect, host plants can be classified as (i) good hosts, which include such species on which these insects thrive well, producing manifold yield, (ii) poor hosts, on which lesser yield is obtained due to reduced survival of the insects, and (iii) non-hosts, on which no lac is produced due to mortality prior to sexual maturity (Srivastava, 2002; 2007).

On the basis of preference in use for lac cultivation by Indian cultivators, centuries of practical experience and distribution in our country, the lac hosts are placed under three categories, viz. (i) common or major hosts, (ii) occasional hosts, and (iii) rare hosts.

The lac hosts are mostly confined to 'Dicotyledonous' group of 'Angiosperms'. The largest concentration of lac host plants of lac insects in India, occur in the family Fabaceae (Leguminosae) while the family 'Moraceae' with single genus Ficus, comes next in importance in lac cultivation (18%). The species belonging to this family find an important place for cultivating baisakhi lac crop as they are not deciduous for long period during hot summer months (Srivastava, 2002; 2007).

According to Roonwal *et al*. (1962) there are 113 species of host plants belonging to 53 genera which are categorised in to common or major hosts (7 genera, 14 species) occasional hosts (6 genera, 14 species) and rare hosts (40 genera, 85 species). Among the plant species, *Butea monosperma* Roxb., *Schleichera oleosa* (Lour.) Oken, and *Zizyphus mauritiana* Lamk. are good hosts (Mishra *et al*., 2000) and are commercially exploited for lac cultivation. *Acacia catechu*, *Prosopis juliflora* (Sw.) DC., *Ficus elastica* Roxb., *Ficus lacor* Buch.-Ham., *Ficus religiosa* L., *Ficus semicordata* Buch.-Ham. ex Smith, and *Cajanus cajan* (L.) Millsp. are less preferred hosts for the lac insect. In contrast, *Azadirachta indica* A. Juss., *Citrus medica* L., *Eucalyptus globulus* Labill., and *Ricinus communis* L. are rare hosts for the lac insect, because *of* insect infestation and completion of life cycle are less favoured on these four plant species. The good lac hosts are classified in the following groups based on the findings of series of experiments conducted on them towards various aspects of lac cultivation (Srivastava, 2002).

A. Host plants of commercial importance

Butea monosperma (Fabaceae), *Zizyphus mauritiana* (Rhamnaceae), *Schleichera oleosa* (Sapindaceae).

B. Host plants of specific importance

- **Summer Brood Preserver:**

  Albizzia lucida (Mimosaceae), *Ougeinia oojeinensis* (Sandan – Fabaceae), *Ficus cunea* (Porho – Moraceae), *F. lacor* (Pakur), *F. religiosa* (Pipal).

- **Alternate Kusumi hosts**

  Albizzia lucida (Mimosaceae), *Acacia catechu* (Khair, Aghani – Mimosaceae).

- **Winter Brood preserver**

  Flemingia macrophylla (Bhalia, Fabaceae).

C. Host plants of regional importance

Acacia arabica (Babool- – Mimosaceae), *Grewia disperma* (Tiliaceae) – Assam, *G.serrulata* (Pansaura-Tiliaceae) – Assam, *Leea aspera* (Vitaceae), *L. crispa* (Vitaceae) – Assam, West Bengal, *L. robusta* (Vitaceae) – West Bangal, *Shorea talura* (Jalari- Dipterocarpaceae) – Mysore and Madras, *Zizyphus xylopyra (*Ghont- Rhamnaceae) – M.P., U.P. and Punjab.

D. Host plants for plantation use

Flemingia macrophylla, Albizzia lucida, Cajanus cajan, Zizyphus mauritiana, Flemingia semialata.

The factors that determine whether the lac insect will flourish on a particular host species or not is the character of the sap of host plant. It is believed that the sap reactions of a good lac host should be near about neutral or slightly acidic (e.g. pH values between 5.8 and 6.0) and that the sap density of good lac host plants in lower than that on non-lac hosts. The sap reactions of non-lac hosts show distinct acidity or alkalinity. There are two strains of the lac insect, the strain that thrives on Kusum is called kusumi strain and the one that comes up on all other hosts is known as rangeeni strain because of the deeper colour of the lac it produces. Both the strains have two generations in a year. About 90 per cent of lac produced in India comes from rangeeni strain.

3.3.2 Major commercial Lac host species in the study area:

1. ***Schleichera oleosa* Lour. (Vern. Name – Kusum)**

Habit: A large , deciduous (nearly) tree, with a short, stout bole, attaining a height of up to 20 ft. and a girth of 8 ft. and over (**Figure 3.6**).

Figure 3.8 A Kusum tree with Lac infestation

Distribution and Habitat of Kusum: These plants are well distributed throughout Sub-Himalayan tracts from the Sutlej to Nepal (apparently absent from Assam and Bengal), Chhotanagpur, Travancore and throughout Myanmar. In Sub-Himalayan tracts and outer hills, common on well-drained boulder deposits, often occurring in quantity alongside of ravines or along with banks, marking edges of terraces common on south face of Siwalik range, on sides of ravines on sand stone or on boulder beds. In Madhya Pradesh these are scattered in mixed forests chiefly near stream banks, common in Raipur district. Plants are also characterised by typical of mixed deciduous forests of a somewhat dry type soil. Kusum plants are generally known as hardy plants that can tolerate a variety of extreme (both frost and drought) temperatures.

Lac cultivation: Kusum has been considered as the best tree for lac cultivation due to production of finest grade of coloured shellac. The species is not gregarious and generally found thinly scattered over forests, rendering lac cultivation on it rather difficult, is a host of "All India" importance. In this species, there are two commonly (but not botanically) recognized varieties, viz. 'Charka' and 'Kariya'. The former variety has a lighter coloured bark then the latter and does not produce lac well. Lac grown on it often results in failure of the crop. Variation in production of seedlac normally ranges from 68-69% in different crop seasons of total kusmi lac production. Approximately 4 kg broodlac is needed for inoculating an average Kusum tree which produces an average of 30 kg broodlac per tree.

2. ***Butea monosperma*** **(Lam.) Taub (vern. Name – Dhak, Palas)**

Habit: A medium sized deciduous tree, with a small somewhat crooked trunk, 10-15 ft in height and 5-6 ft. girth (**Figure 3.7**).

Figure 3.9 Palas tree with Lac infestation

Distribution and Habitat: Palas trees are found throughout the plains of India and Myanmar, ascending in the outer Himalayas to almost 3,000 ft. or occasionally higher and on hills of southern India to 4,000 ft. These are absent in most arid regions, typical of grassland, frequently gregarious, as in the Tarai region of northern India. Plants can grow in water logged situations of black cotton soil and even in saline soil. Often they have formed pure patches in grazing ground and other open places. Palas plants are escaping extermination due to immunity from grazing and power of reproduction from seed and root suckers. They have also the ability of recovering from the effects of constant lopping.

Lac cultivation: Palas is the most important host plant, accounting for the bulk of the lac produced in India. The lac produced however, ranks in quality below that produced from Kusum and Ber (Troup, 1919). According to Srinivasan (1956) two varieties, viz. ‘Charka’ and ‘Kariya’ of this species occur which are however, botanically inseparable; the former variety has lighter coloured bark than the latter. Lac produces easily in the kariya variety but generally not so well in the charka variety.

Variation in production of seedlac normally ranges from 50-56% in different crop season of total rangeeni lac production. Approximately 750 g to 1 kg broodlac is normally needed for inoculating in an average Palas tree which produces an average of 5 kg broodlac per tree.

3. *Zizyphus mauritiana* **Lamk. (Vern names – Baer, Ber and Beri).**

Habit: A small to moderate sized deciduous (almost evergreen) tree, with a short bole, spreading rounded crown and drooping branches armed with stipular spines (**Figure 3.8**).

Figure 3.10 Ber tree with Lac infestation

Distribution and Habitat: Ber plants are distributed throughout the greater part of India, either wild or naturalized, ascending to 5,000 ft. in the Himalaya (e.g. on waste lands in valleys of Kumaon Hills). These are also found in forests of Siwaliks and Sub-Himalayan tracts of Punjab and North-Western Province (Pakistan) also in the Deccan and upper Myanmar. This species thrives well in comparatively dry regions as tree or bushy form and survive best on sandy or slightly alluvium and on variety of soils such as laterite, black cotton soil and even moderate saline soil, open waste lands on poor dry ground and on abandoned cultivation in dry localities. They often formed pure crops on sandy or gravelly alluvium of dry river-beds.

Lac cultivation: Palas is a hardy and popular host species for lac insects. Lac produced from host plant is good colour and quality. Variation in production of seedlac normally ranges from 52-59% in different crop season of total rangeeni lac production. Approximately 1.5 kg broodlac is needed for inoculating an average Ber tree, which produces an average of 7 kg broodlac per tree.

4.1 Introduction

Lac insect, a tiny scale insect belonging to family Tachardiidae (Kerriidae), and order Hemiptera is one of the important beneficial insects known for its unique product of economic importance i.e. lac. Nineteen species of lac insects have been observed in India and the most common Indian lac insect of commercial importance is *Kerria lacca* (Kerr). The tiny red–coloured larvae of lac insect settle on the young succulent shoots of the host plants and secrete a thick resinous fluid which covers their bodies. Lac culture has been traditionally linked with the culture and livelihoods of the tribal community in India. Lac culture is also practiced traditionally in some pockets of various districts of Odisha, indicating that agro-climatic condition of region is suited for lac cultivation.

The lac ecosystem is a very complex ecosystem with multitrophic web of flora and fauna representing a highly diverse system. The life cycle of insect begins with appearance of crawler as its first larval stage is very soft, oval shaped body. The first instar of the insect is mobile in nature and in initial stage it crawls over the tender shoot of host trees. Piercing and sucking type of mouthparts are found. By piercing its proboscis into the phloem portions of tender shoots, it feeds the phloem sap. After 2-3 days of settlement, the lac crawler starts producing resin in minute. Except three body openings, the lac insect covers itself completely by its secretion the lac resin. Generally, 200-300 lac insect crawlers settled in one square inch area. The male and female insects are identified at this stage. Male insects have red in colour and length around 1-1.4 mm in length. They prefer tender shoots found in the high position or in the portion of the major host species where suitable temperature, light, rainfall, ventilation and adequate bark surface are found. Lac insects prefer these branches for their settlement (Hazarika *et al*., 2018). Required quantities of healthy brood lac weighing from 250 g to 750 kg are usually used per host tree The quantity of brood lac used depends upon the size of the host tree and inoculated in the four seasons of *rangeeni* (*katki* and *baisakhi*) and *kusumi* (*aghani* and *jethwi*).This first procedure by which young ones duly attached with the host plant is known as Brood lac inoculation. Inoculation of lac is done only a few days before swarming of crawlers. The newly emerged crawlers are suitable place on tender, succulent stems to settle within 7 days of inoculation. These are minute, soft bodied and sedentary in nature. So, they are organised in such a manner to find out succulent branches at a least distance. To avoid insufficient or when there is no larval settlement, the broodlac bundles are carefully shifted to different branches on the same tree after 7 - 8 days of the inoculation process. This is for uniform distribution of the brood and process which is known as shifting. After 21 days of inoculation, emergence of larvae completed and the phunki lac sticks were removed from host plants. The Broodlac without brood called phunki, is in fact a sticklac. Phunki are usually removed from the host plants 21 days after BLI without damaging the lac insect settlement on the plants and harvested in time (Bhattacharya, 2007; Sharma and Jaiswal, 2002).

Lac is the only resin of animal origin and one of the most valuable gifts of nature to mankind (Pal, 2009; Mohanta *et al*., 2012). During the whole life cycle of the lac insect, it spends only a few hours of active movement and after settlement it spends complete sedentary life by sucking sap from tender shoots specific plants known as lac hosts. Due to immobile nature during its life span, it is highly susceptible to abiotic and biotic factors which bring adverse effects on its biology and productivity. A number of natural enemies (predators and parasitoids) infest lac insect during their sedentary life stages as well as in the storage crops. The prevalence of these natural enemies has been found to infest the lac insect throughout the year. Biotic and abiotic factors are the major limiting factors bring about reduction in yield of lac crop. Predators and parasitoids come under biotic stress while weather factors promote abiotic stress. The predators of this lac insect consist of both vertebrate and invertebrate species, whereas the parasites are all insects. The loss brought to the lac crop around to 35- 40% of the total destruction annually due to infestation caused by the insect predators and parasites. Parasites cause for a damage of 5-l0% of the total destruction of the lac crop. Sharma *et al*. (2006) have revealed that 35 species of primary and 45 species of secondary parasitoids have been documented in lac insect ecosystem. In some times a severe /complete crop loss has been documented due to attack of insect predators. The insect predators are also cause about 90 % of the total destruction of the lac crops. The most common parasites of lac insect are termed as “Chalcid.” They are small and winged insects which prefers to lay their eggs inside the lac coat either on the body or inside the body of the lac insect. The larva hatched from these eggs feed upon the lac insects, thereby increasing mortality of their host. Chowdhury *et al.* (1971) revealed that the density of population of lac insects cause the rate of parasitisation by the chalcid parasites associated with lac crops. The source of parasitoids for new crop is infested broodlac and from the surroundings of adjoining lac crop. As these natural enemies bring about severe losses in lac crop, little attention is given by lac farmers for the management of the existing complex of natural enemies due to lack of availability and rare knowledge on these natural enemies of lac insect. The adequate information on the existing lac hosts, lac insect enemies’ interactions and reasons for its appearance are unknown to lac cultivators. Therefore, study conducted on various biological attributes and the natural enemies of *Kerria lacca* on some major host plants at the natural forest ecosystem and manipulated agro-ecosystem would provide a baseline database on the promising factors influencing the biology and productivity of lac insects.

4.2 Methods

4.2.1 Biological attributes of Lac insect

The biological attributes of lac insect in some lac host and their natural enemies (predators and parasitoids) were studied during two consecutive years of 2017-18 and 2018-19. The experiment was conducted in Randomized Block Design (RBD) with the five replications, each replication having five plants was selected. Five such sites will be counted from each plant from five places. The various parameters attributing biological study of lac insect on suitable host plants were studied on randomly selected 05 numbers of plants in location one. The brood lac of Rangeeni and Kusumi strain required for the experiment were collected from the mature crop of Rangeeni and Kusumi strain found in the region on natural host plants. The host species such as *Butea monosperma* (Palas) and *Zizyphus mauritiana* (Ber) were inoculated with Rangeeni broodlac, while *Schleichera oleosa* (Kusum) and *Zizyphus mauritiana* (Ber) were inoculated with Kusumi brood lac bearing fully matured females. Selected host plants having healthy broodlac sticks cut into small pieces of 6-8 inches and small bundles were made. For Kusumi and Rangeeni broodlac bundles weighing around 100 g and 50 g each respectively and tied on the base of the succulent branches. To study the different biological attributing parameters *viz*. initial and final density of settlement, initial mortality, density at crop maturity (per sq. cm), weight of female lac cell (mg), weight of resin (mg), yield of sticklac (kg), developmental period and adult longevity were recorded on tagged host plants of ber, kusum and palas in three sets. The observations were taken as per the standard procedure developed by Mohanasundaram *et al*. (2016) and Ramani, 2002.

4.2.1.1 Life Cycle and Life Span

Indian lac insect contains two strains (kusumi and rangeeni), which yields two crops a year viz. jethwi and aghani in case of kusumi strain, and katiki and baisakhi in case of rangeeni. Accordingly, the inoculation period of all the four types of crops differed from each other. In order to study the life cycle and life span of lac insects in different strains and crops, observations were recorded from the date of inoculation of broodlac, their date of settlement of crawlers, emergence of male and emergence of larva (Jaiswal and Sharma, 2002). Lac insects were identified based on their gross morphological features (Kondo and Gullan,2007) and measurements. Examinations were carried out with a 10X-hand lens, and measurements with a steel measuring scale calibrated to 0.1 mm (Ted Pella, Redding, CA).

The following formulae were used to calculate life span of lac insects:

i) Life span of young ones = Date of male emergence - Date of broodlac inoculation
ii) Total life span of male insect = Life span of adult + Life span of young ones
iii) Life span of lac insect = Date of emergence of larva - Date of broodlac inoculation

iv) Life span of adult female = Life span of lac insect - Life span of young ones

Life span of the insect is the actual the life span of the female and the male dies within 2-3 days after copulation. After 2-3 days of emergence and mating the male dies. So, the life span of the insect is actually the life span of female insect.

4.2.1.2 Density of settlement (Individuals cm^{-2})

Initial density of settlement of the lac insect population were taken after 7 days of inoculation where fast instar larvae emerged and settled at suitable portions of tender branches and twigs of reported host plants. Five plants were randomly selected from the one location of the experimental block and for three locations fifteen plants were also selected. After completion of emergence of first instar crawlers from mature females of broodlac, observations were taken by placing a graph paper with a cut by secateurs of one square cm area on the branches of three types of host plants under study. Numbers of lac larvae settled were counted from that area which was selected randomly and (ILRI Ann. Rep., 2004-05). Five plants were randomly selected from the one location of the experimental block. From one plant five lac larvae settled branches and twigs were cut with secateurs. The same procedure was practiced from three such sites of agroforestry (AF), village commons (VC) and strips along the roads (SAR). Settlement density was counted randomly and the branches of same host plants by visually using magnifying glass and mean $\pm$ SD was recorded as density of initial settlement. Similarly, after 21 days of settlement the same procedure was followed.

4.2.1.3 Initial mortality (%)

Initial mortality percentage of first instar crawlers were recorded at 21 days after inoculation of broodlac, repeating the same procedure as described earlier. Under field conditions, the process of appearance of crawler continues up to two weeks of inoculation. The first instar crawlers which are not able to find suitable sites for settlement on host plants die due to starvation within a week or two of its emergences. Investigation at this stage is the actual inference of the number of crawlers have finally settled and started feeding. The initial mortality (%) was calculated by the following formula:

$$\textbf{Initial mortality} = \frac{\textbf{Initial density – Density after 21 days of settlement}}{\textbf{Initial density}} \times 100$$

4.2.1.4 Final density of settlement (Individuals cm^{-2}):

After twenty days of brood lac inoculation and at the period of completion of emergence of crawlers from mature females the observations on final density of settlement on (number per sq.cm) were recorded following the same procedures as presented for initial density of settlement.

Final density of settlement = Initial density of settlement – Initial mortality

4.2.1.5 Sex ratio (% of Male and Female Insects)

During the time of emergence of crawlers, male and female sex of cannot be distinguished separately. After a stipulated period of growth a, larvae could be segregated into male and female lac insects ascertained on their morphological differences (ILRI Ann. Rep., 2004-05 ; Sharma, 2007).

Identification was done through visual observation as well as by using magnifying lens and compound microscope. The process for recording of male and female numbers with mean $\pm$ SD values for same three sites and locations as mentioned earlier was same as in case of initial density of settlement. After counting their number, respective percentages of male and female population were estimated against initial settlement density of larva.

4.2.1.6. Density of female at crop maturity (Individuals cm^{-2})

As lac cells are vulnerable to various biotic and abiotic stresses during their life period on the host plants, affect the density of female cells at crop maturity and differ extensively from initial density of settlement. During their growth period size of the female cell increases and density at crop maturity enables the yield of lac insect at the time of harvest and the requirement of broodlac for next season.

Therefore, it is considered as an important biological parameter of lac insect. After emergence of male lac insects living female lac insects were counted at crop maturity (appearance of yellow spot) (photo 2.12). For density of females at crop maturity mean $\pm$ SD values were calculated (ILRI Ann. Rep., 2004-05) for three sites and places as indicated for initial density of settlement.

4.2.1.7 Diameter of female lac cell (mm)

The diameter of the female cell was calculated from the number of females per cm square at crop maturity for crops on randomly selected five cells from five tagged plants in each three sets of experiments of three different host plants in different sites. Single female cells are globular in shape. Horizontal and vertical diameters were recorded using screw gauge and the average of the two was taken as diameter of the cells (mm). By applying the above procedure, the average density of settlement of females at crop maturity for 2 years the average diameter of the female cell was calculated.

4.2.1.8 Weight of cell (mg)

Female lac insects secrete the resin over the body forms layers after layers forming protective cell. This protective cell is lac and each cell is produced by a single female cell. To measure the weight of cell (mg) randomly selected 05 cells from 05 tagged plants in each three sets of experiments of three host plants were taken after completion of larval emergence. Weight of Individual female cell (in mg) was measured by using physical Monopan balance.

4.2.2 Emergence of natural enemies (predators and parasitoids)

To record the emergence profile of predators and parasitoids from five major lac growing villages viz. Chaindar, Balichua Tiakata, Garadihi, and Chekamara of Garadihi Gram Panchayat in the existing habitats like strips along the road side (SAR), agricultural field/agroforestry (AF), village commons (VC) were selected from 2017 to 2019 in the surroundings of Kuldiha reserve forest (i.e.05 Km radius) of Balasore, Odisha. Various sites having prominent lac cultivation were identified. Information was also collected from nearby lac traders and farmers in the block.

With this information study sites were selected in the district. Host plants of palas (*Butea monosperma*), ber (*Zizyphus mauritiana*), kusum (*Schleichera oleosa*) and from each species of 4 plants (4 twigs from each plant) were randomly selected from both the strains of kusumi (aghani and jethwi crops) and rangeeni (katki and baisakhi). One meter length of lac encrustation branches from inoculated trees of natural stands of lac insect samples were also collected randomly initially one month after inoculation and then at every 07 days interval till crop harvest with four replications. Secateurs were used to cut the tender host branches having the living lac insect encrustation. In order to maintain the turbidity of collected samples these were wrapped with wet cotton swab at the both the ends of cutting branches. Caging was done in specially designed twenty numbers of plastic jars for emergence of parasitoids and predators. In each jar 8-10 brood sticks were kept and the mouth was covered in a ballooning position with a transparent minutely perforated polythene glass. Basing on the agricultural landscape structure wise these jars containing samples of different locations were kept separately. To promote upward movement of the predators and parasites emerging from the brood stick, the basal portion of the all jars were kept dark by covering them with thick black cloth. In specimen tubes the parasites or predators emerging from the stick lacs were collected and performed the morphological studies.

4.2.2.1 Observation recorded

The population of natural enemies of predators and parasitoids were counted from the time of initiation of first appearance up to the completion of emergence species. During the study periods population seasonality of lac natural enemies (predators and parasitoids) of lac insect were documented at weekly intervals.

4.2.3 Computation and Statistics

The data collected from different sets of experiments were subjected to analysis adapting appropriate statistical tools like arithmetic mean, standard deviation. The data was analyzed following procedures as suggested by Gomez and Gomez (1976).

4.3 Results

4.3.1 Biological attributes of Lac insect

4.3.1.1 Life Cycle and Life Span

Duration of life cycle (days) of lac insect, *Kerria lacca* of both the strains were inoculated on various host plants in the surrounds of Kuldiha Wildlife Sanctuary. In Palas strain of katki crop it was inoculated between 05-10 July, settlement of larvae appeared during 25-31 July, male appeared during 18-23 August and larvae appeared between 20- 24 October. In this katki crop duration of life cycle was 110 days. Rangeeni strain of ber of katki crop it was inoculated during 08-15 July, larvae settled during 28-31 July male emerged from 20-26 August and larvae emerged from 25-29 October. Total life cycle of that crop was. In ber of baisakhi crop it was inoculated during 03-08 November, larvae settled from 25-30 November, male insect and larvae emerged from 24-28 February and 25-30 July, respectively. Life cycle of that crop is highest of 270 days from other crops. Kusumi strain from Kusum plant of aghani crop it was inoculated from 02-07 July, larvae settled from 22-25 July, male insect appeared from 26-30 August and larvae emerged from 25-30 January. The life cycle of that crop was 205 days. Kusumi strain of Kusum plant from Jethwi it was inoculated on 01-06 February, settlement of larvae was during 23-27 February, male emerged from15-20 April and the larvae appeared from 13-18 July. The life cycle of that jethwi crop was 165 days. However, kusumi strain of jethwi crop it was inoculated from 01-10 Februay, settlement of larvae was from, 23-28 February, male emerged from 10-13 April and larvae appeared from 05-10 July. The life cycle of that crop was 165 days (**Table 4.1**).

The Life span (days) of lac insect of young, male and female were studied in in three different sites. Katki crop in rangeeni strain of palas life span of young ones were 47 and 36 in AF, SAR and VC, respectively. Life span of in same rangeeni strain of baisakhi crop in ber plant it was 90, 95 and 98 in AF, SAR and VC, respectively. In aghani crop of kusumi strain in palas tree the life span was 54,58 and

53 in AF, SAR and VC, respectively. Jethwi crop of kusuni strain of ber plant was 74, 65 and 72 in AF, SAR and VC, respectively. The same trend was also seen aghani crop of kusumi strain in kusum plant, where life span of young ones was 51, 57 and 58 in AF, SAR and VC, respectively. In jethwi crop of kusumi strain in kusum the life span were 72, 80 and also 80 in AF, SAR and VC, respectively. In katki crop of rangeeni strain in ber it was 43,46 and 48 in AF, SAR and VC, respectively. In baisakhi crop in ber of rangeeni strain it was 101 both for AF and SAR but maximum of 108 was recorded from VC (**Table 4.1, 4.2 and 4.3**). Life span of adult male was 2-3 days. Range of life span of adult female varied from 71- 149, 49- 104 and 71- 152 in katki crop of palas and baisakhi crop of ber of rangeeni strain of AF, SAR and VC, respectively (**Table 4.2, 4.3 and 4.4**).

4.3.1.2 Mean density of initial settlement

Mean density of initial settlement of lac larvae were calculated from different sites. During 2017-18 in ber of rangeeni strain in katki (rainy) contained lowest initial density of settlement (Individuals cm^{-2}) as 48.76, 50.85±26.86 and 60.24±7.68 in AF, SAR and VC, respectively followed by in palas of rangeeni strain in katki crop of initial density of settlement (Individuals cm^{-2}) were 59.596, 64.534 and 67.512 in AF, SAR and VC, respectively. In palas of rangeeni strain in baisakhi it was 80.404, 84.804 and 92.246 in AF, SAR and VC, respectively. While in ber of same strain and crop it was 82.88, 80.65 and 78.01, 246 in AF, SAR and VC, respectively. Highest density was found in ber of kusumi strain in aghani crop as106.41,111.61 and 122.77±8.37; and followed by kusumi crop of kusum plant of aghani strain as 87.73,101.41 and 113.79 in AF, SAR and VC, respectively. Similarly in kusumi strain of jethwi it was 74.92±4.55, 80.65±2.64 and 78.01±5.63; and in ber of kusumi strain in Jethwi crop as 76.06, 97.27 and 101.19 in AF, SAR and VC, respectively (**Table 4.5**). The same pattern was followed during 2018-19. It was lowest in palas of rangeeni strain in katki 55.07, 59.84 and 63.50 and followed by katki crop in ber of rangeeni strain as 48.12,52.67 and 63.99 in AF,SAR and VC, respectively

Table 4.1 Life Cycle Pattern (days) of lac insect *K. lacca* (Kerr.) on various host plants in the surrounds of KWLS

Host plant	Strain	Crop	Date of Inoculation	Date of settlement of larva	Date of male emergence	Date of larval emergence	Life period (days)
Palas	Rangeeni	Katki (Rainy)	05-10 July	25-31 July	18-23 August	20- 24 October	110
Palas	Rangeeni	Baisakhi (Summer)	08-15 July	28-31 July	20-26 August	25-29 October	115
Ber	Kusumi	Aghani (Winter)	01-05 November	20-25 November	21-25 February	20-27 July	260
Ber	Kusumi	Jethwi (Summer)	03-08 November	25-30 November	24-28 February	25-30 July	270
Kusum	Kusumi	Aghani (Winter)	02-07 July	22-25 July	26-30 August	25-30 January	205
Kusum	Kusumi	Jethwi (Summer)	03-10 July	20-25 July	18-25 August	20-26 January	203
Ber	Rangeeni	Katki (Rainy)	01-06 February	23-27 February	15-20 April	13-18 July	165
Ber	Rangeeni	Baisakhi (Summer)	01-10 February	23-28 February	10-13 April	05-10 July	165

Table 4.2 Life span (days) of lac insect, *K. lacca* on different host plants of AF in the surrounds of KWLS

Host plant	Strain	Crop	Date of Inoculation	Date of male emergence	Life span of young	Life span of male insect		Life span of female insect	
						Adult	Total	Adult	Total
Palas	Rangeeni	Katki (Rainy)	01 to 05 Jul	16 to 20 Aug	47	2	49	71	118
Palas	Rangeeni	Baisakhi (Summer)	01 to 05 Nov	30 January to 05 Feb	90	3	93	156	246
Ber	Kusumi	Aghani (Winter)	04 to 08 Jul	25 Aug to 31 Aug	54	2	56	142	196
Ber	Kusumi	Jethwi (Summer)	01 to 05 Jan	16 March to 22 Mar	74	3	77	96	170
Kusum	Kusumi	Aghani (Winter)	05 to 09 Jul	23 to 30 Aug	51	2	53	139	190
Kusum	Kusumi	Jethwi (Summer)	20 to 25 Jan	01 to 10 April	72	3	75	91	163
Ber	Rangeeni	Katki (Rainy)	05 to 09 Jul	17 to 27 Aug	43	2	45	67	110
Ber	Rangeeni	Baisakhi (Summer)	02 to 06 Nov	10 to 14 Feb	101	3	104	149	250

Table 4.3 Life span (days) of lac insect *K. lacca* on different host plants of SAR in the surrounds of KWLS

Host plant	Strain	Crop	Date of Inoculation	Date of male emergence	Life span of young	Life span of male insect		Life span of female insect	
						Adult	Total	Adult	Total
Palas	Rangeeni	Katki (Rainy)	08 to 14 Jul	23 to 24 Aug	47	2	49	62	109
Palas	Rangeeni	Baisakhi (Summer)	10 to 14 Nov	13 to 17 Feb	95	3	98	160	255
Ber	Kusumi	Aghani (Winter)	07 to 11 Jul	1 Sept 06 Sept	58	2	60	143	201
Ber	Kusumi	Jethwi (Summer)	10 to 14 Jan	16 March to 22 Mar	65	2	67	108	173
Kusum	Kusumi	Aghani (Winter)	01 to 04 Jul	26 to 30 Aug	57	2	59	142	199
Kusum	Kusumi	Jethwi (Summer)	18 to 23 Jan	06 to 11 April	80	3	83	86	166
Ber	Rangeeni	Katki (Rainy)	03 to 07 Jul	18 to 21 Aug	46	2	48	70	116
Ber	Rangeeni	Baisakhi (Summer)	10 to 14 Nov	18 to 22 Feb	101	3	104	154	255

Table 4.4 Life span (days) of lac insect *K. lacca* on different host plants of VC in the surrounds of KWLS

Host plant	Strain	Crop	Date of Inoculation	Date of male emergence	Life span of young insect	Life span of male insect		Life span of female insect	
						Adult	Total	Adult	Total
Palas	Rangeeni	Katki (Rainy)	04 to 08 Jul	08 to 15 Aug	36	2	38	71	107
Palas	Rangeeni	Baisakhi (Summer)	08 to 13 Nov	12 to 19 Feb	98	3	101	161	259
Ber	Kusumi	Aghani (Winter)	10 to 14 Jul	01 Sept to 06 Sept	53	2	55	147	200
Ber	Kusumi	Jethwi (Summer)	07 to 11 Jan	18 Mar to 24 Mar	72	3	75	100	172
Kusum	Kusumi	Aghani (Winter)	08 to 12 Jul	4 to 10 Sept	58	2	60	143	201
Kusum	Kusumi	Jethwi (Summer)	15 to 20 Jan	04 to 10 Apr	80	3	83	92	172
Ber	Rangeeni	Katki (Rainy)	07 to 11 July	24 Aug to 29 Aug	48	2	50	67	115
Ber	Rangeeni	Baisakhi (Summer)	05 to 10 Nov	18 to 23 Feb	106	3	109	152	258

Table 4.5 Density of Initial settlement (individuals cm^{-2}) of lac larvae of *K. lacca* on various host plants in different sites of surroundings of KWLS in 2017-18

Host plant	Strain	Crop	Mean density of settlement (individuals cm^{-2})		
			AF	**SAR**	**VC**
Palas	Rangeeni	Katki (Rainy)	59.59±10.94	64.534±6.64	67.512±7.93
Ber	Rangeeni	Katki (Rainy)	48.76±4.44	50.85±26.86	60.24±7.68
Palas	Rangeeni	Baisakhi (Summer)	80.404±5.37	84.804±15.31	92.246±12.00
Ber	Rangeeni	Baisakhi (Summer)	82.882±5.40	80.65±2.64	78.01±5.63
Kusum	Kusumi	Aghani (Winter)	87.73±8.24	101.41±21.23	113.79±12.64
Ber	Kusumi	Aghani (Winter)	106.41±17.85	111.61±18.41	122.77±8.37
Kusum	Kusumi	Jethwi (Summer)	74.92±4.55	80.65±2.64	78.01±5.63
Ber	Kusumi	Jethwi (Summer)	76.06±6.11	97.27±17.05	101.19±16.66

(**Table 4.5**). In baisakhi crop of palas in rangeeni strain it was 73.78, 78.13 and 83.86 in AF, SAR and VC, respectively (**Table 4.6**). In rangeeni strain of ber in baisakhi it was 74.45, 75.06 and 79.07 in AF, SAR and VC, respectively. In kusumi strain of kusum in Aghani it was 85.66, 88.94 and 98.08; and in same crop and same strain of ber it was 100.94,104.59 and 107.77 in AF,SAR and VC, respectively. In kusumi strain of Jethwi crop it was 69.90, 74.45 and 72.82 in kusum plant; for ber of same strain and crop it was recorded as 78.69, 88.67 and 96.56 in AF,SAR and VC, respectively (**Table 4.6**).

4.3.1.3 Density after 21 days of settlement

Density after 21 days of settlement varied in different crops, seasons and strains. During 2017-18 it was 39.18, 47.52 and 55.94 (Individuals cm^{-2}) in katki crop of palas in rangeeni strain: in ber of same strain and crop it was 36.81, 48.22 and 53.66 (Individuals cm^{-2}) in AF, SAR and VC, respectively. In palas of rangeeni strain in baisakhi crop it was 60.534, 66.06 and 73.92; and in same strain and crop of ber it was 60.44, 61.16 and 64.76 in AF, SAR and VC, respectively. In kusumi strain of aghani in kusum it was 71.06, 88.78 and 101.58 (Individuals cm^{-2})

and in ber of same strain and crop it was 86.74,88.72 and 96.98 in AF, SAR and VC, respectively. In kusumi strain of kusum plant in Jethwi crop it was 55.4, 61.68±3.55 and 66.97; in same crop and same strain of ber plant it was 63.22,77.16 and

Table 4.6 Density of Initial settlement (individuals cm^{-2}) of lac larvae of *K. lacca* on various host plants in different sites of surroundings of KWS in 2018 -19

Host plant	Strain	Crop	Mean density of settlement		
			AF	**SAR**	**VC**
Palas	Rangeeni	Katki (Rainy)	55.07±14.15	59.84±10.70	63.50±12.00
Ber	Rangeeni	Katki (Rainy)	48.12±12.23	52.67±11.66	63.99±4.34
Palas	Rangeeni	Baisakhi (Summer)	73.78±5.82	78.13±6.96	83.86±7.49
Ber	Rangeeni	Baisakhi (Summer)	74.45±4.92	75.06±10.21	79.07±7.87
Kusum	Kusumi	Aghani (Winter)	85.66±13.17	88.94±14.21	98.08±13.47
Ber	Kusumi	Aghani (Winter)	100.94±13.93	104.59±14.37	107.77±18.80
Kusum	Kusumi	Jethwi (Summer)	69.90±10.82	74.45±10.51	72.82±7.91
Ber	Kusumi	Jethwi (Summer)	78.69±7.53	88.67±21.00	96.56±18.43

± SD; N=5

83.82 in AF, SAR and VC, respectively (**Table 4.7**). During 2018-19 it was also lowest in katki crop of rangeeni strain of palas as 40.2, 44.83 and 46.24; and in same crop and same strain of ber tree it was recorded as 30.96,38.01 and 46.25 in AF, SAR and VC, respectively. In baisakhi crop of rangeeni strain in palas the density after 21 days of settlement was 59.04, 61.26 and 66.62 (Individuals cm^{-2}); and in same crop and strain in ber it was 57.33, 59.5 and 62.75 in AF, SAR and VC, respectively. The density in kusumi strain of aghani crop in ber was found as 72.89, 70.09 (Individuals cm^{-2}); and followed by same strain and crop in kusum as 69.36, 74.93 and 79.18 in AF, SAR and VC, respectively. In Kusumi strain of Jethwi crop in kusum plant it was 55.8, 58.41 and 61.15; and in same strain and crop of ber it was 63.31, 74.69 and 82.69 in AF, SAR and VC, respectively (**Table 4.8**).

4.3.1.4 Percentage of male and female (sex ratio)

In katki crop of rangeeni strain in palas tree percentage of male population were 31.82 , 36.51, 29.79; and female as 68.19, 63.49 and 70.21 in AF, SAR and VC, respectively (**Table 4.9, 4.10 and 4.11**). In ber of same strain and crop male population was 33.99, 32.99 and 33.63; and female was 66.01, 67.02 and 66.37 in AF, SAR and VC, respectively. However, the lowest no. of male was 22.95 in jethwi crop of kusumi strain in kusum plant in AF and the highest was in Jethwi strain of kusumi plant 32.52. Similarly, the lowest female population was in 63.49 and highest in 79.99 aghani crop ber in kusumi.

Table 4. 7 Density after 21 days of settlement (individuals cm^{-2}) of lac insects *K. lacca* on various host plants in different sites of surroundings of KWLS in 2017-18

Host plant	Strain	Crop	Mean density of settlement		
			AF	**SAR**	**VC**
Palas	Rangeeni	Katki (Rainy)	39.18±9.26	47.52±6.70	55.94±5.74
Ber	Rangeeni	Katki (Rainy)	36.81±2.25	48.22±10.36	53.66±7.38
Palas	Rangeeni	Baisakhi (Summer)	60.534±8.24	66.06±14.10	73.926±15.23
Ber	Rangeeni	Baisakhi (Summer)	60.44±6.53	61.16±6.56	64.76±4.87
Kusum	Kusumi	Aghani (Winter)	71.06±9.72	88.78±18.39	101.58±14.79
Ber	Kusumi	Aghani (Winter)	86.74±12.04	88.72±12.87	96.98±10.66
Kusum	Kusumi	Jethwi (Summer)	55.4±7.64	61.68±3.55	66.97±5.42
Ber	Kusumi	Jethwi (Summer)	63.22±6.42	77.16±22.93	83.82±10.95

± SD; N=5

Table 4.8 Density after 21 days of settlement (individuals cm^{-2}) of lac insects K. *lacca* on various host plants in different sites of surroundings of KWLS in 2018-19

Host plant	Strain	Crop	Mean density of settlement		
			AF	**SAR**	**VC**
Palas	Rangeeni	Katki (Rainy)	40.2±10.30	44.83±9.83	46.24±13.44
Ber	Rangeeni	Katki (Rainy)	30.96±11.10	38.01±12.79	46.25±4.77
Palas	Rangeeni	Baisakhi (Summer)	59.04±7.51	61.26±3.95	66.62±4.86
Ber	Rangeeni	Baisakhi (Summer)	57.33±8.20	59.5±8.32	62.75±3.78
Kusum	Kusumi	Aghani (Winter)	69.36±15.40	74.93±14.73	79.18±8.30
Ber	Kusumi	Aghani (Winter)	72.89±13.19	70.09±8.03	78.61±7.97
Kusum	Kusumi	Jethwi (Summer)	55.8±9.62	58.41±12.31	61.15±12.56
Ber	Kusumi	Jethwi (Summer)	63.31±12.21	74.69±21.44	82.69±15.61

± SD; N=5

Table 4. 9 Percentage of male and female (individuals cm^{-2}) of lac larvae of *K. lacca* on various host plants in different sites of surroundings KWLS in 2017 -18

Host plant	Strain	Crop	Percentage of male and female (individuals cm^{-2})					
			AF		SAR		VC	
			M	F	M	F	M	F
Palas	Rangeeni	Katki (Rainy)	29.80 (8.32)	70.2 (8.32)	35.06 (5.90)	64.94 (5.90)	33.33 (5.58)	66.67 (5.58)
Ber	Rangeeni	Katki (Rainy)	33.60 (7.70)	66.40 (7.70)	31.09 (13.49)	68.91 (13.49)	36.80 (7.22)	63.20 (7.22)
Palas	Rangeeni	Baisakhi (Summer)	18.53 (5.61)	81.47 (5.61)	30.00 (8.84)	70.00 (8.84)	31.99 (9.72)	68.01 (9.72)
Ber	Rangeeni	Baisakhi (Summer)	29.71 (7.22)	70.29 (7.22)	34.28 (6.71)	65.72 (6.71)	28.07 (7.95)	71.93 (7.95)
Kusum	Kusumi	Aghani (Winter)	23.21 (1.92)	76.79 (1.92)	22.18 (8.70)	77.82 (8.70)	25.22 (10.34)	74.78 (10.34)
Ber	Kusumi	Aghani (Winter)	36.62 (11.33)	63.38 (11.33)	18.67 (7.43)	81.33 (7.43)	21.41 (7.65)	78.59 (7.65)
Kusum	Kusumi	Jethwi (Summer)	27.06 (4.15)	72.94 (4.15)	31.62 (13.78)	68.38 (13.78)	34.87 (8.83)	65.13 (8.83)
Ber	Kusumi	Jethwi (Summer)	31.52 (2.18)	68.48 (2.18)	33.38 (9.29)	66.62 (9.29)	35.17 (13.48)	64.83 (13.48)

Figures in parentheses are ± SD; N= 5

Table 4. 10 Percentage of male and female (individuals cm^{-2}) of lac larvae of *K. lacca* on various host plants in different sites of KWLS in 2018 -19

Host plant	Strain	Crop	Percentage of male and female					
			AF		SAR		VC	
			M	F	M	F	M	F
Palas	Rangeeni	Katki (Rainy)	33.83 (9.81)	66.17 (9.81)	37.96 (13.50)	62.04 (13.50)	26.25 (8.04)	73.75 (8.04)
Ber	Rangeeni	Katki (Rainy)	34.38 (10.38)	65.62 (10.38)	34.88 (5.82)	65.12 (5.82)	30.46 (6.89)	69.54 (6.89)
Palas	Rangeeni	Baisakhi (Summer)	27.73 (8.70)	72.27 (8.70)	26.34 (9.00)	73.66 (9.00)	18.81 (5.01)	81.19 (5.01)
Ber	Rangeeni	Baisakhi (Summer)	29.34 (9.73)	70.66 (9.73)	37.67 (5.63)	62.33 (5.63)	23.23 (7.52)	76.77 (7.52)
Kusum	Kusumi	Aghani (Winter)	22.68 (7.67)	77.32 (7.67)	18.54 (7.92)	81.46 (7.92)	25.64 (8.55)	74.36 (8.55)
Ber	Kusumi	Aghani (Winter)	28.41 (7.22)	71.59 (7.22)	21.35 (6.49)	78.65 (6.49)	20.46 (6.03)	79.54 (6.03)
Kusum	Kusumi	Jethwi (Summer)	25.42 (12.75)	74.58 (12.75)	30.95 (7.64)	69.05 (7.64)	30.10 (10.95)	69.90 (10.95)
Ber	Kusumi	Jethwi (Summer)	30.05 (12.03)	69.95 (12.03)	26.63 (14.92)	73.37 (14.92)	31.65 (5.91)	68.35 (5.91)

Figures in parentheses are ± SD of 5 places

Table 4.11 Percentage of male and female of lac larvae of *K. lacca* on various host plants in different sites of KWLS of 2 years

Host plant	Strain	Crop	Percentage of Male and Female					
			AF		SAR		VC	
			M	F	M	F	M	F
Palas	Rangeeni	Katki (Rainy)	31.82 (2.85)	68.19 (2.85)	36.51 (2.05)	63.49 (2.05)	29.79 (5.01)	70.21 (5.01)
Ber	Rangeeni	Katki (Rainy)	33.99 (0.55)	66.01 (0.55)	32.99 (2.68)	67.02 (2.68)	33.63 (4.48)	66.37 (4.48)
Palas	Rangeeni	Baisakhi (Summer)	23.13 (6.51)	76.87 (6.51)	28.17 (2.59)	71.83 (2.59)	25.40 (9.32)	74.60 (9.32)
Ber	Rangeeni	Baisakhi (Summer)	29.53 (0.26)	70.48 (0.26)	35.98 (2.40)	64.03 (2.40)	25.65 (3.42)	74.35 (3.42)
Kusum	Kusumi	Aghani (Winter)	22.95 (0.37)	77.06 (0.37)	20.36 (2.57)	79.64 (2.57)	25.43 (0.30)	74.57 (0.30)
Ber	Kusumi	Aghani (Winter)	32.52 (5.81)	67.49 (5.81)	20.01 (1.90)	79.99 (1.90)	20.94 (0.67)	79.07 (0.67)
Kusum	Kusumi	Jethwi (Summer)	26.24 (1.16)	73.76 (1.16)	31.29 (0.47)	68.72 (0.47)	32.49 (3.37)	67.52 (3.37)
Ber	Kusumi	Jethwi (Summer)	30.79 (1.04)	69.22 (1.04)	30.01 (4.77)	70.00 (4.77)	33.41 (2.49)	66.59 (2.49)

Figures in parentheses are ± SD of 5 places

4.3.1.5 Density of settlement of living female at crop maturity

The lowest density of settlement (Individuals cm^{-2}) of living female at crop maturity in rangeeni strain of katki was7.04 in AF and the highest was 15.81 in VC of aghani crop of ber in kusumi strain. In SAR of different crops, it ranged between 7.53 to 13.98 (**Table 4.12,4.13 and 4.14**). During 2017-18, Jethwi crop of kusumi strain is higher ($p < 0.05$), where reverse is found during 2018-19.

4.3.1.6 Diameter of female lac cell (mm)

The range of diameter was 2.86 to 5.17 mm in AF. In SAR (2.85 – 5.26 mm) and in VC it was (2.93 – 5.29 mm). Baisakhi crop has maximum diameter of 5.29 mm (**Table 4.15 and 4.16**).

4.3.1.7 Weight (mg) of female lac cell (dry cell wt.)

The range of weight (mg) of female lac cell (dry cell wt. of female) was 11.93 – 33.1 (mg) in AF. In SAR it was 11.55 - 28.87 (mm). In SAR it was 11.55 -28.87 (mg) and in VC it was 11.86 – 32.87 (mg). In kusumi strain of aghani it was maximum of 32.87 (mg) in VC (**Table 4.17 and 4. 18**).

Table 4.12 Density of settlement of living female at crop maturity of lac insects *K. lacca* on various host plants in different sites of surroundings of KWS in 2017-18

Host plant	Strain	Crop	Mean density of settlement (Individuals cm^{-2})		
			AF	**SAR**	**VC**
Palas	Rangeeni	Katki (Rainy)	7.99±1.77	9.28±2.14	9.38±1.53
Ber	Rangeeni	Katki (Rainy)	6.09±2.01	7.48±1.77	9.69±1.21
Palas	Rangeeni	Baisakhi (Summer)	7.48±0.99	7.54±1.72	7.23±1.20
Ber	Rangeeni	Baisakhi (Summer)	0	0	0
Kusum	Kusumi	Aghani (Winter)	9.78±1.14	11.07±1.61	13.28±2.18
Ber	Kusumi	Aghani (Winter)	13.04±4.25	16.59±2.77	16.77±4.66
Kusum	Kusumi	Jethwi (Summer)	8.7±1.98	9.89±1.98	8.89±2.32
Ber	Kusumi	Jethwi (Summer)	13.17±8.22	7.71±7.40	16.15±2.92

± SD of 5 places N=5

Table 4.13 Density of settlement of living female at crop maturity of lac insects *K. lacca* on various host plants in different sites of surroundings of KWLS in 2018 -19

Host plant	Strain	Crop	Mean density of settlement (Individuals cm^{-2})		
			AF	**SAR**	**VC**
Palas	Rangeeni	Katki (Rainy)	6.09±1.61	7.21±1.39	6.84±2.33
Ber	Rangeeni	Katki (Rainy)	6.48±2.03	7.58±1.58	7.45±1.02
Palas	Rangeeni	Baisakhi (Summer)	7.8±1.02	7.68±0.48	8.83±0.76
Ber	Rangeeni	Baisakhi (Summer)	0	0	0
Kusum	Kusumi	Aghani (Winter)	9.56±1.54	9.28±1.68	10.75±1.98
Ber	Kusumi	Aghani (Winter)	13.94±1.91	11.36±3.94	14.85±3.23
Kusum	Kusumi	Jethwi (Summer)	13.29±1.70	11.14±3.45	13.3±3.46
Ber	Kusumi	Jethwi (Summer)	12.92±6.89	15.97±9.08	13.85±3.97

± SD of 5 places N=5

Table 4.14 Density of settlement of living female at crop maturity of lac insects *K. lacca* on various host plants in different sites of KWLS during (Pooled for two years)

Host plant	Strain	Crop	Mean density of settlement (Individuals cm^{-2}) of living female at crop maturity		
			AF	**SAR**	**VC**
Palas	Rangeeni	Katki (Rainy)	7.04±1.34	8.25±1.46	8.11±1.80
Ber	Rangeeni	Katki (Rainy)	6.29±0.28	7.53±0.07	8.57±1.58
Palas	Rangeeni	Baisakhi (Summer)	7.64±0.23	7.61±0.10	8.03±1.13
Ber	Rangeeni	Baisakhi (Summer)	0	0	0
Kusum	Kusumi	Aghani (Winter)	9.67±0.16	10.18±1.27	12.02±1.79
Ber	Kusumi	Aghani (Winter)	13.49±0.64	13.98±3.70	15.81±1.36
Kusum	Kusumi	Jethwi (Summer)	11.00±3.25	10.52±0.88	11.10±3.12
Ber	Kusumi	Jethwi (Summer)	13.04±0.18	11.84±5.84	15.00±1.63

± SD of 5 places; N=5

Table 4.15 Diameter of female lac cell (mm) of Indian lac insect, *K. lacca* during 2017-18

Host plant	Strain	Crop	Mean diameter of female lac cell (mm)		
			AF	SAR	VC
Palas	Rangeeni	Katki (Rainy)	2.86±0.09	2.85±0.21	2.93±0.15
Ber	Rangeeni	Katki (Rainy)	3.13±0.19	3.03±0.26	3.08±0.28
Palas	Rangeeni	Baisakhi (Summer)	4.07±0.42	4.82±0.35	4.76±0.47
Ber	Rangeeni	Baisakhi (Summer)	0	0	0
Kusum	Kusumi	Aghani (Winter)	4.04±0.17	4.36±0.41	4.07±0.22
Ber	Kusumi	Aghani (Winter)	3.62±0.31	3.81±0.47	3.53±0.41
Kusum	Kusumi	Jethwi (Summer)	3.96±0.34	3.77±0.12	3.74±0.14
Ber	Kusumi	Jethwi (Summer)	0	0	0

± SD of 5 places N=5

Table 4. 16 Diameter of female lac cell (mm) of Indian lac insect, *K. lacca* during 2018-19

Host plant	Strain	Crop	Mean diameter of female lac cell (mm)		
			AF	**SAR**	**VC**
Palas	Rangeeni	Katki (Rainy)	3.47±0.21	3.23±0.15	3.55±0.09
Ber	Rangeeni	Katki (Rainy)	3.43±0.12	3.33±0.13	3.60±0.19
Palas	Rangeeni	Baisakhi (Summer)	5.17±0.19	5.26±0.16	5.29±0.09
Ber	Rangeeni	Baisakhi (Summer)	0	0	0
Kusum	Kusumi	Aghani (Winter)	4.57±0.06	4.59±0.13	4.40±0.18
Ber	Kusumi	Aghani (Winter)	4.27±0.10	4.35±0.11	4.38±0.10
Kusum	Kusumi	Jethwi (Summer)	3.86±0.14	4.11±0.59	3.89±0.29
Ber	Kusumi	Jethwi (Summer)	0	0	0

± SD of 5 places; N=5

Table 4.17 Weight (mg) of female lac cell (dry cell wt. of female) of *K. lacca* on various host plants in the surroundings of KWLS during 2017-18

Host plant	**Strain**	**Crop**	**Mean weight (mg) of female lac cell (dry cell)**		
			AF	**SAR**	**VC**
Palas	Rangeeni	Katki (Rainy)	13.09±1.61	12.32±2.35	15.05±3.07
Ber	Rangeeni	Katki (Rainy)	12.44±2.40	11.55±3.11	11.86±2.73
Palas	Rangeeni	Baisakhi (Summer)	15.97±4.58	16.26±5.02	15.53±4.02
Ber	Rangeeni	Baisakhi (Summer)	0	0	0
Kusum	Kusumi	Aghani (Winter)	29.94±6.16	24.29±5.11	30.41±3.23
Ber	Kusumi	Aghani (Winter)	24.17±7.17	23.29±4.99	26.74±3.15
Kusum	Kusumi	Jethwi (Summer)	25.69±3.50	20.90±3.90	22.37±4.08
Ber	Kusumi	Jethwi (Summer)	0	0	0

± SD of 5 places; N=5

Table 4.18 Weight (mg) of female lac cell (dry cell wt. of female) of *K. lacca* on various host plants in the surroundings of KWLS IN 2018-19

Host plant	Strain	Crop	Mean weight (mg) of female lac cell (dry cell)		
			AF	**SAR**	**VC**
Palas	Rangeeni	Katki (Rainy)	11.93±3.83	14.97±4.42	15.51±2.50
Ber	Rangeeni	Katki (Rainy)	15.02±3.13	17.27±2.74	15.46±4.65
Palas	Rangeeni	Baisakhi (Summer)	19.02±3.79	17.42±2.49	19.34±2.78
Ber	Rangeeni	Baisakhi (Summer)	0	0	0
Kusum	Kusumi	Aghani (Winter)	33.1±3.93	28.87±7.49	32.87±3.19
Ber	Kusumi	Aghani (Winter)	27.49±5.11	26.55±4.97	24.49±5.02
Kusum	Kusumi	Jethwi (Summer)	25.09±4.62	22.75±8.66	23.15± 6.30
Ber	Kusumi	Jethwi (Summer)	0	0	0

± SD of 5 places; N=5

4.3.2 Emergence of natural enemies (predators and parasitoids)

The study sites exhibited emergence of seasonal diversity of enemy insect (predators and parasitoids) associated with lac insect in rangeeni strain (katki and baisakhi) in palas and kusumi strain (aghani and baisakhi) in kusum. In katki crop from AF, SAR and VC three types of predators (*Eublemma amabilis*, *Pseudohypatopa pulverea* and *Chrysopa spp*.) and four types of parasitoids (*Tachardiphagus tachardiae*, *Aprostochetus purpureus*, *Eupelmus tachardiae* and *Parechthrodryinus clavicornis*) were identified (**Table 4.19**). In baisakhi crop of rangeeni strain of palas there were same three types of predators and two types of parasitoids (*Tachardiphagus tachardiae* and *Eupelmus tachardiae*) were observed (**Table 4.20**). In kusumi strain of aghani crop in kusum tree too similar types of predators and 4 types parasitoids as in katki crop were found in three study sites (**Table 4.21**). Similarly, in jethwi crop of kusumi strain in kusum crop (**Table 4.22**) two types of predators (*Eublemma amabilis* and *Pseudohypatopa pulverea*) were found in all sites of AF, SAR and VC.

In katki crop peak density of predators ranged between (4.48 - 7.98), SAR (6.96 - 9.49) and in VC (5.11 - 11.28) which is presented in (**Table 4.23**). *Eublemma amabilis* is the most dominant having peak density of 11.28 in VC followed by SAR (9.49) and least in AF (7.20) *Pseudohypatopa pulverea* (9.12) in VC followed by (SAR) 8.08 and AF (7.04). *Chrysopa spp*. presented in lower density. Among the parasitoids *Aprostochetus purpureusis* the most dominant species followed by *Parechthrodryinus clavicornis*, *Parechthrodryinus clavicornis* and *Eupelmus tachardiae*.

Table 4.19 Natural enemies associated with lac insects (Katki lac) in palas in the surroundings of KWS during 2017 and 2018

Species	Peak density						Peak active period					
	2017			2018			2017			2018		
	AF	SAR	VC	AF	SAR	VC	AF	SAR	VC	AF	SAR	VC
Eublemma amabilis	7.98	9.44	11.08	7.20	9.49	11.28	31-Aug (35 SMW)	31-Aug (35 SMW)	24-Aug (34 SMW)	31-Aug (35 SMW)	24-Aug (34 SMW)	24-Aug (34 SMW)
Pseudohypatopa pulverea	7.39	6.96	8.03	7.04	8.08	9.12	31-Aug (35 SMW)	07-Sep (36 SMW)	07-Sep (36 SMW)	31-Aug (35 SMW)	31-Aug (35 SMW)	31-Aug (35 SMW)
Chrysopa spp.	4.48	4.71	5.13	4.14	4.25	5.11	03-Aug (31 SMW)	03-Aug (31 SMW)	03-Aug (31 SMW)	10-Aug (32 SMW)	03-Aug (31 SMW)	10-Aug (32 SMW)
Tachardiphagus tachardiae	2.01	2.03	2.77	2.07	2.58	2.79	09-Nov (45 SMW)	09-Nov (45 SMW)	26-Oct (43 SMW)	26-Oct (43 SMW)	02-Nov (44 SMW)	02-Nov (44 SMW)
Aprostochetus purpureus	5.72	6.90	7.65	5.07	6.68	6.96	28-Sept (39 SMW)	05-Oct (40 SMW)	05-Oct (40 SMW)	28-Sept (39 SMW)	05-Oct (40 SMW)	05-Oct (40 SMW)
Eupelmus tachardiae	1.15	1.53	1.77	1.51	1.69	2.10	26-Oct (43 SMW)	19-Oct (42 SMW)	26-Oct (43 SMW)	02-Nov (44 SMW)	26-Oct (43 SMW)	26-Oct (43 SMW)
Parechthrodryinus clavicornis	2.65	2.50	3.25	2.49	2.70	3.00	19-Oct (42 SMW)	05-Oct (40 SMW)	12-Oct (41 SMW)	12-Oct (41 SMW)	12-Oct (41 SMW)	28-Sep (39 SMW)

AF: Agroforestry system; VC: Village commons; SAR: Strip along road side; SMW: Standard Meteorological Week

The figures in the parentheses indicate Range (number of insects/30 cm stick lac)

Table 4.20 Natural enemies associated with lac insects of Baisakhi in palas in the surroundings of KWLS during 2017 and 2018

Species	Peak density						Peak active period					
	2017-18			2018-19			2017-18			2018-19		
	AF	**SAR**	**VC**	**AF**	**SAR**	**VC**	**AF**	**SAR**	**VC**	**AF**	**SAR**	**VC**
Eublemma amabilis	5.67	6.11	6.27	5.03	5.36	5.47	04-Apr (14 SMW)	28-Mar (13 SMW)	04-Apr (14 SMW)	28-Mar (13 SMW)	04-Apr (14 SMW)	04-Apr (14 SMW)
Pseudohypatopa pulverea	4.80	5.00	5.47	5.14	5.26	5.45	02-May (18 SMW)	25-Apr (17 SMW)	02-May (18 SMW)	25-Apr (17 SMW)	25-Apr (17 SMW)	02-May (18 SMW)
Chrysopa spp.	2.97	3.17	3.33	2.72	2.73	3.85	20-Dec (51 SMW)	27-Dec (52 SMW)	27-Dec (52 SMW)	27-Dec (52 SMW)	27-Dec (52 SMW)	03-Jan (01 SMW)
Tachardiphagus tachardiae	7.70	7.77	7.92	5.535	6.43	7.44	09-May (19 SMW)	09-May (19 SMW)	16-May (20 SMW)	02-May (18 SMW)	09-May (19 SMW)	02-May (18 SMW)
Eupelmus tachardiae	0.34	0.36	0.51	0.42	0.47	0.61	27-Dec (52 SMW)	27-Dec (52 SMW)	20-Dec (51 SMW)	03-Jan (01 SMW)	10-Jan (02 SMW)	10-Jan (02 SMW)

AF: Agroforestry system; VC: Village commons; SAR: Strip along road side; SMW: Standard Meteorological Week

The figures in the parentheses indicate Range (number of insects/30 cm stick lac)

Table 4.21 Natural enemies associated with lac insects (aghani lac) in kusum tree in the surroundings of KWLS during 2017-18 and 2018 -19

Species	Peak density						Peak active period					
	2017-18			2018-19			2017-18			2018-19		
	AF	SAR	VC	AF	SAR	VC	AF	SAR	VC	AF	SAR	VC
Eublemma amabilis	7.52	7.66	8.41	7.28	7.08	7.88	25-Aug (34 SMW)	01-Sep (35 SMW)	25-Aug (34 SMW)	18-Aug (33 SMW)	25-Aug (34 SMW)	18-Aug (33 SMW)
Pseudohypatopa pulverea	6.48	6.87	7.85	5.60	6.86	7.13	08-Sep (36 SMW)	08-Sep (36 SMW)	15-Sep (37 SMW)	15-Sep (37 SMW)	08-Sep (36 SMW)	15-Sep (37 SMW)
Chrysopa spp.	3.33	3.71	3.63	3.52	3.798	4.08	18-Aug (33 SMW)	18-Aug (33 SMW)	11-Aug (32 SMW)	11-Aug (32 SMW)	11-Aug (32 SMW)	18-Aug (33 SMW)
Tachardiphagus tachardiae	7.50	7.61	7.89	7.34	7.50	7.68	03-Nov (44 SMW)	03-Nov (44 SMW)	27-Oct (43 SMW)	27-Oct (43 SMW)	03-Nov (44 SMW)	03-Nov (44 SMW)
Aprostochetus purpureus	2.06	2.83	2.99	1.99	2.64	2.94	03-Nov (44 SMW)	10-Nov (45 SMW)	10-Nov (45 SMW)	17-Nov (46 SMW)	17-Nov (46 SMW)	10-Nov (45 SMW)
Eupelmus tachardiae	1.76	1.73	2.75	1.6	1.73	2.00	16-Dec (50 SMW)	09-Dec (49 SMW)	09-Dec (49 SMW)	09-Dec (49 SMW)	09-Dec (49 SMW)	16-Dec (50 SMW)
Parechthrodryinus clavicornis	1.33	1.77	1.84	1.18	1.75	1.84	20-Oct (42 SMW)	20-Oct (42 SMW)	13-Oct (41 SMW)	27-Oct (43 SMW)	27-Oct (43 SMW)	20-Oct (42 SMW)

AF: Agroforestry system; VC: Village commons; SAR: Strip along road side; SMW: Standard Meteorological Week

The figures in the parentheses indicate Range (number of insects/30 cm stick lac)

Table 4.22 Natural enemies associated with lac insects (jethwi lac) in kusum plant in the surroundings of KWS during 2017-18 and 2018 -19

Enemy Species	Peak density						Peak active period					
	2017 -18			2018-19			2017 -18			2018 -19		
	AF	SAR	VC	AF	SAR	VC	AF	SAR	VC	AF	SAR	VC
Eublemma amabilis	5.94	6.01	6.04	5.53	6.03	6.06	07-Jul (27 SMW)	30-Jun (26 SMW)	30-Jun (26 SMW)	30-Jun (26 SMW)	23-Jun (25 SMW)	23-Jun (25 SMW)
Pseudohypatopa pulverea	3.02	3.46	3.93	3.46	3.49	3.51	07-Jul (27 SMW)	30-Jun (26 SMW)	07-Jul (27 SMW)	23-Jun (25 SMW)	30-Jun (26 SMW)	30-Jun (26 SMW)
Tachardiphagus tachardiae	8.28	8.39	9.16	7.95	8.61	9.58	14-Jul (28 SMW)	07-Jul (27 SMW)	07-Jul (27 SMW)	30-Jun (26 SMW)	07-Jul (27 SMW)	07-Jul (27 SMW)
Aprostochetus purpureus	7.64	7.97	8.50	7.86	8.02	8.72	07-Jul (27 SMW)	30-Jun (26 SMW)	30-Jun (26 SMW)	14-Jul (28 SMW)	07-Jul (27 SMW)	07-Jul (27 SMW)
Parechthrodryinus clavicornis	4.71	5.99	6.81	4.46	5.125	6.81	07-Jul (27 SMW)	07-Jul (27 SMW)	30-Jun (26 SMW)	30-Jun (26 SMW)	07-Jul (27 SMW)	30-Jun (26 SMW)

AF: Agroforestry system; VC: Village commons; SAR: Strip along road side; SMW: Standard Meteorological Week

The figures in the parentheses indicate Range (number of insects/30 cm stick lac)

Table 4.23 Peak Population density (Density/30 cm stick lac) of Katki lac in palas trees in the surroundings of KWLS

Enemy	2017			2018		
	AF	SAR	VC	AF	SAR	VC
Eublemma amabilis	7.98±0.55	9.44±0.54	11.08±0.49	7.20±0.10	9.49±0.43	11.28±0.43
Pseudohypatopa pulverea	7.39±0.13	6.96±0.31	8.03±0.19	7.04±0.30	8.08±0.15	9.12±0.26
Chrysopa spp.	4.48±0.20	4.71±0.27	5.13±0.18	4.14±0.17	4.25±0.15	5.11±0.37
Tachardiphagus tachardiae	2.01±0.10	2.03±0.12	2.77±0.12	2.07±0.15	2.58±0.15	2.79±0.07
Aprostochetus purpureus	5.72±0.14	6.90±0.09	7.65±0.14	5.07±0.05	6.68±0.05	6.96±0.19
Eupelmus tachardiae	1.15±0.06	1.53±0.17	1.77±0.08	1.51±0.19	1.69±0.12	2.10±0.11
Parechthrodryinus clavicornis	2.65±0.1	2.50±0.3	3.25±0.12	2.49±0.16	2.70±0.24	3.00±0.08

±SD; N=5

The peak active period of *Eublemma amabilis* varied from 24-Aug (34 SMW) to31-Aug (35 SMW), for *Pseudohypatopa pulverea* it ranged from 31-Aug (35 SMW) - 07-Sep (36 SMW) and for *Chrysopa spp* it was 03-Aug (31 SMW) to10-Aug 10-Aug (32 SMW) in different sites of AF, SAR and VC (**Table 4.19**). Similarly, the active period of parasitoids varied from 28-Sep to 19-Oct (42 SMW). The seasonal population of *Eublemma amabilis* ranged *between* 3.96 - 6.01 followed by *Pseudohypatopa pulverea* (3.7 - 5.35) and *Chrysopa spp (*2.07- 3.19). In case of parasitoids it ranged from 0.70- 2.68 (**Table 4.24).**

In baisakhi crop of palas the peak density of predators (**Table 4.25)** ranged for *Eublemma amabilis* (5.03 – 6.27), for *Pseudohypatopa pulverea* (5.00 – 5.45) and for *Chrysopa spp (2.72 -3.85). Eublemma amabilis* was also dominant predator in baisakhi crop. Among the parasitoids *Tachardiphagus tachardiae* was the dominant species followed by *Eupelmus tachardiae*. In VC it was more as compared to other sites. Peak active period (**Table 4.20)** of *Eublemma amabilis* 28-Mar (13 SMW)-04-Apr (14 SMW), *Pseudohypatopa pulverea* 25-Apr (17 SMW) - 02-May (18 SMW and *Chrysopa spp* 20-Dec (51 SMW) - 03-Jan (01 SMW). Similarly, *Tachardiphagus tachardiae* had peak active period of 02-May (18 SMW) - 16-May (20 SMW). *Eupelmus tachardiae* had 20-Dec (51 SMW) -10-Jan (02 SMW) as peak active period. In *Eublemma amabilis* seasonal (**Table 4.26)** density ranged from (2.40 - 3.35) followed by *Pseudohypatopa pulverea* (1.85 -2.57) and *Chrysopa spp* (0.04 – 0.94). *In Tachardiphagus tachardiae* seasonal density *varied between* 2.25-3.13 and for *Eupelmus tachardiae* it was between 0.07 and 0.11 .

In aghani crop of kusumi strain in kusum tree three types of predators (*Eublemma amabilis*, *Pseudohypatopa pulverea* and Chrysopa *spp*.) and four types of parasitoids (*Tachardiphagus tachardiae, Aprostochetus purpureus, Eupelmus tachardiae* and *Parechthrodryinus clavicornis*) were present as in katki crop (**Table 4.21).** These were more prone to infestation by predators and parasitoids. Peak density of predator *Eublemma amabilis* ranged (7.08 -8.41), *Pseudohypatopa pulverea* (5.60 - 7.85) and *Chrysopa spp*. (3.33 – 4.08). Peak density of parasitoids *Tachardiphagus tachardiae* ranged from (7.34 - 7.89), for Aprostochetus purpureus (1.99 - 2.94), for Eupelmus tachardiae (1.6 -2.75) and for *Parechthrodryinus* *clavicornis* (1.33 - 1.84). Peak density was highest in VC followed by SAR and AF (**Table 4.27**). Peak active period varied in different sites. Peak active period of *Eublemma amabilis* ranged from18-Aug (33 SMW) - 01-Sep (35 SMW), *Pseudohypatopa pulverea* 08-Sep (36 SMW) - 15-Sep (37 SMW) and *Chrysopa spp.* 11-Aug (32 SMW) - 18-Aug (33 SMW). Active period of parasitoids *Tachardiphagus tachardiae* ranged from 27-Oct (43 SMW) - 03-Nov (44 SMW), *Aprostochetus purpureus* 10-Nov (45 SMW) - 17-Nov (46 SMW), *Eupelmus tachardiae* 09-Dec (49 SMW) - 16-Dec (50 SMW), *Parechthrodryinus clavicornis* 13-Oct (41 SMW) - 27-Oct (43 SMW). Seasonal population density (**Table 4.28)** of predator *Eublemma amabilis* ranged (2.88 – 4.18), Pseudohypatopa pulverea (1.88 – 2.95) and *Chrysopa spp* (1.05 – 1.95). Parasitoids of *Tachardiphagus tachardiae* (2.58 – 3.89), *Aprostochetus purpureus* (0.55 – 0.98), *Eupelmus tachardiae* (0.68 – 1.04) and *Parechthrodryinus clavicornis* (0.35 - 0.57). Max. density was in VC followed by SAR and AF.

In jethwi crop of kusum strain two types of predators (*Eublemma amabilis*, *Pseudohypatopa pulverea*) and three types of parasitoids (*Tachardiphagus tachardiae*, *Aprostochetus purpureus* and *Parechthrodryinus clavicornis*) were found (**Table 4.22).** The range of peak density of *Eublemma amabilis* was (5.53 - 6.06) was maximum in VC followed by *Pseudohypatopa pulverea (*3.02 – 3.93) (**Table 4.29**).The peak active period ranged from 23-Jun (25 SMW and 23-Jun (25 SMW) for *Eublemma amabilis*, *Pseudohypatopa*, respectively. Parasitoids had different ranges peak active periods. The range of seasonal variation was different among parasitoids and predators in across sites and crops (**Table 4.30**)

4.4 Discussion

4.4.1 Biological attributes of Lac insect

4.4.1.1 The life cycle duration and life span

The life cycle duration and life span of lac insects varied with different strains, season of crops as well as on specific host plants and sites. For the above experiment, the broodlac was inoculated on various tender branches of hosts to allow the tiny insects to come out of female lac cell. The results of present findings to find out settlement of larva, male and larval emergence as well as life cycle and life span in AF, SAR and VC have been reported in for 2017-18 and 2018-19. It was observed that life cycle period was more in jethwi crop of kusumi strain in ber plant. Life cycle period of katki crop of rangeeni strain in palas and ber was 110 and 165 days, respectively. Life span of young ones varied from 36 – 106 days and for female it was 107 – 259 days. The life span of adult male ranged from 2 -3 days. This may due to variation of temperature between various sites as also reported by Sharma (2007); Bhagat and Mishra (2002); Mishra *et al*. (1999).

Table 4.24 Seasonal Population density (Density/30 cm stick lac) of Katki lac in palas trees in the surroundings of KWLS

Enemy	2017			2018		
	AF	SAR	VC	AF	SAR	VC
Eublemma amabilis	4.42±0.105	5.21±0.07	5.24±0.06	3.96±0.22	4.97±0.14	6.01±0.21
Pseudohypatopa pulverea	3.77±0.06	3.91±0.08	4.24±0.07	3.65±0.14	4.42±0.13	5.35±0.05
Chrysopa spp.	2.07±0.04	2.42±0.10	2.79±0.05	2.37±0.05	2.75±0.08	3.19±0.13
Tachardiphagus tachardiae	0.73±0.03	1.01±0.05	1.33±0.05	0.82±0.06	1.12±0.06	1.47±0.1
Aprostochetus purpureus	1.70±0.06	2.21±0.03	2.62±0.08	1.70±0.07	2.40±0.03	2.68±0.07
Eupelmus tachardiae	0.30±0.02	0.40±0.02	0.59±0.02	0.49±0.02	0.54±0.02	0.79±0.06
Parechthrodryinus clavicornis	0.79±0.03	1.00±0.04	1.17±0.03	0.88±0.05	1.06±0.04	1.23±0.02

±SD; N=5

Table 4.25 Peak Population density (Density/30 cm stick lac) of baisakhi lac in palas trees in the surroundings of KWLS

Enemy	2017-18			2018-19		
	AF	SAR	VC	AF	SAR	VC
E. amabilis	5.67±0.23	6.11±0.28	6.27 ±0.25	5.03±0.38	5.36 ±0.211	5.47±0.24
P. pulverea	4.80±0.35	5.00 ±0.35	5.47 ±0.26	5.14 ±0.12	5.26 ±0.277	5.45±0.36
Chrysopa spp.	2.97±0.17	3.17±0.25	3.33 ±0.15	2.72 ±0.19	2.73 ±0.169	3.85±0.31
T. tachardiae	7.70±0.08	7.77±0.13	7.92 ±0.07	5.535±0.50	6.43 ±0.162	7.44±0.06
E. tachardiae	0.34±0.14	0.36±0.13	0.51 ±0.07	0.42 ±0.05	0.47 ±0.01	0.6 ±0.04

± SD; N=5

Table 4.26 Seasonal Population density (Density/30 cm stick lac) of baisakhi lac in palas trees at different sites

Enemy	2017-18			2018-19		
	AF	SAR	VC	AF	SAR	VC
Eublemma amabilis	2.84±0.01	3.15±0.08	3.35± 0.04	2.40 ±0.02	2.69 ±.04	2.93±0.07
Pseudohypatopa pulverea	1.85±0.06	1.96 ±0.06	2.41±0.09	1.98± 0.06	2.20 ±0.01	2.57 ±0.10
Chrysopa spp.	0.73 ±0.07	0.93 ± 0.04	0.94± 0.06	0.40 ±0.03	0.55 ±0.08	0.91 ±0.02
Tachardiphagus tachardiae	2.94 ±0.01	2.96 ±0.06	3.13± 0.06	2.25 ±0.03	2.26 ±0.03	2.74 ±0.07
Eupelmus tachardiae	0.07± 0.01	0.09 ±0.004	0.11±0.02	0.07 ±0.01	0.08 ±0.01	0.12 ±0.004

± SD; N=5

Table 4.27 Peak Population density (Density/30 cm stick lac) of aghani lac in kusumi trees in the surroundings of KWLS

Enemy	2017-18			2018-19		
	AF	SAR	VC	AF	SAR	VC
Eublemma amabilis	7.52 ±0.51	7.66 ±0.46	8.41±0.33	7.28 ±0.16	7.08±0.22	7.88 ±0.46
Pseudohypatopa pulverea	6.48 ±0.15	6.87 ±0.43	6.55 ±0.12	5.608 ±0.58	6.86±0.27	7.13 ±0.20
Chrysopa spp.	3.33 ±0.09	3.71 ±0.09	3.63 ±0.12	3.52 ±0.12	3.798±0.13	4.08 ±0.18
Tachardiphagus tachardiae	7.50 ±0.16	7.61 ±0.16	7.89 ±0.13	7.34 ±0.22	7.50±0.18	7.68 ±0.18
Aprostochetus purpureus	2.06 ±0.09	2.83 ±0.08	2.99 ±0.05	1.99 ± 0.28	2.64±0.74	2.94 ±0.21
Eupelmus tachardiae	1.76 ±0.09	1.73 ±0.08	2.75 ±0.05	1.6 ±0.05	1.73±0.10	2.00 ±0.28
Parechthrodryinus clavicornis	1.33 ±0.25	1.77 ±0.06	1.84 ±0.05	1.18 ±0.17	1.75±0.19	1.84 ±0.04

± SD; N=5

Table 4.28 Seasonal Population density (Density/30 cm stick lac) of aghani lac in kusumi trees in the surroundings of KWLS

Enemy	2017-18			2018-19		
	AF	**SAR**	**VC**	**AF**	**SAR**	**VC**
Eublemma amabilis	2.88 ±0.07	3.41 ±0.16	4.06±0.41	3.00 ±0.08	3.61±0.09	4.18±0.23
Pseudohypatopa pulverea	2.08 ±0.05	2.53 ±0.14	2.91±0.14	1.88 ±0.02	3.01±0.08	2.95±0.10
Chrysopa spp.	1.05 ±0.06	1.48 ±0.05	1.55 ±0.04	1.08 ±0.12	1.44±0.05	1.59±0.05
Tachardiphagus tachardiae	2.58 ±0.04	3.01 ±1.22	3.89 ±1.17	2.58 ±0.10	3.15±0.13	3.95±0.19
Aprostochetus purpureus	0.55 ±0.02	0.80 ±0.07	0.98 ±0.03	0.54 ±0.03	0.74 ±0.07	0.94±0.02
Eupelmus tachardiae	0.68 ±0.04	0.80 ±0.02	1.04 ±0.03	0.68 ±0.03	0.82 ±0.03	1.01 ±0.04
Parechthrodryinus clavicornis	0.35 ±0.14	0.51 ±0.02	0.56 ±0.01	0.37 ±0.03	0.50 ±0.01	0.57 ±0.02

± SD; N=5

Table 4.29 Peak Population density (Density/30 cm stick lac) of jethwi lac in kusumi trees in the surroundings of KWLS

Enemy	2017-18			2018-19		
	AF	SAR	VC	AF	SAR	VC
Eublemma amabilis	5.94 ±0.33	6.01 ±0.31	6.04 ±0.28	5.53 ±0.26	6.03±0.57	6.06±0.23
Pseudohypatopa pulverea	3.02 ±0.28	3.46 ±0.28	3.93 ±0.30	3.46 ±0.20	3.49±0.19	3.51±0.24
Tachardiphagus tachardiae	8.28 ±0.11	8.39 ±0.28	9.16 ±0.11	7.95 ±0.23	8.61±0.08	9.58±0.15
Aprostochetus purpureus	7.64 ±0.23	7.97 ±0.25	8.50 ±0.17	7.86 ±0.15	8.02±0.16	8.72±0.07
Parechthrodryinus clavicornis	4.71 ±0.27	5.99 ±0.23	6.81 ±0.13	4.46 ±0.23	5.125± 0.24	6.81±0.32

± SD; N=5

Table 4.30 Seasonal population density (mean density/30 cm stick lac) of jethwi lac in kusumi trees in the surroundings of KWLS

Enemy	2017-18			2018-19		
	AF	SAR	VC	AF	SAR	VC
Eublemma amabilis	1.73±0.09	1.90±0.03	1.93 ±0.08	1.58 ±0.08	1.84±0.05	1.90 ±0.09
Pseudohypatopa pulverea	0.65±0.04	0.74±0.05	0.88 ±0.06	0.69±0.04	0.71±0.01	0.76 ±0.04
Tachardiphagus tachardiae	3.42±0.10	3.90±0.06	4.17 ±0.03	3.25 ±0.12	3.86±0.06	4.23 ±0.01
Aprostochetus purpureus	3.11±0.22	3.58±1.24	3.75 ±0.03	3.22 ±0.07	3.60±0.12	4.20 ±0.09
Parechthrodryinus clavicornis	1.34±0.05	1.68±0.03	2.54 ±0.02	1.28 ±0.12	1.56±0.08	2.40 ±0.02

± SD; N=5

In Jethwi crop of kusumi in ber it was 270 days and in aghani crop of kusumi strain it was 260 days. The similar range were also reported earlier by Jaiswal and Sharma (2002); Kapur (1962). The longer period of life cycle in rangeeni strain might be due to high temperature (Bhagat and Mishra, 2002). Range of life span of male insect was 38 -109 days in AF, SAR and VC. However, it was 2- 3 days in adult male are almost similar to the earlier findings (Jaiswal and Sharma, 2002**;** Jaiswal, 2007).

4.4.1.2 Initial density of lac after 21 days of settlement

After inoculation of brood lac in tender shoots infestation of lac insects occurred and larvae settled in suitable places. It was observed that density of initial settlement of larvae (Individuals cm^{-2}) in all the host plants of each crop have more in VC followed by SAR and AF .In AF the range was 48.12-106.41 (Individuals cm^{-2}), in SAR 50.85 -111.61 and in VC 60.24 - 122.77 (Individuals cm^{-2}). After 21 days of settlement the highest population density was seen in VC (46.24 - 101.58) followed by SAR (47.52 - 104.59) and in AF (30.96 - 86.74). Earlier Kapur (1962) had reported that in one square inch from the surface of the branch, the range of initial density of settlement was 150-300. Sharma and Jaiswal (2002) also recorded about 150 larvae settled in that area. The effect of climatic conditions has direct influence on host plants (Jagannathan, 1956). The difference in density of settlement in three study sites might also be due to variation of microclimatic conditions among them.

4.4.1.3 Percentage of male and female (Sex ratio)

In the early stages of development, the sexes of insects are identified from the shape of the lac cells. For male insects, it grows more in the direction of the longitudinal axis and female more along the vertical axis of the lac cells **(**Jaiswal and Sharma, 2002; Kapur,1962). Before reaching adult stage, the insects shed their thorax when male metamorphosis is completed but for female it is incomplete. During this period male and female insects get maturity (Jaiswal and Sharma, 2002). In the present study, the percentage of male and female (sex ratio) ranged between 22.95 - 33.99 and 66.01-73.76 in AF , in SAR 20.01 - 36.51 and 63.49 - 79.99 and in VC 25.43- 33.63 and 66.37 - 79.07 respectively. It indicated that the range of male and female population was more in VC. Sex ratio was approximately 1: 3. This is similar to the earlier findings of Jaiswal and Sharma (2002); Sharma and Jaiswal (2002). Sex ratio ranged widely and depends upon host species (Jaiswal and Sharma, 2002; Srivastava and Kumar, 1985). Male insects have no contribution towards lac production, only female insects play major role in lac culture but male insects are very essential in proper percentage to fertilise female for higher yield.

4.4.1.4 Density of living female at crop maturity and Diameter of female lac cell

Density of settlement (Individuals cm^{-2}) of living female at crop maturity depends on the environmental factors and existing host species diversity (Sharma et al,2007). Density of settlement of living female at crop maturity (Individuals cm^{-2}) in AF ranged between (6.29- 13.49), SAR (7.53 - 13.98) and VC (8.03 -15.81)**.** The range and mean also conform to the findings of Sharma et al (2007). Diameter of lac cell depends upon species, crops and climatic factors (Jagannathan, 1956 and Sharma *et al*., 2007). Diameter of female lac cell (mm) ranged from **(**3.43 - 5.17), (3.23 - 5.26) and (3.55- 4.40) in AF, SAR and VC, respectively. The variation in diameter of female cells are similar to the findings reported elsewhere **(**Sharma *et al*. ,2007).

4.4.1.5 Weight (mg) of female lac cell (dry cell wt. of female)

The mean weight (mg) of female lac cell (dry cell wt.) ranged between **(**11.93 - 29.94) in AF, in SAR (11.55 - 28.87) and (14.97 -28.87) in VC**.** The findings in the present study were similar with the findings of Sharma *et al*. (2007).

4.4.2 Emergence of natural enemies (predators and parasitoids).

Many researchers have worked on the emergence of the natural enemies which were observed in the study sites. Sharma *et al*. (1997) reported 14 species of parasitoids, among which *A. purpureus* (55.82%) and *T. tachardiae* (28.37%) were the most dominant species. Bhattacharya and Yogi (2015) reportrd 72 insect parasitoids and predators and out of which predator- *E. amabilis* and parasitoids-*T. tachardiae* and *A.purpureus* as being dominant in lac.

Bhattacharya *et al*. (2007) reported that emergence of 14 natural enemy insects (predators and parasitoids) among which *Eublemma amabilis* and *Pseudohypatopa (= Holcocera) pulverea* were major predators. Jaiswal *et al*. (2007) stated that *E. amabilis* Moore (Lepidoptera: Noctuidae) and *P. pulverea* Meyr (Lepidoptera: Blastobasidae) were the two most dominant predators of lac insect and carried lac crop loss ranges from 20 to 40%. Jaiswal *et al*. (2001) also stated that the lac insect associated predators and parasitoids were located in limited numbers of lac cultivated regions of Odisha. Chattopadhyay (2011) found that the *P. pulverea* predator of lac insect was most harmful predator in major lac growing regions of our country. The previously findings were agreed with associated species of insect predators and parasitoids as reported in traditional lac production areas of north and eastern India (Jaiswal *et al*., 2001).The present exploration is also more or less similar in accordance of earlier findings of study of Meena *et al*. (2018) who described that 11 species of insect fauna associated with *Kerria lacca* from 8 families under which 3 were representing predator species of *E. amabilis, P. pulverea, C. zastrowi;* primary parasitoids *T. tachardiae, A. purpureus, T. clavicornis, E. dewitzi* and hyper-parasitoids *A. fakhrulhajiae, E. tachardiae, B. greeni, B. tachardiae* in western plains of India**.** Sharma *et al*. (2010) also recorded that maximum 57.6 % parasitisation of lac insects due to *A. purpureus* while hardly 20 per cent parasitisation was found nearly twenty years back. At the same time, predators are very harmful and may make loss to the lac crop about 35-45% annually. There have been reports of around 20 predators found from different regions of our country, among these *Eublemma amabilis* and *Pseudohypatopa pulverea* were the most injurious (Sharma *et al*., 2008; Monobrullah *et al*., 2015).

Daharia and Katlam (2013) studied the prevalent lac natural enemies in four different lac cultivated districts of Mahasamund, Jashpur, Rajpur and Kanker in Chhatisgarh. They revealed that *E. ammabilis* Moore and *P. pulverea* Meyr as major predators in the state. However, among the parasitoids of *T. tachardiae* was found as major parasitoids. *E. amabilis* is reported as a key predator of commercial *K lacca* (Khobragade *et al*., 2012; Ramesh, 2013), and *P. pulverea* (Kumar *et al*., 2007; Ghosal *et al*.,2010) and parasite (Kumari *et al*., 2012). Moreover, *Chrysopa* also a predator of *K lacca* was studied by Ramesh (2013). In the present study, there was meagre population of *Chrysopa spp*.

Present finding is in conformity with previous experimental findings of Monobrullah *et al*. (2015) in which they revealed *A. purpureus*, the most alarming endoparasitoid of lac insect and determined direct correlation among low lac yield and parasitisation. Pandey *et al*. (2008) found that the emergence of more number of natural bio-agents (predators and parasitoids associated with lac insect *K. lacca* on *B. monosperma,* in *katki* (rainy) crop than *baisakhi* (summer) crops. Predators *viz. E. amabilis* and *P. pulverea* were seen in almost all the studied areas, whereas the parasitoids viz., *T. tachardiae*, *T. somervilli* and *A. purpureus* of lac insect in less numbers in the districts Allahabad and Mirzapur. Population of associated fauna varied considerably from crop to crop, place to place and in different months.

Srivastava *et al*. *(*1984); Monobrullah *et al*. *(*2015) found that in the *katki* and *baisakhi* crop, peak population of parasitoid coincided with the time of crop maturity are in conformity with the present findings. During the time of crop maturity, the lac associated fauna are most active which affects fecundity and resin yield of lac crop. Sharma and Ramani (2001) also revealed that during rainy season crop parasitization of lac insect affected the fecundity (32.55 and 34.71 %) and resin yield (17.92 and 17.44 %) of kusmi and rangeeni strains respectively. Besides that, prasitoids population was also dominant at sexual maturity period in baisakh*i* crop. This might bring about complete failure of lac crop. Sharma *et al*. *(*2010) revealed that emergence of parasitization found to be the vital factor for encoring pre-summer lac insects' mortality. The present findings are in also in conformity with the results of Mohanasundaram *et al*. (2016) who have reported that during critical/sexual maturity period *A. purpureus* alone represented 100 per cent population promoting complete lac insect mortality on *ber* and *palas* of *baisakh* crop.

Findings of the Present study are in similar with Sharma *et al*. (2007) who reported that parasitoids of lac insect make severe loss to the crop by adverse effect on the resin yield and the fecundity of the insects, mainly during rainy seasons. Due to parasitism the average decline in resin production by a single female varied between17.25-39.80 per cent in *rangeeni* and 25.24-37.91 per cent in *kusmi* strain. Chattopadhyay (2011) also revealed that *A. purpureus* belongs to the order hymenoptera are the most prevalent lac associated parasitoids. The parasites exhibited different patterns of peak emergence. Among the parasitoids of lac insect, *Aprostocetus purpureus* and *T. tachardiae* were observed regular regularly in large numbers in all the four lac crops (baisakhi, katki, jethwi and aghani) by Srivastava *et* *al.* (1984). Rahman *et al*. (2009) noticed that the moth *E. amabilis* is very harmful to lac insect and lac encrustation. Prior to pupation a single larva injures 42-50 mature lac cells and brings more loss to the kartki crop than to the baishakhi crop. Mohanasundaram *et al.* (2023) affirmed that three parasitoids such as *Aprostocetus purpureus*, *Tachardiaephagus tachardiae*, *Tyndarichus clavicornis* and one predator *Eublemma amabilis* were abundant in both lac crops of rangeeni summer season (baisakhi) and rainy season (katki) lac crops on ber and palas.

Variation of population was observed between different locations, the hosts and the crop seasons. During the year 2012-2015 Mohansundram *et al*. (2018) affirmed that the variations of lac insect associated predators and parasitoids population for both strains of kusmi and rangeeni; *T. tachardiae* and *A. purpureus* population was 14.7 and 62.7 respectively and maximum in ber 50.2, during katki crop.

Monobrullah *et al*. (2015) also stated that during rainy season (katki) crop, prevalence of *A. purpureus*, and *P. clavicarnis* was more during September-October, whereas *T. tachardiae* was more in October-November. Predator *(E. amabilis* and *P. pulverea)* were more abundant during crop maturity period in both the crops of *baisakhi and* katki. A variation in population was observed among the location, host and crop season. Srivastava *et al*. (1984) noticed that higher peak of associated parasitoid population in the katki crop accorded with the time of crop maturity period (October and November) are in conformity with the present findings.

Higher emergence of populations of parasitoids and predators were found in the village commons due to lack of maintenance and sanitation of lac culture area. In this area, there are no operations between inoculations of brood lac on host plant and the harvest of the lac secretion produce. Intensive maintenance of lac ecosystem considered as an effective practice for controlling parasitoids and predators which includes undergrowth (ground cover) cleaning, removal of dried, dead and criss-cross branches of host plants which is seen in agricultural fields. The removal of branches from the dense crown to reduce crown density and enhances air circulation as well as reduced humidity which are unfavourable for emergence of parasitoids and predators of host plants in agricultural fields. It was found that mean number of associated natural enemies of both predators and parasitoids per 30 cm lac encrustation stick was more in village commons than the other locations around the KWLS (**Tables 4.2**). This may be due to variation in climatic conditions between different sites. Climate has direct as well as indirect effect on these insects and also on the host plants on which these insects survive (Jagannathan, 1956). The variation in eco-climatic factors of different sites may be attributed to vegetation types. Village commons have dense (thick) forest in comparison to other locations. Due to continuous nature of the canopy, it acts as safeguard from the adversities of climatic factors of temperature, wind and rainfall. This site provides favourable environment for emergence of natural enemies than other sites. Therefore, the lac insects are more susceptible to natural enemies in village commons.

Present studies are more or less similar to Uike (2015), reported that the *E. amabilis* and *P. pulverea* were as major predators and *Chysopa sp*. was as minor predator. This investigation is also same to Meena *et al*. (2018) described that 11 species of fauna associated with lac insects belonging to 8 families, among which there were 3 species of predators such as *E. amabilis, P. pulverea, C. zastrowi*; among the parasitoids *T. tachardiae, A. purpureus, T. clavicornis, E. dewitzi* and hyper-parasitoids *A. fakhrulhajiae, E. tachardiae, B. greeni, B. tachardiae.* Present findings are also in accordance with Mohansundram *et al*. (2018) who reported variations of lac insect associated fauna of predators and parasitoids in relation to different lac host plant for both *rangeeni* and *kusmi* strain. *T. tachardiae* and *A. purpureus* population was 14.7 and 62.7 respectively and maximum in ber 50.2 of katki crop during year 2012-2015. Different lac associated fauna such as *T. tachardiae, A. purpureus, P. clavicornis, E. amabilis, P. pupverea* and hyper parasitoids *B. greeni, B. tachardiae* and *Elasmus clavipennis* was explored in *katki*, *baisakhi, jethavi* and *aghani* crop of different host plants of palas, ber, kusum, *Flemingia* and redgram.

Malhotra and Katiyar (1975) cited by Sharma and Jaiswal (2002) also enumerated that *E. amabilis* and *P. pulverea* as key associated predators causing severe loss of 35 to 40 per cent to lac crop. Their larvae nourished on the scales from silken tubes and swallow between 40 and 60 percent scales throughout their growth period. The *Cryosopa spp*. are associate sporadic pests that often create significant mortality (Sharma & Jaiswal, 2002). Rahman *et al*. (2009) also revealed that *E. amabilis* is most harmful predator to lac insect and lac encrustation. Prior to pupation a single larva injures 42-50 mature lac cells and promoting more adversity to katki crop as compared to the baishakhi crop.

The parasitoids of lac insect causing the greatest mortality of *K. lacca* are affecting adversely the resin yield and the fecundity of the lac insects, particularly during rainy seasons. Sharma *et al*. (1997) in a study also reported that fourteen parasitic species belonging to 13 genera of ten families were associated with the *K. lacca*. Among these, *A. purpureus* and *T. tachardiae* were most dominant species and comprises of around 55.82, 28.37 per cent respectively of the total population of parasitoids. Subbarayudu and Maheswar (1998) revealed that three species of parasitoids of *K. lacca* of were *Tetrastichus purpureus* (*A. purpureus), T. tachardia* and *C. tschirchii*. They enumerated that parasitization of enormous number of 18.40 and 26.00% in both strains of Kusmi and Rangeeni, respectively. *A. purpureus* exclusively gives rise to 7.8 and 11.8% parasitization in the kusmi and rangeeni strain, respectively, whereas, up to 9 and 6 parasitoids were found in rangeeni and kusmi strains, respectively from a single cell.

The present research results get confirmation partly from the past findings of Sharma *et al*. (1997) where parasitoids of *A. purpureus* and *T. tachardiae* detected most abundant species comprising 55.82 per cent and 28.37 per cent, respectively of the total population of parasitoids. However, this alteration may be found due to varied agro climatic conditions of the region. Sharma and Ramani (2001) reported that rainy season crops of both strains of kusmi and rangeeni of *K. lacca* are severely affected fecundity and resin production due to parasitisation. Sharma *et al*. (2007) also stated that due to parasitism the resin produced by a single female reduced severely. Mohansundram *et al*. (2016) reported that the prevalence of the lac associated predators and parasitoids during baisakhi (summer) season crop for two consecutive years, which stated that, parasitoids alone constitute 93 and 89 per cent population, followed by predator and hyper parasitoids on ber, respectively. Similar trend was found on palas for both the years, among which, *A. purpureus* was significantly more abundant which constitute 71.56 per cent on ber and 74.47 per cent on palas, respectively. They further revealed that *A. purpureus* population had increased by 538 per cent in over four decades. Maximum population of *A. purpureus* was found during the SMW 17 to 22 after inoculation. These findings reported that the emergence of *A. purpureus* as the pest of lac insect causing huge economic losses, which are more or less similar to our results.

Overall, different parameters of biological attributes such as density of settlement, sex ratio, mean female cell size, mean cell weight and mean resin weight was maximum in village commons and can be exploited for further multiplication for commercial cultivation. Size and weight of the female lac cell played an important role as thickness of lac encrustation determines lac yield. The life cycle of kusmi strain lac insects is about six months and it produces two crops in a year. Rangeeni strain also had crops but two different life cycles of about *four* month and eight months durations.

Rangeeni crop was found to be more threatened to associated pest attack in lac insects and destruction is more in the rainy season crop which results the severe crop loss. This loss can be reduced through proper identification of lac insect pests and their effective management approaches. The current investigation determines that adequate pest management strategy to be followed for specific crop season depending upon the nature of emergence profile of lac associated fauna of key parasitoids/predators. Populations' variation of parasitoid and predator was found in palas of katki crop season. Among the parasitoids, *A. purpureus* was the most key parasitoids followed by *T. tachardiae* and *P. clavicornis*. In katki lac, crop maturity period is regarded as the most vulnerable phase which reduced quality of broodlac. During this period increased incidence of parasitoids and predators may induce to entire crop failure. Since, this knowledge pertaining to the most critical stage of associated fauna in lac ecosystem can assist in developing a pest management programme among the lac growing farmers and researchers.

Chapter 5

Host plant diversity of Lac

5.1 Introduction

Tropical forests are well known for the most species-diverse terrestrial ecosystems in the earth. The biodiversity of these forests provides a variety of resources which help to sustain the livelihood of local communities (Mishra, 1968). Tropical forests of India comprise of around 86% of the total forest area, in which tropical dry deciduous and moist deciduous forests have areas of 53% and 37% respectively. The remaining 10% is retained by semi evergreen and wet evergreen forests (Singh and Singh, 1991). It is ascertained that species diversity in the tropical forests are greatly variable as comparable to dry deciduous forests that are explicitly exploited and degraded (Murphy and Lugo, 1986; Gentry, 1992). Abundant kinds of economically important plants are available in these forests. Tropical forests are declining rapidly due to Over-exploitation resulting in one of the most significant environmental and economic obstacles all over the world (Hare *et al*., 1997).

Shrinkage of forest areas in the study sites led to the ecological problem such as soil erosion, extinction of many ethno-botanically important species of plants and animals (Bora and Kumar, 2003). Inventory of plant species providing information on diversity will play an important tool for strengthening ability of *in-situ* and *ex-situ* conservation of biodiversity as well as the socio-economic setup of local communities that occurred from depletion of forests (Baraloto *et al*., 2013). Malik *et al*. (2014) and Malik and Bhatt (2016) also stated that know-how composition and diversity of tree species is vital to understand the structure of a forest community for formulation and implementation of conservation strategy of the forest ecosystem. A significant portion of diversity of the study site has already been lost due to the versatile issues like illicit felling, habitat loss, forest fire, timber and fuel wood collection, livestock grazing pressures etc.

Odisha is traditionally an agrarian state and well-known for its rich and abundant biodiversity in India and in Southeast Asia as well. Saxena and Brahmam (1994) reported 2,727 species of plants under 228 families and 1062 genera of which

2561 species are indigenous and 166 species are cultivated in Odisha. While more than 100 species are listed as classified as threatened plants, Odisha is a rich source of forest produce and the forest cover is 51,619 sq. km which constitutes 33.15% of the state's geographic area (Forest Survey of India, Report 2019). Kuldiha Wildlife Sanctuary possesses floristically important tropical deciduous forest of Odisha, India. It is endowed with vast natural resources, diversified agro-edaphic conditions, rich flora and fauna, wide range of cropping patterns, various socio-cultural groups and people with multiple economic strata. The wide ranges of topographic, edaphic and climatic conditions have led to consociation of a variety of vegetation on different landscapes of village commons in this hill range.

Due to overexploitation of medicinal plants, fuel wood collection, timber collection, illicit felling, uncontrolled grazing and forest fire causing habitat degradation and declining of plant diversity of site at an alarming pace. Among species of much ecological and economic importance to the forest fringes in the surroundings of Kuldiha Wildlife Sanctuary are Kusum (*Schleichera oleosa*), Palash (*Butea monosperma*) and Ber (*Zizyphus mauritiana*). Kusum (*Schleichera oleosa*), is the best lac host species for production of Kusumi lac strain. Palash (*Butea monosperma*) plant is very suitable for production of Rangeeni lac strain within a period of 5-6 years of regeneration. Ber (*Zizyphus mauritiana*) is also suitable for Kusumi and Rangeeni strains of lac within a period of 4-5 years of regeneration. Therefore, lac cultivation is expected to result in disturbances in forest community which in turn may lead to change in population structure of this species. Lac host species which not only provides livelihood to millions of lac growers but also helps in conserving vast stretches of village commons need priorities for conservation and protection and also required to be monitored. The information on distribution of plant communities is useful to understand the population dynamics of each species and how these major lac host species distributed in relation to the other species in the same community are also studied.

No published detailed information on the species composition and diversity of the trees in the study site is available. Therefore, a necessity prevails to identify the vegetation composition and floristic status of upper storey and assess their diversity. A comprehensive phytosociological analysis of the village commons (VC), agroforestry system (AF) and strips along road (SAR) was done by incorporating parameters like relative density, abundance, relative frequency, relative basal area and Important Value Index, which will be applicable to plan for proper management intervention to enhance the sustainability development of forest biodiversity supporting livelihood through lac-based activities in the study area.

5.2 Material and Methods

5.2.1 Study area

The present study has been carried out in Nilgiri block of Balasore district, Odisha, India. Ten sites each in village commons adjacent to Kuldiha Wildlife Sanctuary, Agroforestry system (AF) and Strips along the roads (SAR). The study areas have a subtropical climate with three distinct seasons i.e. summer, monsoon and winter. The mean annual rain fall is about 1630 mm. and enjoys a tropical climate. Because of its proximity to Bay of Bengal, climatically this tract is comparatively humid- hot. The mean maximum temperature is 38°C during April – May and minimum 8°C during November – January. The maximum temperature at times falls beyond 42°C. Forest type is mostly tropical deciduous forest type (Champion and Seth, 1968). Soil types vary from sandy to heavy red sandy loam found in the area. The rock of the site consists of Khondolites are represented by quartz, garnet, sillemanite, schist and garnetiferous quartzites. A good exposure of laterite is found in this area in the south west portion. This is an alteration product of khondolites.

5.2.2 Methodology and Data Collection

The study was based on the primary data collected from major lac growing villages of Balasore district, Odisha. The study was conducted in three different landscapes namely Village commons around protected area, Agroforestry system and Road side strips.

Five major lac growing villages namely Tiakata, Garadihi, Chaindar, Balichua and Chekamara of Garadihi Gram Panchayat were surveyed in all the possible habitats for recording the data for the year 2018-19 to fringe forests (i.e. 05 Km) around Kuldiha reserve forest of Balasore, Odisha. The study involved intensive field visits at regular intervals and careful investigations of the floral resources. The plants were collected, properly identified and when it was confusing to identify species in the field, the species were documented and herbarium specimens were prepared. The herbarium specimens were sent to College of Forestry, Odisha University of Agriculture and Technology (OUAT), Bhubaneswar, Odisha for proper identification. Standard field and herbarium methods (Jain and Rao, 1977; Bridson and Forman, 1998) were followed for collection and preservation of plant samples. Herbarium specimens were prepared and the nomenclatures of the plant species were designated based on the regional floras like Flora of Presidency of Madras (Gamble and Fischer, 1935) and Flora of Orissa (Saxena and Brahmam, 1994). Each plant species recorded in the different quadrants in village commons were classified by family and genera.

5.2.3 Vegetation Assessment

Phytosociological characteristics of tree species were studied by randomly laying out 10 quadrats of 10 x 10 m^2 sizes for trees (≥10 cm dbh.) covering entire study area. In the 100 m^2 quadrats the number of individuals of each tree species was counted and circumference at breast height (CBH 1.37 m) from the ground was measured by using a girth tape. Buttressed trees were measured above the buttress. All the tree species in the quadrats were counted to estimate the diversity, frequency, density, abundance and Importance Value Index (IVI) of the woody vegetation.

The size and the number of quadrats for study were determined following the principles of Kershaw (1973) and Misra (1968). Floristic composition, density, diversity, dominance, distribution and tree population structure were studied according to Curtis and McIntosh (1950), Misra (1968), Shimwell (1971), Mandal and Josh (2014), (Abule *et al*., 2007), (Moore *et al*., 1986); (Shukla *et al*., 1980). The importance value index (IVI) was calculated as reported by Curtis and McIntosh (1950), Mishra (1968), Curtis (1953), (Kassahun *et al*., 2008); Cottam *et al*. (1956).

It is used to identify the inclusively influence of each species in the community structure.

Abundance Frequency ratio (A/F)

Abundance to frequency ratio (A/F) has been computed following Whitford (1949): WI = abundance/frequency (A/F Ratio) to assess the spatial distribution pattern of species and depending upon the ratios, distribution may be regular, random or contagious. A value of <0.025 would denote a regular distribution, values between 0.025-0.05 a random distribution and a value >0.05 would signify a contagious distribution. The data obtained were also used to enumerate community indices such as Shannon-Wiener's diversity index (Shannon and Wiener, 1963) of species diversity of upper storey vegetation) and Pielou's evenness index (1966).

Shannon-Weiner index (H)

The diversity of the species was computed using the Shannon-Weiner index (H) as :

$H = \sum^{s} pi \ln pi \quad i=1$

Where s = Total number of species; pi = proportion of individuals in each species or abundance of the i-th species; and Ln is the natural logarithms to the base e.

All the collected data are put in the excel spread sheet and according to the family of tree species the Simpson's formula has been worked out. Tree species whose numbers are more than 1, was assumed for calculating the Simpson diversity index as reported by Simpson (1949). Tree species whose numbers found 1 or less was considered to have no diversity (Anandan *et al*., 2014).

Simpson's Species Diversity Index

Simpson's Diversity Index is a measure of diversity which takes into account the number of species present, as well as the relative abundance of each species. The formula for calculating D is presented as:

$$D = 1 - \left(\frac{\sum n(n-1)}{N(N-1)} \right)$$

Where n=the total number of individuals of each species

N=the total number of individuals of all species.

Pielou's index

Evenness Index was calculated using Pielou's index (D= -Σ pi2 / ln S), where S = species richness of the community, pi = proportion of individuals or abundance of the i^{th} species and ln is the natural logarithms to the base (Magurran, 1988).

Association Index

The inter-specific association was determined by association index which helps in assesing the main associates of an important species in the forest (Sukla *et al*., 2015). It was estimated by the equation:

Association Index of a Species (A) =

$$\frac{\text{Total no.of quadrats in which a species occures along with another species(B)in the stand x 100}}{\text{Total no.of quadrats in which a species occurs in that stand}}$$

5.3 Results

5.3.1 Floristic composition in village commons

The phytosociological analysis of the trees in village commons around Kuldiha forest range recorded the presence of a total of 44 number of tree species under 31 genera belonging to 17 families **(Table 1).** The number of species per genus was higher than 1.4 and the number of species per family was about 2.6. Majority of families are represented by one or two species only. The foremost dominant family was Fabaceae which contained 13 species followed by Moraceae 5 species; Myrtaceae 3 species; Anacardiaceae, Apocynaceae, Arecaceae, Combretaceae, Ebenaceae, Meliaceae, Rhamnaceae, Rubiaceae, Rutaceae (2 species each); Bombacaceae, Burseraceae, Dipterocarpaceae, Sapindaceae and Sapotaceae (1 species each) (**Table 5.1**).

The total tree density across the study sites recorded was 1750 individuals per ha and total basal area/ha of 1322.5 sq. m. The tree density varied from 10 to 120 individuals per ha and the basal area ranged from 3.22 to 164.56 m^2 ha^{-1} (**Table 5.1**).

Butea monosperma exhibited the highest density (120 plants/ha) followed by *Hollarhena antidyesenterica* (110 plants/ha) and the lowest density was found at *Neolamarckia cadamba* (10 plants/ha) (**Table 5.1**). *Shorea robusta* occupied the highest basal area of 164.56 m^2 ha^{-1}, followed by *Hollarhena antidyesenterica* (93.31 m^2 ha^{-1}) and *Schleichera oleosa* (77.26 m^2 ha^{-1}). The lowest basal area (3.22 m^2 ha^{-1}) was measured in *Melia azedarach*. The Importance Value Index (IVI) of tree species varied from 1.82 to 20.74 (**Table 5.1**). This indicated that in the study area *Shorea robusta* and *Schleichera oleosa* were the most dominant species whereas *Neolamarckia cadamba* and *Melia azedarach* were found to be the least dominant species (**Table 5.1**). The most dominant trees in descending order of IVI were *Shorea robusta* (20.74), *Schleichera oleosa* (16.16), *Madhuca indica* (15.07), *Butea monosperma* (14.53), *Acacia auriculiformis* (11.45), *Eucalyptus tereticornis* (10.74) (Table 1). The least dominant species in ascending order of IVI are *Neolamarckia cadamba* (1.82) and *Melia azedarach* (2.25), *Albizia lebbeck* (3.31), *Dalbergia lanceolaria* (3.33), *Ficus racemosa* (3.37), *Ficus religiosa* (3.61) (**Table 5.1**). Most of the recorded species in the study area revealed random distribution (26 species). Insignificant number of species indicated clumped /contagious (13 species) and regular distribution (5 species). The association index of species for lac host species such as *Scheleichera oleosa*, *Butea monosperma* and *Ziziphus mauritiana* varied widely (**Table 5.1**) and the most important associates were *S. robusta*, *B. lanzana*, *S. cerasoides* and *S. cumin* in the study sites.

Table 5.1 Phytosociological Attributes of Trees in the Village Commons

Sl. No.	Scientific Name	Local name	Family	Density/ha	Basal Area/ha (m^2/Ha)	Association index of lac host species			A/F	IVI
						Kusum	Palas	Ber		
1.	*Acacia auriculiformis*	Acacia	Fabaceae	100	64.45	0.17	0.25	0.50	1.00	11.45
2.	*Acacia leucophloea*	Dhalaguhira	Fabaceae	20	37.10	0.33	0.05	1.00	0.05	5.67
3.	*Acacia nilotica*	Babul	Fabaceae	50	24.66	0.33	0.13	1.00	0.13	6.45
4.	*Adina cordifolia*	Kurum	Rubiaceae	30	11.78	0.50	0.08	1.50	0.03	5.19
5.	*Aegle marmelos*	Bela	Rutaceae	20	13.05	0.33	0.05	1.00	0.05	3.85
6.	*Albizia lebbeck*	Sirisha	Fabaceae	20	5.89	0.33	0.05	1.00	0.05	3.31
7.	*Albizia procera*	Dhalasiris	Fabaceae	30	19.41	0.50	0.08	1.50	0.03	5.77
8.	*Alstonia scholaris*	Chhatiyana	Apocynaceae	20	15.38	0.33	0.05	1.00	0.05	4.03
9.	*Anogeissus acuminata*	Phasi	Combretaceae	40	20.95	0.67	0.10	2.00	0.03	7.32
10.	*Neolamarckia cadamba*	Kadambo	Rubiaceae	10	5.09	0.17	0.03	0.50	0.10	1.82
11.	*Azadirachta indica*	Nimba	Meliaceae	30	19.89	0.50	0.08	1.50	0.03	5.80
12.	*Bombax ceiba*	Simili	Bombacaceae	40	36.08	0.67	0.10	2.00	0.03	8.46

13.	*Boraassus flabellifer*	Tala	Arecaceae	20	16.81	0.33	0.05	1.00	0.05	4.14
14.	*Buchanania lanzan*	Char	Anacardiaceae	50	11.32	0.50	0.13	1.50	0.06	6.30
15.	*Butea monosperma*	Palaso	Fabaceae	120	55.86	0.67	0.30	2.00	0.08	14.53
16.	*Cassia fistula*	Sunari	Fabaceae	30	4.54	0.50	0.08	1.50	0.03	4.64
17.	*Cassia siamea*	Sana chakunda	Fabaceae	50	35.37	0.67	0.13	2.00	0.03	8.98
18.	*Dalbergia lanceolaria*	Sajanapati	Fabaceae	20	6.16	0.33	0.05	1.00	0.05	3.33
19.	*Dalbergia latifolia*	Kala Sishu	Fabaceae	20	16.81	0.33	0.05	1.00	0.05	4.14
20.	*Dalbergia sissoo*	Sishu	Fabaceae	30	9.91	0.33	0.08	1.00	0.08	4.19
21.	*Diospyros malabarica*	Kala Kendu/Maaka da kendu	Ebenaceae	30	44.34	0.50	0.08	1.50	0.03	7.65
22.	*Diospyros melanoxylon*	Kendu	Ebenaceae	40	34.65	0.67	0.10	2.00	0.03	8.35
23.	*Eucalyptus tereticornis*	Eucalyptus	Myrtaceae	80	70.18	0.17	0.20	0.50	0.80	10.74
24.	*Feronia elephantum*	Kaitha	Rutaceae	40	27.89	0.50	0.10	1.50	0.04	6.98
25.	*Ficus benghalensis*	Bara	Moraceae	20	34.45	0.33	0.05	1.00	0.05	5.47

26.	*Ficus cuspidifera*	Dimiri	Moraceae	30	17.21	0.50	0.08	1.50	0.03	5.60
27.	*Ficus hispida*	Baidimiri	Moraceae	30	11.22	0.50	0.08	1.50	0.03	5.15
28.	*Ficus racemosa*	Dimiri / Lowa	Moraceae	20	6.70	0.33	0.05	1.00	0.05	3.37
29.	*Ficus religiosa*	Aswastha	Moraceae	10	28.72	0.17	0.03	0.50	0.10	3.61
30.	*Hollarhena antidyesenterica*	Kulchi/Kurei	Apocynaceae	110	93.31	0.33	0.28	1.00	0.28	15.07
31.	*Madhuca indica*	Mahula	Sapotaceae	40	33.86	0.50	0.10	1.50	0.04	7.43
32.	*Melia azedarach*	Bilatinimba	Meliaceae	20	3.22	0.17	0.05	0.50	0.20	2.25
33.	*Phoenix sylvestris*	Khajuri	Arecaceae	30	29.00	0.33	0.08	1.00	0.08	5.63
34.	*Protium serratum*	Rimuli	Burseraceae	20	10.18	0.33	0.05	1.00	0.05	3.64
35.	*Pterocarpus marsupium*	Bijasal/ Piasal	Fabaceae	40	10.20	0.67	0.10	2.00	0.03	6.51
36.	*Scheleichera oleosa*	Kusum	Sapindaceae	90	77.26	1.00	0.23	3.00	0.03	16.16
37.	*Semecarpus anacardium*	Bhalia	Anacardiaceae	30	10.73	0.50	0.08	1.50	0.03	5.11
38.	*Shorea robusta*	Sal	Dipterocarpaceae	100	164.56	0.50	0.25	1.50	0.11	20.74

39.	*Syzygium cerasoides*	Poijamu/ Kaduaiamu	Myrataccae	60	36.97	0.50	0.15	1.50	0.07	8.81
40.	*Syzygium cumini*	Jamu	Myrataccae	40	45.59	0.50	0.10	1.50	0.04	8.32
41.	*Tamarindus indica*	Tentuli	Fabaceae	30	36.86	0.50	0.08	1.50	0.03	7.09
42.	*Terminalia tomentosa*	Asana	Combretaceae	40	39.78	0.50	0.10	1.50	0.04	7.88
43.	*Ziziphus mauritiana*	Barakoli	Rhamnaceae	20	14.40	0.33	0.05	1.00	0.05	3.96
44.	*Ziyiphus xylopyrus*	Gonti/Khatabe r	Rhamnaceae	30	10.73	0.50	0.08	1.50	0.03	5.11
	Total			**1750**	**1322.5**					**300**

A/F= Abundance to Frequency Ratio; IVI- Importance Value Index

5.3.2 Phytosociological Attributes of Trees in the Agroforestry system

In the Agroforestry system, a total of 24 tree species belonging to 19 genera and 12 families. Various attributes of phytosociology are summarized in the **Table 5.2**. Fabaceae was the major family with six tree species. The density ranged from 10 to 90 individuals per ha. Highest density was found in *Shorea robusta* (90 individuals/ha) followed by *Scheleichera oleosa* and *Madhuca indica* (80 individuals/ha each). Basal area of the tree species ranged from 1.99 (m^2/ha) to 57.34 (m^2/ha). Highest basal area was recorded in *Schleichera oleosa* (57.34 m^2/ha) followed by *Shorea robusta* (35.15 m^2/ha) (**Table 5.2**). As per the IVI of the tree species, most important/dominant species was found to be *Scheleichera oleosa* (35.57) followed by *Shorea robusta* (31.38) and *Madhuca indica* (24.61). *Ziziphus xylopyrus* and *Albizzia lebbeck* were found to be least dominant species with IVI values of 4.43. The association index of species for lac host species such as Scheleichera oleosa and Ziziphus mauritiana varied widely (**Table 5.2**) and the most important associates were *Shorea robusta*, *Madhuca indica*, *Phoenix sylvestris* and *Syzygium cumini* in the study area.

Table 5. 2 Phytosociological Attributes of Trees in the Agroforestry system

Scientific Name	Local name	Family	density /ha	Total Basal Area/Ha.(m^2/Ha	Association index of lac host species			A/F	IVI
					Kusum	Palas	Ber		
Acacia auriculiformis	Acacia	Fabaceae	50	7.96	0.40	1.00	1.00	0.13	12.90
Acacia nilotica	Babul	Fabaceae	50	6.47	0.40	1.00	1.00	0.13	12.53
Acacia mangium	Mangium	Fabaceae	20	5.10	0.20	0.50	0.50	0.20	6.06
Aegle marmelos	Bela	Rutaceae	10	5.10	0.20	0.50	0.50	0.10	4.73
Albizia lebbeck	Sirisha	Fabaceae	10	3.90	0.20	0.50	0.50	0.10	4.43
Azadirachta indica	Nimba	Meliaceae	20	17.91	0.40	1.00	1.00	0.05	11.38
Boraassus flabellifer	Tala	Arecaceae	20	28.05	0.40	1.00	1.00	0.05	13.90
Buchanania lanzan	Char	Anacardiaceae	30	5.89	0.40	1.00	1.00	0.08	9.72
Butea monosperma	Palaso	Fabaceae	30	11.54	0.40	1.00	1.00	0.08	11.13
Diospyros malabarica	Kala Kendu/Maakada kendu	Ebenaceae	10	1.99	0.40	1.00	1.00	0.03	6.08
Diospyros melanoxylon	Kendu	Ebenaceae	20	12.28	0.40	1.00	1.00	0.05	9.98
Madhuca indica	Mahula	Sapotaceae	80	30.41	0.60	1.50	1.50	0.09	24.61
Mangifera indica	Mango	Anacardiaceae	50	21.36	0.40	1.00	1.00	0.13	16.23
Phoenix sylvestris	Khajuri	Arecaceae	30	26.61	0.60	1.50	1.50	0.03	17.00
Pterocarpus marsupium	Bijasal/ Piasal	Fabaceae	10	5.10	0.20	0.50	0.50	0.10	4.73
Schleichera oleosa	Kusum	Sapindaceae	80	57.34	1.00	2.50	2.50	0.03	35.57
Shorea robusta	Sal	Diopterocarpaceae	90	35.15	1.00	2.50	2.50	0.04	31.38
Syzygium cumini	Jamu	Myrataccae	30	29.46	0.40	1.00	1.00	0.08	15.58
Tamarindus indica	Tentuli	Fabaceae	20	14.73	0.40	1.00	1.00	0.05	10.59

Tectona grandis	Saguan	Verbenaceae	40	3.68	0.20	0.50	0.50	0.40	8.38
Terminalia arjuna	Arjun	Combretaceae	10	17.91	0.20	0.50	0.50	0.10	7.92
Terminalia tomentosa	Asana	Combretaceae	10	23.01	0.20	0.50	0.50	0.10	9.18
Ziziphus xylopyrus	Gonti/Khataber	Rhamnaceae	10	3.90	0.20	0.50	0.50	0.10	4.43
Ziziphus mauritiana	Barakoli	Rhamnaceae	20	26.83	0.40	1.00	1.00	0.05	13.60

A/F= Abundance to Frequency Ratio, IVI – Importance Value Index

5.3.3 Phytosociological Attributes of Trees in the strips along the road

In the Agroforestry system, a total of 25 tree species belonging to 25 genera and 17 families. Various attributes of phytosociology are summarized in the Table 3. Fabaceae was the major family with five tree species followed by Arecaceae. The density ranged from 10 to 130 individuals per ha. Highest density was found in *Madhuca indica* (130 individuals/ha) followed by *Ziziphus mauritiana* (80 individuals/ha each). Basal area of the tree species ranged from 1.61 (m^2/ha) to 97.55 (m^2/ha). Highest basal area was recorded in *Madhuca indica* (97.55 m^2/ha) followed by *Artocarpus heterophyllus* (93.03 m^2/ha) (Table 3). As per the IVI of the tree species, most important/dominant species was found to be *Madhuca indica* (29.55) followed by *Artocarpus heterophyllus* (22.01) and *Schleichera oleosa* (13.13). *Dillenia* and *Spondias* were found to be least dominant species with IVI values of 1.25 and 2.5 respectively. The association index of species for lac host species such as *Scheleichera oleosa* and *Ziziphus mauritiana* varied widely (Table 3) and the most important associates were *M. indica and A. heterophyllus* in the study area.

Table 5.3 Phytosociological Attributes of Trees in the Strips along roads

Scientific Name	Local name	Family	density/ha	Total Basal Area/Ha.	Association index of lac host species			A/F	IVI
					Kusum	Palas	Barakoli		
Aegle marmelos	Bela	Rutaceae	30	11.21	0.5	0.67	0.33	0.08	4.86
Albizia lebbeck	Siris	Fabaceae	40	15.36	0.75	1.00	0.50	0.04	6.56
Artocarpus heterophyllis	Panas	Moraceae	60	93.03	1.25	1.67	0.83	0.02	22.01
Averrhoa carambola	Karamanga	Oxalidaceae	10	5.75	0.25	0.33	0.17	0.10	1.97
Boraassus flabellifer	Tala	Arecaceae	20	0.00	0.25	0.33	0.17	0.20	1.94
Bauhinia purpurea	Kanchan	Fabaceae	40	4.55	1	1.33	0.67	0.03	4.69
Butea monosperma	Palas	Fabaceae	30	11.54	0.75	1.00	0.50	0.03	4.93
Cocos nucifera	Nadia	Arecaceae	30	0.00	0.5	0.67	0.33	0.08	2.91
Dillenia indica	Oaau	Dilleniaceae	10	1.61	0.25	0.33	0.17	0.10	1.25
Embiica officinalis	Anla	Phyllanthaceae	20	8.43	0.5	0.67	0.33	0.05	3.42
Eucalyptus tereticornis	Eucalyptus	Myrtaceae	30	20.41	0.5	0.67	0.33	0.08	6.46
Feronia elephantum	Kaitha	Rutaceae	40	16.09	0.75	1.00	0.50	0.04	6.68
Gmelina arborea	Gambhari	Verbinaceae	30	20.45	0.75	1.00	0.50	0.03	6.48
Madhuca indica	Mahula	Sapotaceae	130	97.55	1.5	2.00	1.00	0.04	29.55
Mangifera	Amba	Anacardiaceae	40	24.99	1	1.33	0.67	0.03	8.24

indica									
Phoenix sylvestris	Khajuri	Arecaceae	50	0.00	0.5	0.67	0.33	0.13	4.83
Pterocarpus marsupium	Piasal	Fabaceae	20	30.71	0.5	0.67	0.33	0.05	7.29
Moringa oleifera	Sajana	Moringaceae	70	28.41	1.5	2.00	1.00	0.02	11.75
Scheleichera oleosa	Kusum	Spindaceae	70	36.52	1	1.33	0.67	0.04	13.13
Shorea robusta	Sal	Dipterocarpaceae	30	32.74	0.75	1.00	0.50	0.03	8.62
Spondias mangifera	Ambada	Anacardiaceae	10	8.77	0.25	0.33	0.17	0.10	2.50
Syzygium cumini	Jamu	Myrtaceae	40	15.22	0.75	1.00	0.50	0.04	6.53
Tamarindus indica	Tentuli	Caesalpiniaceae	40	40.76	1	1.33	0.67	0.03	10.99
Tectona grandis	Saguan	Lamiaceae	70	27.23	0.75	1.00	0.50	0.08	11.51
Ziziphus mauritiana	Barakoli	Rhamnaceae	80	24.05	1.5	2.00	1.00	0.02	11.95
			1040						

A/F= Abundance to Frequency Ratio, IVI – Importance Value Index

A comparison of diversity indices across the three landscapes revealed that village commons was least disturbed site followed by agroforestry fields and road side strips. It is understood for obvious reasons that road side is disturbed due to its exposure and the area around the wildlife sanctuary is protected. High species diversity was found in village commons (44) followed by the other two sites; agroforestry (24) and road side (25) (**Table 5.4**). Agroforestry system also showed disturbance almost at the same level as road side strips.

Table 5.4. Pattern of tree species diversity in the periphery sites of KWS arranged according to level of disturbance

Variables	Agroforestry (AF)	Strips along the roadside (SAR)	Village commons (VC)
Shannon Index(H)	2.928	2.890	3.599
Simpson Index(D)	0.053	0.055	0.027
Simpson Index of Diversity(1-D)	0.947	0.945	0.973
Richness(S)	24	25	44
Evenness Index (EI)	0.910	0.935	0.950

5.4 Discussion

The flora of the study sites of village commons was characterized by a variety of plant species. The tree species richness of 44 species represents a moderate level of diversity of plants (**Table 5.1**) whereas in agroforestry fields and road side strips it was 24 and 26 species respectively. The results of the present work are in accordance with that of different ecosystems under tropical climates. Thakur (2015) reported that total of 36 trees, 8 shrubs and 34 herbs found in tropical dry deciduous forest in Sagar district, Madhya Pradesh. A total of 65 species of 36 families was recorded by Pradhan and Rahaman (2015) from three tropical dry deciduous forests of Birbhum District, West Bengal. Vinayaka and Krishnamurthy (2016) reported a total of 231plant species of 96 are trees, 53 herbs, 51 shrubs and 31 are climbers in Hulikal state forest, Karnataka. In Muppuram sacred grove of Kollencode, Tamilnadu, Sukumaran et al. (2018) recorded 36 trees, 18 shrubs, 26 herbs and 22 climbers. Composition of the forest and hence its type depend on aggregation of various species. Various factors, like seed dispersal, microclimate and other biotic factors promote the distribution of the species in an ecosystem. Tree species richness of study site was lower as compared to species recorded in Similipal biosphere reserve (Reddy *et al*., 2007) which may be attributed to anthropogenic pressure and/ or low rainfall. The Fabaceae were exhibited to be the most dominant for their ability to produce numerous seeds, quick germination and symbiotic characters which might have promoted species of the plant family to easily establish within habitat types. However, the studies were similar with the works of Deka *et al*. (2012), Khan *et al*. (1986) who showed that legumes were the fore most dominant species on vegetative analysis of tree species and shrubs in tropical forests. Pausas and Austin (2001) reported on species richness in relation to environment i.e. suitable habitat and an environmental condition promotes pollination, dispersal of seeds and ensuring establishment of species. Some families have characterised due to presence of least dominant species could be associated with unsuitable climatic conditions, diseases and trampling by herbivores which resulted in poor growth and establishment. This finding was in line with the work of Sumina (1994) on anthropogenically disturbed sites in Chukotka Peninsula on plant communities. Edaphic parameter (soil nutrients), light and destruction of undergrowth during timber felling showed lowest species of some families. Austin *et al*. (1996) studied that species richness and establishment of vegetation in an ecosystem depends on edaphic parameter (soil nutrients). Egbe *et al*. (2012) and also Coley and Barone (1996) reported similar activities affecting growth and distribution of species.

Plant diversity of an area is measured by density, abundance and distribution of individual species (Wattenberg and Breckle, 1995). The results of the study were in conformity with other findings reported from tropical forests of both India and elsewhere. In the different tropical forests tree density ranged between 550-1800 individuals/ ha (Visalakshi, 1995) whereas in neotropical dry forests it was 3700 individuals/ha (Gentry, 1995). The stand density of 1750 stems/ ha in the study site is comparable with the stem density in other tropical forests of different ecosystems e.g., 516.23 stems ha^{-1} for Nayagarh Fortest Division, Odisha (Sahoo and Panda, 2015; Sahoo *et al*., 2017), 352 stems ha^{-1} in Northern Eastern Ghats (Panda et al., 2013); 443 stems ha^{-1} in Malyagiri hills of Odisha (Sahu *et al*., 2012); 298 stems ha^{-1} at Mudumalai Forest Reserve, India and 689 stems ha^{-1} at Sinharaja, Sri Lanka (Condit, 2000). Mishra *et al*. (2008) reported a tree density 650 - 970 individuals/ ha in Simlipal Biosphere Reserve which was lesser than the stem density recorded in this study.

Importance Value Index of different plants in the present study area compared with report of Tewari and Singh (1987) in mixed forests of Central Himalaya and the findings of the study sites might have varied due to the change in species composition, disturbance and altitude as reported by Procter *et al*. (1988). In Simlipal Biosphere Reserve, Mishra *et al*. (2012) found that *Shorea robusta* was the most dominant species having IVI of 77.67 followed by *Terminalia alata* (16.13) and *Anogeissus latifolia* (13.43). *Wendlandia sp.* was found to be the rarest species of the reserve forest with an IVI of 0.25. Most of the species in the present investigation showed less IVI values and occupied low ecological status of the ecosystem suggesting positive interactions among the tree species (Mishra *et al*., 2012*)*. Higher IVI values of plants depend on their good regeneration ability, more adaptability to specific site and environmental conditions. In the present investigation trees of *Shorea robusta, Scheleichera oleosa* and *Butea monosperma* showed wide association and good regenerating ability in the different sites of village commons. Moreover, adequate knowledge on IVI would play an important role for deciding the conservation practices of specific host plant population of lac insects that is facing the vulnerability of extirpation by forest dependants in and the surroundings of this village commons. Tree species like *Schleichera oleosa, Butea monosperma. Ziziphus mauritiana, Shorea robusta, Buchanania lanzan, Madhuca indica, Dalbergia sissoo, Dalbergia latifolia, Pterocarpus marsupium* have local economic importance. Similarly, plant species like *Acacia nilotica Azadirachta indica, Aegle marmelos, Alstonia scholaris* etc. have been used by the tribal population since time immemorial for medicinal purposes. Similar uses of studied species have been reported by various researchers (Brahmam and Saxena, 1990; Mehra *et al*., 2014; Bajpai *et al*., 2016; Rout *et al*., 2018). These plant species need to be conserved on priority basis against the factors like illicit harvesting, grazing by domestic animals and many other anthropogenic activities (WP, 2008-2017).

Most of the upper storey vegetation showed generally random type of distribution in the present study. The abundance frequency ratio (A/F) for trees and shrubs indicates that forest seedlings grow close to the mother plant in the natural vegetation. Similar observations were also reflected by Deka *et al*. (2012), Giliba *et al*. (2011), Sobuj and Rahman (2011) and Al-Amin *et al*. (2004) who mentioned different vegetation types.

Adaptation of the species influences the species diversity which increases with the stability of the community. Shannon-Weiner (H′) index varied from 0.0295 to 0.184 with a total diversity value 3.599 of the trees. The findings were comparable with the report of Kumar *et al*. (2010), Panda *et al*. (2013), Sundarapandian and Swamy (2000) in tropical forests of Indian sub-continent which falls within the range of 0.67 to 4.86. These findings suggest that the village commons represent a species diverse system. Maximum species diversity of 0.184 was recorded in *Butea monosperma* while the minimum of 0.0511 was found in many species of the study area indicating that over storey vegetation of the site had higher diversity. The dominance (Simpson's index) in the present study was 0.0273 (**Table 5.4**) have been compared with the reports in other forests (Lalfakawma *et al*., 2009; Sahu *et al*., 2012). By this comparison, it indicates that influence of anthropogenic and ecological factors brings about declining of vegetation of the ecosystem.

Generally higher diversity index is observed in tropical forests which varies from 5.06 and 5.40 for young and old stands, respectively (Knight, 1975). The diversity value for Indian forests have been reported in the range of 0.8 to 4.1 (Parthasarthy *et al*., 1992; Visalakshi, 1995). Thus, the diversity index of tree species obtained in the present study is comparable with that of Indian tropical forests. However, these values are lower than the other tropical forests (e.g. Knight, 1975) which may perhaps be due to climatic differences and high degree of natural disturbances, which are important factors in influencing the tropical forest species diversity (Foster, 1990). The lower diversity values in Indian forests may also be due to the differences in the degree of anthropogenic activities and/ or low rainfall.

Tropical forest in the periphery of Kuldiha Wildlife Sanctuary of Balasore district is the predominant forest type, which acts as one of the richest reservoirs of floral genetic diversity harboring number of indigenous forest plants, medicinal herbs, underutilized fruits and wild tubers. Tribals constitute the major chunk of the population and forest has been deeply integrated with their culture, food habit, health care, lifestyle and livelihoods since time immemorial. These plants not only play a significant role in the livelihood security but also as a subsidiary income for the tribal population who collect and sell the plant products during lean season of the years. Phytosociology in three different landscapes namely village commons, agroforestry fields and road side strips indicated the presence of the lac host plants like *S. oleosa, B. monospera* and *Z. mauritiana*. Village commons accounted for higher level of species diversity (44) followed by road side strips (25) and agroforestry fields (24). All species were mostly showing random distribution. Some of the most common associates were *S. robusta*, *B. lanzan*, *S. cerasoides* and *S. cumin* in village commons as well as agroforestry fields and *Madhuca indica* and *Artocarpus heterophyllus* along the road side strips. Adequate conservation and management practices of these plant species not only maintain the forest biodiversity but also meet the basic needs of tribal population living in the peripheral areas of the village commons. The documentation of the tree diversity in the present study provides a base line input in understanding the threats of tropical forests a suitable long term management intervention and conserving the phytodiversity of forest ecosystem that would ensure sustained supply of goods and services for communities in the study area.

6.1 Introduction

In India since time immemorial production and trade of lac played a major role, which is mentioned in 'Atharaveda' and 'Mahabharat'. Lac is only animal resin which is a natural, non-toxic, odourless, biodegradable, tasteless and not harmful to health. Most of the tribal people of the lac growing areas adopt lac cultivation as a subsidiary source of occupation next to agriculture. Lac cultivation provides employment opportunities during the off agricultural season (Pal *et al*., 2012). Performance of different hosts of lac insect played a prominent role to find out productive potential of different of different host plants. Productivity parameters are quantitative and qualitative attribute which finds the potentiality functions of the host plant for commercial lac production. Now-a-days adequate and efficient use of locally available lac host plants has to be made. The lac insect mainly feeds all its nutrition from the sap of tender shoots of certain plants known as host plants. The major native host plants in Odisha are Kusum (*Schleichera oliosa*), Ber (*Ziziphus mauritiana*) and Palas (*Butea monosperma*). Availability of massive number of native lac host plants and conducive climatic conditions in Odisha are the main reason for large scale lac cultivation. Namdev *et al*. (2015) revealed that the lac production on *B. monosperma* and *Z mauritiana* was very low due to lack of nutrient management of these host plants. Meshram (2018) calculated productivity parameters of the host plant for commercial lac production. Patel (2013) studied the relative performance of Ber (*Z. mauritiana*) in both the strains of kusmi and rangeeni. Although, a few studies have been carried out to assess the lac productivity in different regions of the country, information on lac production attributes in Odisha in general and the study area in particular is limited. Therefore, the present study was carried out not only in order to fill in knowledge gap in the existing information of production of lac but also for future promotion of lac cultivation in the region.

6.2 Materials and Methods

6.2.1 Extraction of Resin and Female Cell Weight

Female lac insects secrete the resin over the body forms layers after layers forming protective cell. This protective cell is lac and each cell is produced by a single female cell. To measure the weight of resin (per cell) from harvested branches with fully developed and matured lac encrusted twigs, known as stick lac collected from ber, palas and kusum host plants (Sharma,2017). Lac resin incrustation was removed from collected sticklac known as scraping. The harvesting period of different crops varies from each other. The katki crop is harvested in Oct. /Nov.; baisakhi in May/June; aghani in Jan/Feb.; and jethwi in June/July.

This scrapped lac was weighed and washed in water to remove water soluble materials, air dried in shade and grinded to get finer particles. Alcoholic solvent extraction method was used to separate resin in which grinded lac particles were dissolved in 90% alcohol (1:4 weight/ volume). It was then made into solution, insoluble residues were allowed to settle down; the solution was then filtered and kept in open for evaporation of alcohol (Kamath, 1962; Bose *et al*., 1963). Weight of resin (15-20 % wax and other residues) was measured by physical Monopan balance. To calculate the weight of resin (per cell), resin produced/ cm^2 was divided by number of female cells/cm^2 area. Individual cell weight of female was measured by dividing the total number of female cells/cm^2 with amount of lac produced in cm^2 area. It was done before the extraction of resin. The number of stick lac per plant were calculated from randomly selected 05 numbers of tagged plants in each three sets of experiments of three host plants.

6.2.3 Length of stick lac

Female lac insect remains sedentary all its life period after setting on the branches of the host plant. It is also the main produce of lac. Well-developed encrustation of lac insect on the host plant which is ready to harvest known as sticklac (Sharma *et al*., 2015; Shah *et al*., 2014). Hence the yield of raw lac from the host plant at harvest depends upon the length of lac encrustation (sticklac) (Meshram, 2018). To measure the length of stick lac per plant, randomly selected 05 number of stick lac per plant from 05 tagged plants in each three sets of experiments of three host plants were recorded by measuring scale.

6.2.4 Weight of stick lac

Fully matured encrusted sticklac of 30cm were harvested by cutting from the twigs of host plants. Weighed (g) from randomly selected 05 number of sticklac lac per plant from 05 tagged plants respectively for each three host plants were taken to record individual sticklac yield (Meshram, 2018). Sticklac which is known as raw lac used as marketable produce. Weight of stick lac/plant was calculated by multiplying mean number of stick lac on different host plants with mean fresh weight of 30 cm stick lac (g).

6.2.5 Weight of scrapped lac (g) from 30 cm stick lac

Scrapped lac was collected by scrapping the encrusted resin from 30 cm stick lac of tagged host plants and weight was measured by physical Monopan balance.

6.2.6 Computation and Statistics

The data collected from different sets of experiments were subjected to analysis adapting appropriate statistical tools like arithmetic mean, standard deviation. The data was analyzed following procedures as suggested by Gomez and Gomez (1976).

6.3 Results

6.3.1 Weight (mg/cell) of resin

In katki crop of rangeeni strain of palas the range of resin produced by single female lac in AF, SAR and VC was 8.34 – 11.23, 7.80 – 10.08 and 7.73 – 9.36 (mg/cell), respectively (**Table 6.2 and Table 6.2**). The range of production of resin in aghani crop of winter strain in kusumi was 21. 98 – 26.30, 24.68 – 27.45 and 23.85 -26.59 (mg/cell) in AF. SAR and VC, respectively. Production of resin in aghani crop of kusumi strain in ber was recorded to be 22.98 - 24.06, 19.09 – 20.30 and 19.40 – 22.57 (mg/cell), respectively. The production of resin in jethwi crop of kusumi strain in kusum varied between 18.24 -19.42, 15.29 -21.24 and 19.01 – 20.55 (mg/cell), in AF. SAR and VC, respectively. In katki crop of rangeeni strain in ber the range of resin production was 9.79 – 10.23, 9.52 – 11.13 and 9.11 – 11.33 (mg/cell), in AF, SAR and VC, respectively. Among all the sites Resin production was the highest in VC. In jethwi (kusumi strain) and baisakhi (rangeeni strain) crops of ber plants, there was no yield of resin as insects did not survive due to intense heat.

6.3.2 Number of stick lac (per plant) on various host plants

In katki crop of rangeeni strain in palas plant the production of number of stick lac per plant was the lowest (**Table 6.3 and Table 6.4**) with values ranging from 11.43 - 12.66, 14.92 - 16.35 and 15.54 – 19.27 in AF, SAR and VC, respectively. In katki crop of rangeeni strain in ber plant the range was 14.16 – 15.35, 15.85 – 17.52 and 16.82 – 19.28 in AF. SAR and VC, respectively. In baisakhi crop of rangeeni strain in palas tree it was 11.88 – 13.25, 16.95 – 18.32 and 16.12 – 18.77 in AF. SAR and VC, respectively. In kusumi aghani crop of kusum plant it was the highest range of 210.60 – 215.28, 214.06 – 217.26 and 237.98 – 238.51 in AF. SAR and VC, respectively. This was followed by jethwi crop of kusumi strain in kusum plant and contained the range of 171.57 – 181.48, 182.72 – 186.75 and 222.26 – 227.75 in AF, SAR and VC, respectively. In aghani crop of kusumi strain in ber the production of sticlac varied between 14.87 – 17.78, 17.90 – 21.04 and 18.30 – 29.18 in AF, SAR and VC, respectively. Number of stick lac/plant was maximum in VC among the all sites.

Table 6.1 Weight (mg/cell) of resin produced by female insect of *Kerria lacca* (Kerr.) on various host plants in the surroundings of KWLS in 2017-18

Host plant	Strain	Crop	Mean weight (mg/cell) of resin		
			AF	SAR	VC
Palas	Rangeeni	Katki (Rainy)	8.34±4.09	7.80±3.82	7.73±1.46
Ber	Rangeeni	Katki (Rainy)	9.79±2.27	11.13±2.34	9.11±2.53
Palas	Rangeeni	Baisakhi (Summer)	10.48±2.29	14.75 ± 4.68	14.24 ±4.12
Ber	Rangeeni	Baisakhi (Summer)	0	0	0
Kusum	Kusumi	Aghani (Winter)	21.98±6.63	24.68±8.78	26.59±5.09
Ber	Kusumi	Aghani (Winter)	22.98±7.14	20.30±8.58	22.57 ±7.42
Kusum	Kusumi	Jethwi (Summer)	18.24 ±5.33	15.29±7.04	19.01±5.64
Ber	Kusumi	Jethwi (Summer)	0	0	0

± SD; N=5

Table 6.2 Weight (mg/cell) of resin produced by female of *K. lacca* on various host plants in the surroundings of KWLS in 2018-19

Host plant	Strain	Crop	Mean weight (mg/cell) of resin		
			AF	SAR	VC
Palas	Rangeeni	Katki (Rainy)	11.23±3.17	10.08±3.57	9.36±2.10
Ber	Rangeeni	Katki (Rainy)	10.23±3.32	9.52±1.96	11.33±1.74
Palas	Rangeeni	Baisakhi (Summer)	11.82±3.78	16.61±	15.19±2.26
Ber	Rangeeni	Baisakhi (Summer)	0	0	0
Kusum	Kusumi	Aghani (Winter)	26.30±8.24	27.45±	23.85±5.96
Ber	Kusumi	Aghani (Winter)	24.06±7.61	19.09±4.26	19.40±2.53
Kusum	Kusumi	Jethwi (Summer)	19.42±7.76	21.24±4.88	20.55±5.00
Ber	Kusumi	Jethwi (Summer)	0	0	0

± SD; N=5

Table 6.3 Number of stick lac (per plant) on various host plants in the surroundings of KWLS during 2017-18

Host plant	Strain	Crop	Mean number of stick lac per plant		
			AF	SAR	VC
Palas	Rangeeni	Katki (Rainy)	11.43±2.85	16.35±3.30	15.54±2.16
Ber	Rangeeni	Katki (Rainy)	14.16±2.37	15.85±4.60	16.82±5.60
Palas	Rangeeni	Baisakhi (Summer)	11.88±2.70	16.95±4.09	16.12±3.36
Ber	Rangeeni	Baisakhi (Summer)	0	0	0
Kusum	Kusumi	Aghani (Winter)	210.60±23.13	214.06±21.92	237.98±5.40
Ber	Kusumi	Aghani (Winter)	14.87±3.07	17.90±8.63	18.30±7.10
Kusum	Kusumi	Jethwi (Summer)	171.57±57.87	182.72±50.78	222.26± 8.58
Ber	Kusumi	Jethwi (Summer)	0	0	0

± SD; N=5

Table 6.4 Number of stick lac (per plant) on various host plants in the surroundings of KWLS during 2018-19

Host plant	Strain	Crop	Mean number of sticklac (per plant)		
			AF	SAR	VC
Palas	Rangeeni	Katki (Rainy)	12.66±2.52	14.92±5.43	19.27±2.73
Ber	Rangeeni	Katki (Rainy)	15.35±3.45	17.52±3.49	19.28±4.93
Palas	Rangeeni	Baisakhi (Summer)	13.25±4.02	18.32±5.15	18.77±3.58
Ber	Rangeeni	Baisakhi (Summer)	0	0	0
Kusum	Kusumi	Aghani (Winter)	215.28±23.40	217.268±33.30	238.51±5.40
Ber	Kusumi	Aghani (Winter)	17.78±3.99	21.04±8.10	29.18±3.97
Kusum	Kusumi	Jethwi (Summer)	181.48±47.77	186.75±59.13	227.75±13.20
Ber	Kusumi	Jethwi (Summer)	0	0	0

± SD; N=5

6.3.3 Length of stick lac (cm)

The length of stick lac (cm) in katki lac of rangeeni strain in palas was the lowest among all crops and sites (**Table 6.5 and Table 6.6**) which varied between 36.81 – 39.88, 40.07 – 46.38 (cm) and 43.85 – 46.38 cm in AF, SAR and VC, respectively. In same crop and strain in ber plant the range was 67.14 – 68.93, 71.64 – 74.31 and 78.54 – 82.06 cm in AF, SAR and VC, respectively. In baisakhi crop of rangeeni strain in palas tree it was 28.99 – 36.56, 36.99 -43.29 and 39.76 - 43.29 cm in AF, SAR and VC, respectively. The highest value of length of sticlac was found in aghani crop of kusumi strain in ber plant which was 69.20- 66.47, 69.75 - 73.19 and 75.05 – 77.89 (cm) in AF, SAR and VC, respectively. In jethwi crop of kusumi strain in kusum plant the length ranged from 30.96 – 32.06, 38.07 - 41.15 and 42.49- 44.39 cm in AF, SAR and VC, respectively.

6.3.4 Yield of 30 cm stick lac

In katki crop of rangeeni strain in palas tree the range of yield of 30 cm stick lac (g) was 24.86- 26.89, 29.64 – 31.65 and 30.47 – 30.60 in AF, SAR and VC, respectively. In same strain and crop of ber plant it was 31.85 – 33.39, 35.37 - 41.28 and 41.28 – 42.69 (g) in AF, SAR and VC, respectively. In baisakhi crop of rangeeni strain in palas it was 28.46 -32.96, 32.79 – 34.13 and 36.05 – 39.65 (gm) in AF, SAR and VC, respectively. The highest production was in aghani crop of kusumi strain in kusum and ranged 54.47 – 56.46, 56.46 – 63.21 and 67.21 – 69.76 (g) in AF, SAR and VC, respectively. Next to this the second highest yield was in in same crop and strain in ber, where it was 50.72 – 51.99, 51.99 -56.79 and 63.78 – 65.39 (g) in AF, SAR and VC, respectively. The yield from jethwi crop kusumi strain in kusum it was 45.85, 49.06 and 55.96 (g) in AF, SAR and VC, respectively (**Table 6.7 and Table 6.8**).

6.3.5 Yield of stick lac (kg)/ plant

The yield range of stick lac (kg)/ plant differed in different locations, crops and lac hosts. In katki crop of rangeeni strain in palas tree the range of yield of stick lac (kg)/ plant was 0.30 – 0.35, 0.47 – 0.48 and 0.47 – 0.59 (kg)/ plant in AF, SAR and

VC, respectively (**Table 6.9 to Table 6.10**). In same crop and strain of ber it was 0.45 – 0. 51, 0.54 – 0.73 and 0.71 – 0.83 (kg)/ plant in AF, SAR and VC, respectively. In baisakhi rangeeni strain of palas it was 0.34 – 0.43, 0.55 – 0.61 and 0.59 – 0.74 (kg)/ plant in AF, SAR and VC, respectively. The aghani crop of kusumi strain in kusum produced the highest yield which ranged 11.57 – 11.92, 13.61 – 13.40 and 16.00 – 16.64 (kg)/ plant in AF, SAR and VC, respectively. The aghani crop of kusumi strain in ber it was 0.73 – 0.91, 1.05 – 1.25 and 1.19 – 1.92 (kg)/ plant in AF, SAR

Table 6.5 Length of stick lac (cm) of different host plants in the surroundings of KWLS during 2017-18

Host plant	**Strain**	**Crop**	**Mean length of stick lac (cm)**		
			AF	**SAR**	**VC**
Palas	Rangeeni	Katki (Rainy)	36.81±14.33	40.07±10.61	43.85±12.06
Ber	Rangeeni	Katki (Rainy)	67.14±13.20	71.64±18.18	78.54±17.43
Palas	Rangeeni	Baisakhi (Summer)	28.99±10.98	36.99±6.04	39.76±4.37
Ber	Rangeeni	Baisakhi (Summer)	0	0	0
Kusum	Kusumi	Aghani (Winter)	37.73±9.76	45.06±o.65	47.604±7.73
Ber	Kusumi	Aghani (Winter)	66.474±14.12	69.758±24.60	75.06±13.63
Kusum	Kusumi	Jethwi (Summer)	30.96±13.32	38.07±12.25	42.498±8.52
Ber	Kusumi	Jethwi (Summer)	0	0	0

± SD; N=5

Table 6.6 Length of stick lac (cm) of different host plants in the surroundings of KWLS during 2018-19

Host plant	Strain	Crop	Mean length of stick lac (cm)		
			AF	SAR	VC
Palas	Rangeeni	Katki (Rainy)	39.88±13.32	46.38±7.13	49.12±5.73
Ber	Rangeeni	Katki (Rainy)	68.93±9.61	74.31±16.94	82.06±9.14
Palas	Rangeeni	Baisakhi (Summer)	36.56±12.81	43.29±6.45	46.00±5.50
Ber	Rangeeni	Baisakhi (Summer)	0	0	0
Kusum	Kusumi	Aghani (Winter)	41.44±12.54	44.98±5.70	49.24±7.03
Ber	Kusumi	Aghani (Winter)	69.20±20.72	73.19±17.87	77.89±10.94
Kusum	Kusumi	Jethwi (Summer)	32.06±8.30	41.15±14.85	44.39±8.95
Ber	Kusumi	Jethwi (Summer)	0	0	0

± SD; N=5

Table 6.7 Yield of 30 cm stick lac (g) in the surroundings of KWLS during 2017-18

Host plant	Strain	Crop	Mean Yield of 30 cm Stick lac (g)		
			AF	SAR	VC
Palas	Rangeeni	Katki (Rainy)	24.86±6.73	29.64±4.26	30.47±3.47
Ber	Rangeeni	Katki (Rainy)	31.85±2.58	35.37±8.07	42.69±2.34
Palas	Rangeeni	Baisakhi (Summer)	28.46±6.45	32.79±6.64	36.05±6.95
Ber	Rangeeni	Baisakhi (Summer)	0	0	0
Kusum	Kusumi	Aghani (Winter)	56.46±15.55	56.46±15.55	67.21±8.10
Ber	Kusumi	Aghani (Winter)	50.72±17.27	56.79±10.75	63.78±9.12
Kusum	Kusumi	Jethwi (Summer)	41.85±5.66	49.066±9.74	55.966±11.37
Ber	Kusumi	Jethwi (Summer)	0	0	0

± SD; N=5

Table 6.8 Yield of 30 cm stick lac (g) during in the surroundings of KWLS during 2018-19

Host plant	Strain	Crop	Mean yield of 30 cm stick lac (g)		
			AF	**SAR**	**VC**
Palas	Rangeeni	Katki (Rainy)	26.89±5.15	31.65±3.12	30.60±3.74
Ber	Rangeeni	Katki (Rainy)	33.394±7.59	41.288±6.01	42.81±2.41
Palas	Rangeeni	Baisakhi (Summer)	32.96±5.04	34.13±8.31	39.65±2.90
Ber	Rangeeni	Baisakhi (Summer)	0	0	0
Kusum	Kusumi	Aghani (Winter)	54.478±17.31	63.21±13.23	69.76±6.83
Ber	Kusumi	Aghani (Winter)	51.992±14.59	51.992±14.59	65.39±8.63
Kusum	Kusumi	Jethwi (Summer)	41.85±5.66	49.066±9.74	55.966±11.37
Ber	Kusumi	Jethwi (Summer)	0	0	0

± SD; N=5

Table 6.9 Yield of stick lac (kg) per plant in the surroundings of KWLS during 2017-18

Host plant	Strain	Crop	Mean yield of stick lac(Kg) / plant		
			AF	**SAR**	**VC**
Palas	Rangeeni	Katki (Rainy)	0.30±0.15	0.48±0.10	0.47±0.08
Ber	Rangeeni	Katki (Rainy)	0.45±0.09	0.54±0.12	0.71±0.23
Palas	Rangeeni	Baisakhi (Summer)	0.34±0.11	0.55±0.18	0.59±0.20
Ber	Rangeeni	Baisakhi (Summer)	0	0	0
Kusum	Kusumi	Aghani (Winter)	11.92±3.92	13.40±3.68	16.00±1.98
Ber	Kusumi	Aghani (Winter)	0.73±0.24	1.05±0.57	1.19±0.55
Kusum	Kusumi	Jethwi (Summer)	7.02±1.99	8.92±2.94	12.42±2.47
Ber	Kusumi	Jethwi (Summer)	0	0	0

± SD; N=5

Table 6.10 Yield of stick lac (kg)/plant on different host plants in the surroundings of KWLS during 2018-19

Host plant	**Strain**	**Crop**	**Mean yield of stick lac (g) / plant**		
			AF	**SAR**	**VC**
Palas	Rangeeni	Katki (Rainy)	0.35±0.12	0.47±0.16	0.59±0.12
Ber	Rangeeni	Katki (Rainy)	0.51±0.18	0.73±0.21	0.83±0.23
Palas	Rangeeni	Baisakhi (Summer)	0.43±0.14	0.61±0.18	0.74±0.12
Ber	Rangeeni	Baisakhi (Summer)	0	0	0
Kusum	Kusumi	Aghani (Winter)	11.57±3.39	13.61±3.12	16.64±1.74
Ber	Kusumi	Aghani (Winter)	0.91±0.25	1.25±0.54	1.92±0.44
Kusum	Kusumi	Jethwi (Summer)	7.49±1.71	9.24±3.82	12.68±2.14
Ber	Kusumi	Jethwi (Summer)	0	0	0

± SD; N=5

and VC, respectively. In jethwi crop of kusumi strain in kusum it was 7.02 - 7.49, 8.92 – 9.24 and 12.42 – 12.68 (kg)/ plant in AF, SAR and VC, respectively.

6.3.6 Yield of scrapped lac (g) /30 cm stick lac

The lowest yield of scrapped lac in katki crop of rangeeni strain in pals was 12.33 – 14.35, 15.78 – 16.71 and 16.75 – 18.62 (g)/ plant in AF, SAR and VC, respectively (**Table 6.11 and Table 6.12**). In same crop and strain of ber it was 17.73- 18.3, 18.35 – 19.55 and 19.55 – 20.82 (g)/ plant in AF, SAR and VC, respectively. In baisakhi crop of rangeeni strain in palas it was 12.71 – 15. 44, 13.03 – 18.44 and 14.60 -16.7 (g)/ plant in AF, SAR and VC, respectively. In aghani crop of kusumi strain in kusum the yield of scrapped lac was the highest of 11.57- 19.89, 13.61 – 22.15 and 16.64 – 22.03 (g)/ plant in AF, SAR and VC, respectively.

6.4 Discussion

6.4.1 Weight of resin (mg)

After fertilisation lac resin is produced by female insects, which gives protection to mother lac insects and also to the young ones in the later period. Insects having high fecundity produces more resin **(**Jaiswal and Sharma, 2002). Generally, lac insects settle very close to each other, the lac secretion from the adjacent cells combined with each other and creates a continuous encrustation on the tender shoots of lac hosts (Kapur,1962). The average resin produced from study sites ranged from 7.73 – 26.59 mg/cell **(Table 6.1 and Table 6.2)** which is similar to the results obtained by Jaiswal and Sharma (2002); Sharma *et al*.(2007).

6.4.2 Number of stick lac (per plant) on various host plants

The mature lac insects made encrustation on twigs of tender shoots of lac hosts and when ready to harvest are called as stick lac. The range of stick lac / plant production varied from 11.43 to 227.75. Maximum number was found in Jethwi crop of kusumi strain in kusum (**Table 6.3 and Table 6.4**). Similar observations were made by Jangel (2013), who reported that in rangeen strain of palas number of sticlac per plant varied from 14 to 41.33. Sahu (2016) also reported that in palas of rangeen strain it ranged from 16.44 – 22.00. Meshram (2018) recorded average number of stick lac as 10.93 -237.91. The maximum number of stick lac was found in kusum of 237.91 followed by other hosts of ber, palas and *Flemingia* having 35.00, 25.65 and 10.93 (numbers) of stick lac/ plant in both the strains of rangeeni and baisakhi. Their findings are similar to our investigation and they had also reported that there may be variations due to difference on canopy size and tender branches of lac hosts.

Table 6.11 Yield of scrapped lac (g) from 30 cm stick lac in the surroundings of KWLS during 2017-18

Host plant	Strain	Crop	Mean yield of scrapped lac (g) / 30 cm stick lac		
			AF	SAR	VC
Palas	Rangeeni	Katki (Rainy)	12.33±3.26	16.72 ± 1.47	18.626±2.01
Ber	Rangeeni	Katki (Rainy)	18.3±2.65	19.558±3.69	20.82±1.33
Palas	Rangeeni	Baisakhi (Summer)	15.448±3.40	18.44±3.53	16.778±1.34
Ber	Rangeeni	Baisakhi (Summer)	0	0	0
Kusum	Kusumi	Aghani (Winter)	19.894±2.56	22.156±1.57	22.032±1.54
Ber	Kusumi	Aghani (Winter)	19.014±2.40	20.914±1.66	21.558±1.70
Kusum	Kusumi	Jethwi (Summer)	17.464±4.78	19.53±2.58	19.86±2.24
Ber	Kusumi	Jethwi (Summer)	0	0	0

± SD; N=5

Table 6.12 Yield of scrapped lac (g) from 30 cm stick lac in the surroundings of KWLS during 2018 - 19

Host plant	Strain	Crop	Mean Yield of scrapped lac (g) from 30 cm stick lac		
			AF	SAR	VC
Palas	Rangeeni	Katki (Rainy)	14.35±3.14	15.78±1.37	16.75±1.83
Ber	Rangeeni	Katki (Rainy)	17.73±1.37	18.35±2.87	19.55±0.72
Palas	Rangeeni	Baisakhi (Summer)	12.718±3.52	13.03±2.26	14.60±2.24
Ber	Rangeeni	Baisakhi (Summer)	0	0	0
Kusum	Kusumi	Aghani (Winter)	19.49±1.68	20.94±2.10	21.426±1.93
Ber	Kusumi	Aghani (Winter)	17.77±3.65	20.12±1.60	21.30±1.37
Kusum	Kusumi	Jethwi (Summer)	18.322±4.01	20.038±2.50	19.444±2.16
Ber	Kusumi	Jethwi (Summer)	0	0	0

± SD; N=5

6.4.3 Length of stick lac

The range of length of stick lac (cm) varied from 28- 82.06 (cm) (**Table 6.5 and Table 6.6**). The maximum length of 82.06 (cm) was found in katki crop of rangeeni strain in ber. In kusum strain of aghani crop in ber had second highest length of stick lac (77.89 cm). In rangeeni strain of baisakhi crop of in palas tree it was 28.99 – 36.56, 36.99 -43.29 and 39.76 - 43.29 (cm) in AF, SAR and VC, respectively. The highest range was found in aghani crop of kusumi strain in ber plant which was 69.20- 66.47, 69.75 - 73.19 and 75.05 – 77.89 (cm) in AF, SAR and VC, respectively. The present findings were similar to the findings of Sahu (2016), who reported that the average length of stick lac of palas in rangeeni strain of katki crop ranged from 68.66 – 77.56 cm. Meshram (2018) also found average length of stick lac per tree as 88.42 cm in ber, as 61.34 cm in *Flemingia*, in pals upto 53.92 cm and in kusum as 52.14 cm per lac host plant of rangeeni and kusumi strain, respectively. There were some variations due to availability of tender branches of lac hosts and availability of nutrients for plant growth.

6.4.4 Yield of stick lac

In katki crop of rangeeni strain in palas tree the range of yield of 30 cm stick lac (g) was 24.86- 26.89, 26.29.64 – 31.65 and 30.47 – 30.60 in AF, SAR and VC, respectively. In same strain and crop of ber plant it was 31.85 – 33.39, 35.37 - 41.28 and 41.28 – 42.69 (g) in AF, SAR and VC, respectively. In baisakhi crop of rangeeni strain in palas the yield was 28.46 - 32.96, 32.79 – 34.13 and 36.05 – 39.65 (g) in AF, SAR and VC, respectively. The highest production was in aghani crop of kusumi strain in kusum which ranged from 54.47 – 56.46, 56.46 – 63.21 and 67.21 – 69.76 (g) in AF, SAR and VC, respectively. The yield from jethwi crop kusumi strain in kusum it was 45.85, 49.06 and 55.96 (g) in AF, SAR and VC, respectively (**Table 6.7 and Table 6.8**). The present investigations were similar to the findings of Janghel (2013) who reported that average weight of 30 cm stick lac ranged from 28.74 to 58.91 (g) in rangeeni strain of palas. Patel et al. (2014) also revealed that yield of 30 cm stick lac (g) ranged from 24.26 to 80.59 (g) and 21.86 – 76.00 (g) in kusum and rangeeni strain respectively. Namdev (2014) recorded the average weight of stick lac in kusumi strain of ber from 16.88 – 92.03 g. Meshram (2018) also reported the yield of 30 cm stick lac which ranged from 33.96 – 47.68 g per plant. The above findings conform to the to the observation made in the present investigation.

The yield range of stick lac (kg)/ plant differed in different locations, crops and lac hosts. In katki crop of rangeeni strain in palas tree the range of yield of stick lac (kg)/ plant was 0.30 – 0.35, 0.47 – 0.48 and 0.47 – 0.59 (kg)/ plant in AF, SAR and VC, respectively (**Table 6.9 to Table 6.10**). In the same crop and strain of ber it was 0.45 – 0. 51, 0.54 – 0.73 and 0.71 – 0.83 (kg)/ plant in AF, SAR and VC, respectively. In baisakhi crop of rangeeni strain in palas it was 0.34 – 0.43, 0.55 – 0.61 and 0.59 – 0.74 (kg)/ plant in AF, SAR and VC, respectively. The aghani crop of kusumi strain in kusum exhibited the highest yield varied between 11.57 – 11.92, 13.61 – 13.40 and 16.00 – 16.64 (kg)/ plant in AF, SAR and VC, respectively. The aghani crop of kusumi strain in ber it was 0.73 – 0.91, 1.05 – 1.25 and 1.19 – 1.92 (kg)/ plant in AF, SAR and VC, respectively. In jethwi crop of kusumi strain in kusum the sticlac yield was 7.02 - 7.49, 8.92 – 9.24 and 12.42 – 12.68 (kg)/ plant in AF, SAR and VC, respectively. The findings reported by Patel *et al. (*2014) are at par to the observation made in the present study wherein the authors revealed that the host plant of ber produced 4.00- 5.70 (kg) of kusumi lac and 3.20 – 4.55 (kg) of rangeeni lac. Sharma and Ramani (2010) also investigated that mean yield of stick lac produced from palas was 1-2 – 2.8 (kg) of rangeeni; in kusum it was 10.00- 100.00 (kg) and in ber it was 3.00 – 12.00 (kg) from kusumi strain. Meshram (2018) also revealed that yield of stick lac ranged from 0.305 to 54.94 (kg)/ plant.

6.4.6 Yield of scrapped lac (g) /30 cm stick lac

The lowest yield of scrapped lac was recorded in katki crop of rangeeni strain in palas which was 12.33 – 14.35, 15.78 – 16.71 and 16.75 – 18.62 (g)/ plant in AF, SAR and VC, respectively (Table 6.11 and Table 6.12). In same crop and strain of ber it was 17.73- 18.3, 18.35 – 19.55 and 19.55 – 20.82 (g)/ plant in AF. SAR and VC, respectively. In baisakhi crop of rangeeni strain in palas it was 12.71 – 15. 44, 13.03 – 18.44 and 14.60 -16.7 (g)/ plant in AF, SAR and VC, respectively. In aghani crop of kusumi strain in kusum the yield of scrapped lac was the highest with 11.57-19.89, 13.61 – 22.15 and 16.64 – 22.03 (g)/ plant in AF, SAR and VC, respectively. The results of the present investigation were similar to the findings of Patel *et al.* (2014), according to him average weight of scrapped lac / 30 cm stick lac ranged from 12.43 to 48.04 (g) in kusumi strain and 7.54 to 22.37(g) in rangeeni strain and higher production was found in kusumi strain and lower in rangeeni strain. Meshram (2018) also revealed that average weight of scrapped lac ranged from 16.06 - 96.00 (g) and the maximum weight was recorded in kusum (23.96 g) followed by ber (22.49 g), flemingia (20.51 g) and palas (16.06 g) for both the strains.

From the study, it is revealed that Yield of stick lac and scrapped lac from aghani crop (winter season) in kusumi strain of kusum plant was maximum in Village Commons followed by Strips Along the Roads and Agroforestry. Overall, the study reveals that winter crops (Aghani) with kusumi strain in Kusum tree (*Butea monosperma*) has better productive capacity and hence can be promoted in pilot scale in the region as commercial crop for uplifting livelihood condition of the tribal people in the area and the state of Odisha as well.

Chapter 7

Summary and Conclusion

Lac cultivation provides livelihood to millions of dwellers and also helps in conserving forests and biodiversity associated with lac insect complex. Odisha was having enough potential for cultivation of both rangeeni and kusumi lac strain with Indian lac species, *Kerria lacca (Kerr)* particularly in the inland tribal districts. During lean period of agricultural activities, it provides assured income to farmers. With low costs of inputs, it gives better returns to the farmers. A detailed study was undertaken on biology, productivity and host plant diversity of *Kerria lacca* Kerr. The study was undertaken in periphery whereas of Kuldiha wildlife sanctuary of Nilagiri block of Balasore dwastrict coming under North Eastern Coastal Plain Agro-climatic Zone of Odisha. It was one among the 12 blocks of Balasore district around Kuldiha Wildlife Sanctuary, Odisha. In the study site farmers have been cultivating lac in traditional methods from generation to generation. In the present investigation an attempt was made to study the biological attributes of lac insect and their natural enemies (predators and parasitoids), host plant diversity of lac insect (*Kerria lacca* Kerr) and to assess the productivity of lac insect in some of the major host plants. As the scientific methods of lac culture can prevent the emergence of predators and parasitoids of lac insects, which in turn can result in lac cultivators' self-sufficiency in broodlac production, higher yield of lac, generates higher income, less dependency on forest and finally would help in protecting lac ecosystem. The results obtained from the study in three different locations viz. Agroforestry (AF), Strips Along the Roadsides (SAR) and the Village Commons (VC) in the peripheral whereas of Kuldiha Wildlife Sanctuary, Odisha were summarised below.

1. Survey at study sites revealed that major commercial host plants of *Kerria lacca* (Kerr) were Kusum (*Schleichera oleosa*), Palas (*Butea monosperma)* and Ber (*Zizyphus mauritiana*).
2. Both the strains of kusumi and rangeeni which were also found to be prevalent in the study and both were bivoltine in nature viz. two crops each in a year. In rangeeni strain katki (rainy) and baisakhi (summer) crops

cultivated. However, for kusumi strain aghani (winter) and jethwi (summer) crops were developed.

3. Life period (Life cycle period) in katki crop of rangeeni strain of palas was the lowest of 110 days and for ber it was 115 days. In baishakhi crop of rangeeni strain on palas the life period 260 days and for ber it was the highest of 270 days. For aghani crop of kusumi strain in kusum plant the life cycle period of lac insect was 205 days and for ber it was found to 203 days. Similarly, for jethwi crop in kusumi strain of kusum and ber it was recorded to 165 days for both the plants.
4. Life span of lac insects for various crops varied in different strains, host plants and locations. In AF life span of young varies minimum 47 days in palas (katki crop) of rangeeni strain and maximum 101 days in ber (baisakhi crop) same rangeeni strain. For adult female life span of young varied from 71 -156. In SAR life span of young varied from 47- 101 same as AF and for adult female 62 – 160. In VC life span of young varies from 36 – 106 days and for adult female it was 38 – 109.
5. Life span of adult lac insect male was 2–3 days same for different strains, host plants and locations.
6. Density of Initial settlement (individuals cm^{-2}) of lac larvae of *Kerria lacca* on various host plants in different sites vary. It wit was as the highest in kusumi lac of aghani crop in ber tree (122.77 individuals cm^{-2}) and 107.77 individuals cm^{-2} in VC during 2017-18 and 2018-19, respectively. Lowest Initial settlement (individuals cm^{-2}) has located in rangeeni strain of katki crop in ber tree in AF 48.76 and 48.12 during 2017 – 18 and 2018-19.
7. Density after 21 days of settlement (individuals cm^{-2}) of lac insects on various host plants varies. It was max. 101.58 in aghani crop of Kusumi strain in kusum plant of VC during 2017-18 and also max. 82.69 in Jethwi crop of kusumi strain in ber of VC during 2018-19.
8. Percentage of male and female (individuals cm^{-2}) of lac larvae of *K. lacca* on various host plants vary between 20.01- 36.51 and 63.49 - 79.99 respectively. The sex ratio of lac insect (Male: Female) was approximately more than 1:2. In SAR rangeeni strain of ber, percentage of male population

was the highest of 35.98 but for female population in aghani crop from kusumi strain of ber tree it was 79.99. However, the lowest percentage of male population (20.01) was found in aghani crop of kusumi strain in ber tree and female population of 63.49 in rangeeni strain of palas tree in SAR.

9. The average density of settlement (individuals cm^{-2}) of living female at crop maturity of lac insects on various host plants in different sites varied between 6.29 – 15.00. It was minimum of 6.29 in katki crop of rangeeni strain in AF and maximum of 15.81 in aghani crop of kusumi strain in ber tree of VC.
10. Range of density of settlement (individuals cm^{-2}) of living female at crop maturity of lac insects *K. lacca* on various host plants in different sites was 2.85 - 4.82 and 3.33 – 5.29 during 2017-18 and 2018-19, respectively. It was minimum in katki crop of rangeeni strain in ber and maximum in baishakhi crop of rangeeni strain in same tree species for both the years but varied in different sites.
11. The range of diameter of female lac cell of lac insects varied between 2.85 - 5.29 (mm) in different crops and host plants of the three sites.
12. The range of weight (mg) of female lac cell (dry cell wt. of female) was 11.55 - 30.41 and 11.93 - 33.1 during 2017-18 and 2018-19, respectively. It was the lowest (11.55) of katki crop of rangeeni strain in SAR and the highest of 30.41 in aghani crop of kusumi strain in kusum tree of VC during 2017-18. However, during 2018 -19 a minimum of 11.93 was found in same katki crop of rangeeni strain in palas tree in AF and maximum of 33.1 in aghani crop of kusumi strain in kusum tree of kusum tree also in AF during 2018-19.
13. The range of mean number of stick lac (per plant) of different host plants varied between 11.43 to 238.51 in different crops and host plants of three sites.
14. The range of yield of stick in different crops and plants ranged between 0.30 to 16.64 kg per plant in different crops and sites.
15. The range of yield of scrapped lac varied between 12.33 - 22.156 (g) per stick lac in different crops and sites.

16. Unlike agricultural crops, lac crops were more susceptible to be infested by natural enemies (predators and parasitoids) of lac insects. In Katki crop of rangeeni strain in palas comprised of three species of predators viz. *Eublemma amabilis* Moore, *Pseudohypatopa* (=*Holcocera*) *pulverea Meyr*. and *Chryosopa spp*. Four species of parasitoids such as *Tachardiaphgus tachardiae*, *Parechthrodryinus clavicornis*, *Aprostocetus purpureus* and *Eupelmus tachardiae* were also found.
17. Among the predators *Eublemma amabilis* was the most destructive predator having range of density of 0.30-7.39, 0.82-9.44 and 1.15-11.08 in AF, SAR and VC respectively, in Katki crop of rangeeni strain in palas during 2017. The occurrence was same as 0.77-7.20, 1.59-9.49 and (2.96-11.28) in AF, SAR and VC respectively, during 2018.
18. Active duration (days) of *Eublemma amabilis and Pseudohypatopa* (=*Holcocera*) *pulverea Meyr.* for all the sites in katki crop was same (119 days) as in palas tree.
19. Peak active period represented as Standard Meteorological Week (SMW) of (*Eublemma amabils* was 31-Aug (35 SMW), 31-August (35 SMW) and 24-Aug (34 SMW) in AF, SAR and VC respectively, in katki crop of rangeeni strain in palas during 2017. It was 31-Aug (35 SMW), 24-Aug (34 SMW) and 24-Aug (34 SMW) in AF, SAR and VC respectively, during 2018 in katki crop in palas tree.
20. *Pseudohypatopa pulverea* having range of density of (0.30 - 7.39), (0.91 - 6.96) and (1.16 - 8.03); (0.56 - 7.04), (0.73 - 8.08) and (1.82 - 9.12) respectively, during 2017 and 2018, respectively in katki crop in palas tree.
21. Active duration of *Pseudohypatopa pulverea was* 31-Aug (35 SMW), 07-Sep (36 SMW) and 07-Sep (36 SMW); and 31-Aug (35 SMW), 31-Aug (35 SMW) and 31-Aug (35 SMW) respectively, during 2017 and 2018, respectively in katki crop of palas tree.
22. Range of density *of Chrysopa spp.* was (0.52- 4.48), (0.65- 4.71) and (1.11 - 5.13); (0.10 - 4.14), (0.70 - 4.25) and (1.92 - 5.11) respectively, during 2017 and 2018 in katki crop of palas tree.

23. Active duration (days) of *Chrysopa spp.* was 105 days, same for all sites in katki crop of palas tree.
24. Active duration of *Chrysopa spp.* was 03-Aug (31 SMW), 03-Aug (31 SMW) and 03-Aug (31 SMW); 10-Aug (32 SMW), 03-Aug (31 SMW) and 10-Aug (32 SMW) respectively, during 2017 and 2018 in katki crop of palas tree.
25. Among the parasitoids *Aprostochetus purpureus* had more range of population density of (3.37 - 6.96) in VC and less of (0.75 - 5.72) in AF. Active duration was same of 70 days for all sites and active period was 28-Sept (39 SMW) to 05-Oct (40 SMW) for all sites in katki crop of palas tree.
26. *Parechthrodryinus clavicornis* had maximum range of population density of (0.83 - 3.00) in VC and the lowest of (0.42 - 2.49) in AF. Active duration period was 70 days for all sites. Active duration period varies between 28-Sep (39 SMW) to 19-Oct (42 SMW) in katki crop of palas tree.
27. *Tachardiphagus tachardiae* had more range of population density of *(*0.67 - 2.79) in VC and *less* in AF (0.19 - 2.01). Active duration ranges between 91-98 days. Peak active period varies from 26-Oct (43 SMW) to 09-Nov (45 SMW) in katki crop of palas tree.
28. *Eupelmus tachardiae* had higher range of population density of (0.47 - 2.10) in VC and lesser in AF of (0.14 - 1.15). Active duration period was 70 days for all sites. Peak active period varied from 19-Oct (42 SMW) to 26-Oct (43 SMW) in katki crop of palas tree.
29. Seasonal mean population density of predators viz. *Eublemma amabilwas* rangesd between 3.96 to 6.01, which was maximum in VC and minimum in AF. In *Pseudohypatopa pulverea* it was 3.77 (AF) to 5.35 (VC), *Chrysopa spp.* had 2.07 (AF) to 3.19 (VC) in katki crop of palas tree.
30. Seasonal mean population density of different parasitoids such as *Tachardiphagus tachardiae* had 0.73 (AF) to 1.47 (VC), in *Aprostochetus purpureus* it was 1.70 (AF) to (2.68), in *Eupelmus tachardiae* 0.30 (AF) to 0.79 (VC) and in *Parechthrodryinus clavicornis* 0.79 (AF) to 1.23 had been found in katki crop of palas tree.

31. All the predators and parasitoids have maximum seasonal population density in VC followed by SAR and AF in katki crop of palas tree.
32. In palas tree of baishakhi crop three species of predators viz. *Eublemma amabilis*, *Pseudohypatopa pulverea* and *Chrysopa spp.* and two species of parasitoids such as *Tachardiphagus tachardiae* and *Eupelmus tachardiae* were found.
33. Among the predators the range of density of lac insect population was higher in *Eublemma amabilis* had 1.49 - 6.27 (In VC) followed by 1.40-6.11 (In SAR) and 1.02 - 5.03 (In AF). Peak active period was 28-Mar (13 SMW) and peak active period varied between 28-Mar (13 SMW) to 04-Apr (14 SMW). Seasonal Population density varied between 2.84 (AF) to 3.35 (VC). *Pseudohypatopa pulverea* had a range of population density of 0.19 - 4.80 (AF) to 0.36 - 5.47 (VC) and peak active period ranged between 25-Apr (17 SMW) to 02-May (18 SMW). *Chrysopa spp.* had a range of population density of 0.15 - 2.72 (AF) to 0.84 - 3.85 (VC) and peak active period varied between 20-Dec (51 SMW) to 27-Dec (52 SMW). Seasonal population density was between 1.85 to 2.57 in palas tree of baishakhi crop.
34. Among the parasitoids *Tachardiphagus tachardiae* had the range of density of lac insect population was higher than that of 1.45 - 7.92 (VC) followed by 1.44 - 7.77 (SAR) and 1.40 - 7.70 (AF) and peak active period varied between 02-May (18 SMW) to 09-May (19 SMW). Seasonal population density ranged between 2.40 (AF) to 3.35 (VC). *Eupelmus tachardiae had* the range of density of lac insect population 0.12 - 0.34 (AF) to 0.21 -0.61 (VC) and peak active duration varied between 27-Dec (52 SMW) to 03-Jan (01 SMW). Seasonal population density varied between 0.07 (AF) to 0.12 (VC) in palas tree of baishakhi crop.
35. In aghani lac crop of kusumi strain three species of predators viz. *Eublemma amabilis*, *Pseudohypatopa* (=*Holcocera*) *pulverea* and *Chryosopa spp.*; and four species of parasitoids such as *Tachardiaphgus tachardiae*, *Parechthrodryinus clavicornis*, *Aprostocetus purpureus* and *Eupelmus tachardiae* were also found as in katki crop in palas tree. *Eublemma amabilis* was the dominant species wherein population density varied between 0.15 -

7.28 (In AF) to 0.77 - 7.88 (In VC) followed by SAR (0.20 – 7.66). Active duration was same as of 177 days for all sites. Peak active period varied between 18-Aug (33 SMW) to 01-Sep (35 SMW). Seasonal Population density ranged between 2.88 (AF) to 4.18 (VC). *Pseudohypatopa pulverea* population varied between 0.14 - 5.608 (AF) to 0.22 -7.13 (VC) and active duration was same as in *Eublemma amabilis.* Its Peak active period ranged between 08-Sep (36 SMW) to 15-Sep (37 SMW). Seasonal Population density was found between 1.88 (AF) to 3.01 (VC). In *Chrysopa spp.* range of population density was recorded between 0.11 - 3.33 ((AF) to 0.93 - 4.08 (VC). Active duration was 105 days for all sites. Its Peak active period varied between 11-Aug (32 SMW) to 18-Aug (33 SMW). Seasonal population density was found between 1.05 (AF) to 1.59 (VC).

36. In aghani lac crop of kusumi strain parasitoid *Tachardiphagus tachardiaeis* the dominant species having the maximum population density of (7.89) followed by *Aprostochetus purpureus* (2.99), *Eupelmus tachardiae* (2.75) and *Pwerechthrodryinus clavicornis (*1.84) in village common site. AF sites recorded least population densities. Its Peak active period varied between 27-Oct (43 SMW) to 03-Nov (44 SMW) and seasonal population densities varied between 2.58 (AF) to 3.59 (VC). Peak active period of *Aprostochetus purpureus* ranged between 03-Nov (44 SMW) to 17-Nov (46 SMW) and seasonal population densities varied between 0.55 (AF) to o.98 (VC). For *Eupelmus tachardiae* 09-Dec (49 SMW) to16-Dec (50 SMW) and seasonal population densities varied between 0.68 (In AF) to 1.01 (In VC). For *Pwerechthrodryinus clavicornis* it was 13-Oct (41 SMW) to 27-Oct (43 SMW) and seasonal population densities was estimated between 0.35 (In AF) to 0.67 (In VC).

37. Jethwi crop in kusum plant was less prone to be infested by natural enemies (predators and parasitoids) as compared to other lac crops. Two species of predators viz. *Eublemma amabilis* and *Pseudohypatopa* (=*Holcocera*) *pulverea*. and three species of parasitoids such as *Tachardiaphgus tachardiae*, *Parechthrodryinus clavicornis* and *Aprostocetus purpureus* were found.

38. In jethwi crop *Eublemma amabilis* was the dominant predator and having the maximum population of (6.06) and followed by *Pseudohypatopa* (=*Holcocera*) *pulverea* (3.51). Peak active period of *Eublemma amabilis* varied between 07-Jul (27 SMW) to 30-Jun (26 SMW) and peak seasonal population densities varied between 1.73 (AF) to 1.93 (VC). Peak active period of *Pseudohypatopa* (=*Holcocera*) *pulverea* ranged between 23-Jun (25 SMW) to 07-Jul (27 SMW) and peak seasonal population density varied between 3.02 to 3.51.
39. Maximum weight of resin produced by female of lac insect was 26.59 (mg/cell) in aghani crop of kusumi strain in kusum plant in VC during 2017-18 and minimum of 7.73 (mg/cell) in katki strain of palas tree. During 2018-19 it was the highest (27.45 mg/cell) in SAR and the lowest of (9.36 mg/cell) in VC of the same crop and strain. Resin production was more in aghani crop and least in katki crop.
40. Number of stick lac (per plant) on various host plants ranged from 11.43 - 238.51 in katki crop of rangeeni strain in palas and aghani crop of kusumi strain of kusum plant, respectively.
41. Random distribution was the most common pattern among the host species in three sites (VC, AF and SAR) followed by contagious and regular pattern. The association index of species for lac host species such as *Schleichera oleosa*, *Butea monosperma* and *Ziziphus mauritiana* varied widely. The most important associates for agroforestry were *Shorea robusta*, *Madhuca indica and Mangifera indica.* In village commons the important associates were *Hollarhena antidyesenterica*, *Shorea robusta* and *Syzygium cerasoides*. In the strips along the roadside *Madhuca indica*, *Artocarpus heterophylli* and *Syzygium cumini* were the most dominant associates.
42. In the agroforestry study sites *Scheleichera oleosa* (35.57) and *Shorea robusta* (31.38), in village commons *Shorea robusta (*20.74) and *Scheleichera oleosa (*16.16) and in the strips along the roadside *Madhuca indica (*39.76) and *Artocarpus heterophyllus* (29.99) had the higher IVI values.

43. Evenness Index (EI) was more in the village commons (44), followed by strips along the roadside (0.935) and agroforestry (0.910). The Shannon Index (H) values exhibited similar pattern as the Evenness values of the corresponding study site was 4. It was observed that tree species diversity ranged from 0.973 to 0.947. Higher plant diversity was found in village commons.
44. The study site was proximity to Kuldiha wildlife sanctuary and has been subjected to various kinds of anthropogenic activities. The results of this study with response to variation in species richness and their abundance can be attributed to human interferences.

Among the three land use systems viz. Agroforestry (AF), Strips Along the Roadside (SAR) and Village Commons (VC), density of settlement (Individuals cm^{-2}) of lac insects' of female population was maximum in aghani crop (winter season) of kusumi strain in kusum tree of village commons. Compared to the other land use system village commons are least disturbed which suggests that lac infestation in host trees is highly influenced by anthropogenic disturbances. However, among the four types of crops emergence of predators and parasitoids of lac insects were higher in katki crop. Village Commons affected more followed by Strips Along the Roads and Agroforestry systems. Density and IVI in of major host tree species viz., Palas, Kusum and Ber in Village Commons were more followed by Strips Along the Roads and Agroforestry land use system. However, compared to the other associate species, occurrence and dominance of host trees was less. Higher IVI values were generally regarded as a suitable adaptation in a habitat. This adaption was due to their and formation of association with other species. Host trees having low IVIs require expeditious attention and immediate management interventions for their growth.

Yield of stick lac and scrapped lac from aghani crop (winter season) in kusumi strain of kusum plant was maximum in Village Commons followed by Strips Along the Roads and Agroforestry. Overall, the study reveals that winter crops (Aghani) with kusumi strain in Kusum tree (*Butea monosperma*) has better productive capacity and hence can be promoted in pilot scale in the region as commercial crop for uplifting livelihood condition of the tribal people in the area and the state of Odisha as well. Besides, Strategic research and training to the stake holders on production of elite planting material of host tree species, their scientific management, pest management (management to reduce the influence of natural enemies of lac), lac production management (inoculation to sustainable harvesting and processing) are important activities that are necessary for boosting lac production on a sustained basis.

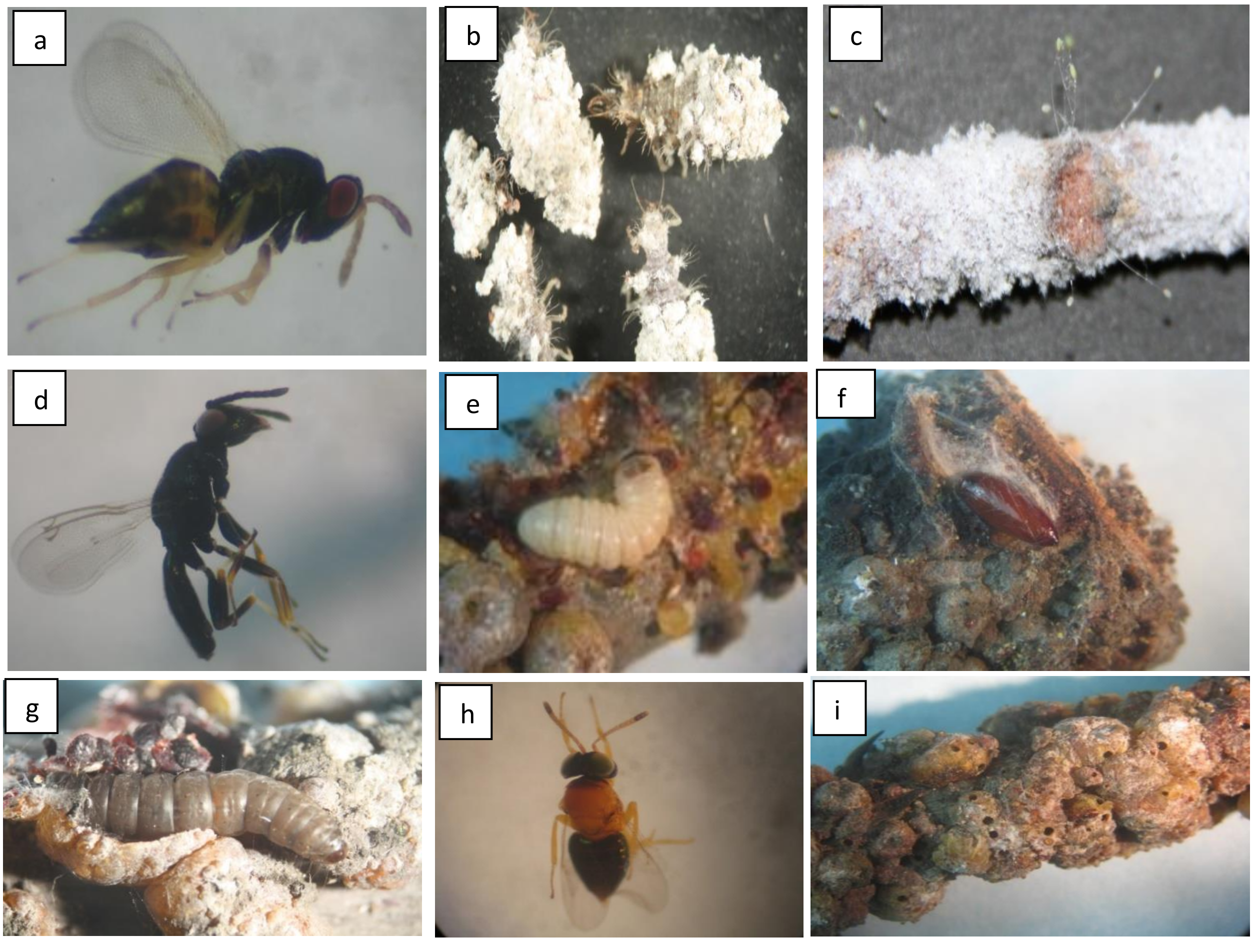


Photo plate 1. Natural enemies of Lac at various stages of lac infestation: a. *Aprostochetus purpureus* (Parasitoid); b. Initial infestation of lac insect by parasitoids; c. Infestation of lac insect by *Chrysopa spp.* (Predator); d. *Eupelmus tachardiae (*Parasitoid); e. *Eublemma amabilis* (Predator); f. Symptoms of infestation by lac natural enemies; g. *Pseudohypatopa pulverea* (Predator); h. *Tachardiphagus tachardiae* (Parasitoid); i. Symptoms of infestation by lac natural enemies.

Photo plate 2. Field survey with Supervisors and Villagers in the study site

Photo plate 3. Collection of Sticklac and processing

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List of Publication(s)

Sl. No.	Title	Journal & Page No.	ISSN/ ISBN No.	First/ Co-author
1	Factors affecting lac crop production and the economy of the tribals living besides Kuldiha Wildlife Sanctuary, Balasore, Odisha	*e- planet.* 17 (1): 39-44 June 2019	ISSN: 0974-4398/ 2008	First author
2	Diversity and ecological status of major lac host species in the village commons of the periphery of Kuldiha Wildlife Sanctuary of Odisha	Indian Journal of Ecology. 49 (2) : 508-514	ISSN: 0304-5250	First author
3	Extent and pattern of occurrence of natural enemies of lac insect around the Kuldiha Wildlife Sanctuary, Odisha	International Journal of Ecology and Environmental Sciences	ISSN: 2320 -5199 (online); https:// Doi.org/10.55863/ Ijees.2024.0144	First author

Paper(s) presented in Workshop/Seminar

Sl. No.	Title of the Paper	Title of Workshop/ Seminar	Organized by	National or International
1	Lac cultivation - An ecological approach for livelihood security in north eastern coastal plain agro – climatic zone of Odisha	Role of women in agricultural production & marketing, 8-9th January, 2019	OUAT, Bhubaneswar, Odisha Indian society of agricultural marketing, Hyderabad	National
2	Conservation of lac host plants by the tribals around Kuldiha Wildlife Sanctuary, Odisha	Participation of indigenous tribes in Biodiversity Conservation, 21-22nd January, 2019	Indian Council of Social Science Research, New Delhi	National

PARTICULARS OF THE CANDIDATE

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ABSTRACT

STUDIES ON BIOLOGY, PRODUCTIVITY AND HOST PLANT DIVERSITY OF *KERRIA LACCA* KERR AROUND KULDIHA WILDLIFE SANCTUARY, ODISHA

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STUDIES ON BIOLOGY, PRODUCTIVITY AND HOST PLANT DIVERSITY OF *KERRIA LACCA* KERR AROUND KULDIHA WILDLIFE SANCTUARY, ODISHA

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Lac cultivation provides livelihood to millions of dwellers and also helps in conserving forests and biodiversity associated with lac insect complex. Odisha was having enough potential for cultivation of both rangeeni and kusumi lac strain with Indian lac species, *Kerria lacca* (*Kerr*) particularly in the inland tribal districts. During lean period of agricultural activities, it provides assured income to farmers. With low costs of inputs, it gives better returns to the farmers. A detailed study was undertaken on biology, productivity and host plant diversity of *Kerria lacca* Kerr. The study was undertaken in periphery whereas of Kuldiha wildlife sanctuary of Nilagiri block of Balasore district coming under North Eastern Coastal Plain Agro-climatic Zone of Odisha. It was one among the 12 blocks of Balasore district around Kuldiha Wildlife Sanctuary, Odisha. In the study site farmers have been cultivating lac in traditional methods from generation to generation. In the present investigation an attempt was made to study the biological attributes of lac insect and their natural enemies (predators and parasitoids), host plant diversity of lac insect (*Kerria lacca* Kerr) and to assess the productivity of lac insect in some of the major host plants. As the scientific methods of lac culture can prevent the emergence of predators and parasitoids of lac insects, which in turn can result in lac cultivators' self-sufficiency in broodlac production, higher yield of lac, generates higher income, less dependency on forest and finally would help in protecting lac ecosystem. The results obtained from the study in three different locations viz. Agroforestry (AF), Strips Along the Roadsides (SAR) and the Village Commons (VC) in the peripheral whereas of Kuldiha Wildlife Sanctuary, Odisha were summarized below.

Survey at study sites revealed that major commercial host plants of *Kerria lacca* (Kerr) were Kusum (*Schleichera oleosa*), Palas (*Butea monosperma)* and Ber (*Zizyphus mauritiana*).Both the strains of kusumi and rangeeni which were also found to be prevalent in the study site which were bivoltine in nature *viz*. two crops each in a year. In rangeeni strain katki (rainy) and baisakhi (summer) crops were cultivated, however, for kusumi strain aghani (winter) and Jethwi (summer) crops were reared.

Life period (Life cycle period) of katki crop rangeeni strain of palas was the lowest of 110 days and for ber it was 115 days. In baishakhi crop of rangeeni strain on palas the life period 260 days and for ber it was the highest of 270 days. For aghani crop of kusumi strain in kusum plant the life cycle period of lac insect was 205 days and for ber it was found to be 203 days. Similarly, for Jethwi crop in kusumi strain of kusum and ber it was recorded to be 165 days for both the plants. Life span of lac insects for various crops varied in different strains, host plants and locations. In AF life span of young varies minimum 47 days in palas (katki crop) of rangeeni strain and maximum 101 days in ber (baisakhi crop) same rangeeni strain. For adult female life span of young varied from 71 -156. In SAR life span of young varied from 47- 101 same as AF and for adult female 62 – 160. In VC life span of young varies from 36 – 106 days and for adult female it was 38 – 109. Life span of adult male was 2–3 days same different strains, host plants and locations.

Density of initial settlement (individuals cm^{-2}) of lac larvae of *Kerria lacca* on various host plants in different sites vary. It wit was as the highest in kusumi lac of aghani crop in ber tree (122.77 individuals cm^{-2}*)* and 107.77 individuals cm^{-2} in VC during 2017-18 and 2018-19, respectively. Lowest density of initial settlement (individuals cm^{-2}) has located in rangeeni strain of katki crop in ber tree in AF 48.76 and 48.12 during 2017 – 18 and 2018-19. Density after 21 days of settlement (individuals cm^{-2}) of lac insects on various host plants varies. It was max. 101.58 in aghani crop of Kusumi strain in kusum plant of VC during 2017-18 and also max. 82.69 in jethwi crop of kusumi strain in ber of VC during 2018-19. Percentage of male and female (individuals cm^{-2}) of lac larvae of *K. lacca* on various host plants vary between 20.01- 36.51 and 63.49 - 79.99 respectively. The sex ratio of lac insect (Male: Female) was approximately more than 1:2. In SAR rangeeni strain of ber, percentage of male population was the highest of 35.98 but for female population in aghani crop from kusumi strain of ber tree it was 79.99. However, the lowest percentage of male population (20.01) was found in aghani crop of kusumi strain in ber tree and female population of 63.49 in rangeeni strain of palas tree in SAR.

The average density of settlement (individuals cm^{-2}) of living female at crop maturity of lac insects on various host plants in different sites varied between 6.29 – 15.00. It was minimum of 6.29 in katki crop of rangeeni strain in AF and maximum of 15.81 in aghani crop of kusumi strain in ber tree of VC. Range of density of settlement (individuals cm^{-2}) of living female at crop maturity of lac insects *K. lacca* on various host plants in different sites was 2.85 - 4.82 and 3.33 – 5.29 during 2017-

18 and 2018-19, respectively. It was minimum in katki crop of rangeeni strain in ber and maximum in baishakhi crop of rangeeni strain in same tree species for both the years but varied in different sites. The range of diameter of female lac cell of lac insects varied between 2.85 - 5.29 (mm) in different crops and host plants of the three sites.

The range of weight (mg) of female lac cell (dry cell wt. of female) was 11.55 - 30.41 and 11.93 - 33.1 during 2017-18 and 2018-19, respectively. It was the lowest (11.55) of katki crop of rangeeni strain in SAR and the highest of 30.41 in aghani crop of kusumi strain in kusum tree of VC during 2017-18. However, during 2018 -19 a minimum of 11.93 was found in same katki crop of rangeeni strain in palas tree in AF and maximum of 33.1 in aghani crop of kusumi strain in kusum tree also in AF during 2018-19.

The range of mean number of stick lac (per plant) of different host plants varied between 11.43 to 238.51 in different crops and host plants of three sites. The range of yield of stick in different crops and plants ranged between 0.30 to 16.64 kg per plant in different crops and sites. The range of yield of scrapped lac varied between 12.33 - 22.156 (g) per stick lac in different crops and sites.

Unlike agricultural crops, lac crops were more susceptible to be infested by natural enemies (predators and parasitoids) of lac insects. In katki crop of rangeeni strain in palas comprised of three species of predators viz. *Eublemma amabilis* Moore, *Pseudohypatopa* (=*Holcocera*) *pulverea Meyr*. and *Chryosopa spp*. Four species of parasitoids such as *Tachardiaphgus tachardiae*, *Parechthrodryinus clavicornis*, *Aprostocetus purpureus* and *Eupelmus tachardiae* were also found. Among the predators *Eublemma amabilis* was the most destructive predator having range of density of 0.30-7.39*,* 0.82-9.44 and 1.15-11.08 in AF, SAR and VC respectively, in Katki crop of rangeeni strain in palas during 2017. The occurrence was same as 0.77-7.20, 1.59-9.49 and (2.96-11.28) in AF, SAR and VC respectively, during 2018.

Active duration (days) of *Eublemma amabilis and Pseudohypatopa* (=*Holcocera*) *pulverea Meyr.* for all the sites in katki crop was same (119 days) as in palas tree. Peak active period of represented as Standard Meteorological Week (SMW) of *Eublemma amabils* was 31-Aug (35 SMW), 31-August (35 SMW) and

24-Aug (34 SMW) in AF, SAR and VC respectively, in Katki crop of rangeeni strain in palas during 2017. It was 31-Aug (35 SMW), 24-Aug (34 SMW) and 24-Aug (34 SMW) in AF, SAR and VC respectively, during 2018 in katki crop in palas tree. *Pseudohypatopa pulverea* having range of density of (0.30 - 7.39), (0.91 - 6.96) and (1.16 - 8.03); (0.56 - 7.04), (0.73 - 8.08) and (1.82 - 9.12) respectively, during 2017 and 2018, respectively in katki crop in palas tree. Active duration of *Pseudohypatopa pulverea was* 31-Aug (35 SMW), 07- Sep (36 SMW) and 07-Sep (36 SMW); and 31-Aug (35 SMW), 31-Aug (35 SMW) and 31-Aug (35 SMW) respectively, during 2017 and 2018, respectively in katki crop of palas tree. Range of density *of Chrysopa spp.* was (0.52- 4.48), (0.65- 4.71) and (1.11 - 5.13); (0.10 - 4.14), (0.70 - 4.25) and (1.92 - 5.11) respectively, during 2017 and 2018 in katki crop of palas tree. Active duration (days) of *Chrysopa spp.* was 105 days, same for all sites in katki crop of palas tree. Active duration of *Chrysopa spp.* was 03-Aug (31 SMW), 03-Aug (31 SMW) and 03-Aug (31 SMW); 10-Aug (32 SMW), 03-Aug (31 SMW) and 10-Aug (32 SMW) respectively, during 2017 and 2018 in katki crop of palas tree.

Among the parasitoids *Aprostochetus purpureus* had more range of population density of (3.37 - 6.96) in VC and less of (0.75 - 5.72) in AF. Active duration was same of 70 days for all sites and active period was 28-Sept (39 SMW) to 05-Oct (40 SMW) for all sites in katki crop of palas tree. *Parechthrodryinus clavicornis* had maximum range of population density of (0.83 - 3.00) in VC and the lowest of (0.42 - 2.49) in AF. Active duration period was 70 days for all sites. Active duration period varies between 28-Sep (39 SMW) to 19-Oct (42 SMW) in katki crop of palas tree. *Tachardiphagus tachardiae* had more range of population density of *(*0.67 - 2.79) in VC and less in AF (0.19 - 2.01). Active duration ranges between 91-98 days. Peak active period varies from 26-Oct (43 SMW) to 09-Nov (45 SMW) in katki crop of palas tree. *Eupelmus tachardiae* had higher range of population density of (0.47 - 2.10) in VC and lesser in AF of (0.14 - 1.15). Active duration period was 70 days for all sites. Peak active period varied from 19-Oct (42 SMW) to 26-Oct (43 SMW) in katki crop of palas tree. Seasonal mean population density of predators viz. *Eublemma amabil* ranged between 3.96 to 6.01, which was maximum in VC and minimum in AF. In *Pseudohypatopa pulverea* it was 3.77 (AF) to 5.35 (VC), *Chrysopa spp.* had 2.07 (AF) to 3.19 (VC) in katki crop of palas tree. Seasonal mean population density of different parasitoids such as *Tachardiphagus tachardiae* had 0.73 (AF) to 1.47 (VC), in *Aprostochetus purpureus* it was 1.70 (AF) to (2.68), in *Eupelmus tachardiae* 0.30 (AF) to 0.79 (VC) and in *Parechthrodryinus clavicornis* 0.79 (AF) to 1.23 had been found in katki crop of palas tree. All the predators and parasitoids have maximum seasonal population density in VC followed by SAR and AF in katki crop of palas tree.

In palas tree of baishakhi crop three species of predators viz. *Eublemma amabilis, Pseudohypatopa pulverea* and *Chrysopa spp.* and two species of parasitoids such as *Tachardiphagus tachardiae* and *Eupelmus tachardiae* were found. Among the predators the range of density of lac insect population was higher in *Eublemma amabilis* had 1.49 - 6.27 (In VC) followed by 1.40-6.11 (In SAR) and 1.02 - 5.03 (In AF). Peak active period was 28-Mar (13 SMW) and peak active period varied between 28-Mar (13 SMW) to 04-Apr (14 SMW). Seasonal population density varied between 2.84 (AF) to 3.35 (VC). *Pseudohypatopa pulverea* had a range of population density of 0.19 - 4.80 (AF) to 0.36 - 5.47 (VC) and peak active period ranged between 25-Apr (17 SMW) to 02-May (18 SMW). *Chrysopa spp.* had a range of population density of 0.15 - 2.72 (AF) to 0.84 - 3.85 (VC) and peak active period varied between 20-Dec (51 SMW) to 27-Dec (52 SMW). Seasonal population density was between 1.85 to 2.57 in palas tree of baishakhi crop. Among the parasitoids *Tachardiphagus tachardiae* the range of density of lac insect population was higher than that of 1.45 - 7.92 (VC) followed by 1.44 - 7.77 (SAR) and 1.40 - 7.70 (AF) and peak active period varied between 02-May (18 SMW) to 09-May (19 SMW). Seasonal population density ranged between 2.40 (AF) to 3.35 (VC). *Eupelmus tachardiae had* the range of density of lac insect population 0.12 - 0.34 (AF) to 0.21 -0.61 (VC) and peak active duration varied between 27-Dec (52 SMW) to 03-Jan (01 SMW). Seasonal population density varied between 0.07 (AF) to 0.12 (VC) in palas tree of baishakhi crop.

In aghani lac crop of kusumi strain three species of predators viz. *Eublemma amabilis*, *Pseudohypatopa* (*=Holcocera*) *pulverea* and *Chryosopa spp.*; and four species of parasitoids such as *Tachardiaphgus tachardiae*, *Parechthrodryinus clavicornis*, *Aprostocetus purpureus* and *Eupelmus tachardiae* were also found as in katki crop in palas tree. *Eublemma amabilis* was the dominant species where in population density varied between 0.15 - 7.28 (In AF) to 0.77 - 7.88 (In VC) followed by SAR (0.20 – 7.66). Active duration was same as of 177 days for all sites. Peak active period varied between 18-Aug (33 SMW) to 01-Sep (35 SMW). Seasonal population density ranged between 2.88 (AF) to 4.18 (VC). *Pseudohypatopa pulverea* population varied between 0.14 - 5.608 (AF) to 0.22 -7.13 (VC) and active duration was same as in *Eublemma amabilis.* Its peak active period ranged between 08-Sep (36 SMW) to 15-Sep (37 SMW). Seasonal population density was found between 1.88 (AF) to 3.01 (VC). In *Chrysopa spp.* range of population density was recorded between 0.11 - 3.33 ((AF) to 0.93 - 4.08 (VC). Active duration was 105 days for all sites. Its Peak active period varied between 11-Aug (32 SMW) to 18-Aug (33 SMW). Seasonal population density was found between 1.05 (AF) to 1.59 (VC). In aghani lac crop of kusumi strain parasitoid *Tachardiphagus tachardiae* is the dominant species having the maximum population density of (7.89) followed by *Aprostochetus purpureus* (2.99), *Eupelmus tachardiae* (2.75) and *Pwerechthrodryinus clavicornis (*1.84) in village common site. AF sites recorded least population densities. Its peak active period varied between 27-Oct (43 SMW) to 03-Nov (44 SMW) and seasonal population densities varied between 2.58 (AF) to 3.59 (VC). Peak active period of *Aprostochetus purpureus* ranged between 03-Nov (44 SMW) to 17-Nov (46 SMW) and seasonal population densities varied between 0.55 (AF) to o.98 (VC). For *Eupelmus tachardiae* 09-Dec (49 SMW) to 16-Dec (50 SMW) and seasonal population densities varied between 0.68 (In AF) to 1.01 (In VC). For *Pwerechthrodryinus clavicornis* it was 13-Oct (41 SMW) to 27-Oct (43 SMW) and seasonal population densities was estimated between 0.35 (In AF) to 0.67 (In VC).

Jethwi crop in kusum plant was less prone to be infested by natural enemies (predators and parasitoids) as compared to other lac crops. Two species of predators viz. *Eublemma amabilis* and *Pseudohypatopa* (=*Holcocera*) *pulverea*. and three species of parasitoids such as *Tachardiaphgus tachardiae*, *Parechthrodryinus clavicornis* and *Aprostocetus purpureus* were found. In jethwi crop *Eublemma amabilis* was the dominant predator and having the maximum population of (6.06) and followed by *Pseudohypatopa* (=*Holcocera*) *pulverea* (3.51). Peak active period of *Eublemma amabilis* varied between 07-Jul (27 SMW) to 30-Jun (26 SMW) and peak seasonal population densities varied between 1.73 (AF) to 1.93 (VC). Peak active period of *Pseudohypatopa* (=*Holcocera*) *pulverea* ranged between 23-Jun (25 SMW) to 07-Jul (27 SMW) and peak seasonal population density varied between 3.02 to 3.51.

Maximum weight of resin produced by female of lac insect was 26.59 (mg/cell) in aghani crop of kusumi strain in kusum plant in VC during 2017-18 and minimum of 7.73 (mg/cell) in katki strain of palas tree. During 2018-19 it was the highest (27.45 mg/cell) in SAR and the lowest of (9.36 mg/cell) in VC of the same crop and strain. Resin production was more in aghani crop and least in katki crop. Number of stick lac (per plant) on various host plants ranged from 11.43 - 238.51 in katki crop of rangeeni strain in palas and aghani crop of kusumi strain of kusum plant, respectively.

Random distribution was the most common pattern among the host species in three sites (VC, AF and SAR) followed by contagious and regular pattern. The association index of species for lac host species such as *Schleichera oleosa*, *Butea monosperma* and *Ziziphus mauritiana* varied widely. The most important associates for agroforestry were *Shorea robusta*, *Madhuca indica* and *Mangifera indica.* In village commons the important associates were *Hollarhena antidyesenterica, Shorea robusta* and *Syzygium cerasoides*. In the strips along the roadside *Madhuca indica, Artocarpus heterophylli* and *Syzygium cumini* were the most dominant associates. In the agroforestry study sites *Scheleichera oleosa* (35.57) and *Shorea robusta* (31.38), in village commons *Shorea robusta (*20.74) and *Scheleichera oleosa (*16.16) and in the strips along the roadside *Madhuca indica (*39.76) and *Artocarpus heterophyllus* (29.99) had the higher IVI values. Evenness Index (EI) was more in the village commons (44), followed by strips along the roadside (0.935) and agroforestry (0.910). The Shannon Index (H) values exhibited similar pattern as the Evenness values of the corresponding study site was 4. It was observed that tree species diversity ranged from 0.973 to 0.947. Higher plant diversity was found in village commons. The study site was proximity to Kuldiha wildlife sanctuary and have been subjected to various kinds of anthropogenic activities. The results of this study with response to variation in species richness and their abundance can be attributed to human interferences.

Among the three land use systems viz. Agroforestry, Strips Along the Roadside (SAR) and Village Commons (VC), density of settlement (Individuals cm^{-2}) of lac insects' of female population was maximum in aghani crop (winter season) of kusumi strain in kusum tree of village commons. Compared to the other land use system village commons are least disturbed which suggests that lac infestation in host trees is highly influenced by anthropogenic disturbances. However, among the four types of crops emergence of predators and parasitoids of lac insects were higher in katki crop. Village Commons affected more followed by Strips Along the Roads and Agroforestry systems. Density and IVI in of major host tree species viz., Palas, Kusum and Ber in Village Commons were more followed by Strips Along the Roads and Agroforestry land use system. However, compared to the other associate species, occurrence and dominance of host trees was less. Higher IVI values were generally regarded as a suitable adaptation in a habitat. This adaption was due to their and formation of association with other species. Host trees having low IVIs require expeditious attention and immediate management interventions for their growth.

Yield of stick lac and scrapped lac from aghani crop (winter season) in kusumi strain of kusum plant was maximum in Village Commons followed by Strips Along the Roads and Agroforestry. Overall, the study reveals that winter crops (aghani) with kusumi strain in Kusum tree (*Butea monosperma*) has better productive capacity and hence can be promoted in pilot scale in the region as commercial crop for uplifting livelihood condition of the tribal people in the area and the state of Odisha as well. Besides, strategic research and training to the stake holders on production of elite planting material of host tree species, their scientific management, pest management (management to reduce the influence of natural enemies of lac), lac production management (inoculation to sustainable harvesting and processing) are important activities that are necessary for boosting lac production on a sustained basis.