IWST/FP/EXT/MHFD/112

DEVELOPMENT OF INTEGRATED PEST MANAGEMENT (IPM) STRATEGIES AGAINST THE MAJOR DEFOLIATING PESTS OF MANGROVES IN THE THANE DISTRICT OF MAHARASHTRA

PROJECT COMPLETION REPORT

Submitted to

MANGROVE CELL, MAHARASHTRA FOREST DEPARTMENT

By

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PROJECT PROFILE

Project number : IWST/FP/EXT/MHFD/112

Project Title : **DEVELOPMENT OF INTEGRATED PEST MANAGEMENT (IPM) STRATEGIES AGAINST THE MAJOR DEFOLIATING PESTS OF MANGROVES IN THANE DISTRICT OF MAHARASHTRA.**

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Certified that all the data collected during the course of the project period are authentic.

(Signature of PI)

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1. INTRODUCTION

Indian mangrove ecosystems are known to have a biological diversity of 4,011 species which comprises 920 species of plants (23%) and 3,091 species of animals (77%). The zoological component is about 3.5 times greater than the botanical component. No other country in the world has recorded so many species in mangrove ecosystems (Bhatt and Kathiresan, 2011). About 52 creeks present across the 720 km coastline of Maharashtra State have developed mangrove habitats of which 18 are major ones (Shree Bhgwan 2013). In Greater Mumbai, the density of mangrove trees is the highest in Thane Creek (30 trees/25 m2) followed by other creeks (9.5 to 28.5 trees/ 25 m^2) (Vijay *et al*., 2005). The common mangrove species found in Mumbai region are *Avicennia marina*, *Sonneratia alba*, *S. apetala*, *Aegiceras corniculatum*, *Bruguiera cylindrica*, *Salvadora persica*, *Rhizophora mucronata*, *Excoecaria agallocha*, *Acanthus ilicifolius* and *Sesuvium portulacastrum*. Other species such as, *S. caseolaris*, *Lumnitzera racemosa*, *Kandelia candel*, *Ceriops decandra*, *C. tagal*, *B. gymnorhiza*, *A. alba*, *A. officinalis*, *A. corniculatum* are either endangered or threatened species of mangrove (Sharma *et al*., 2003; Vijay *et al*., 2005; other source: Vivek Kulkarni. *www.wli-asia-symposium.com*). According to mangrove conservationist Vivek Kulkarni, the 60 sq. km of mangroves in Mumbai alone is known to attract nearly 206 species of birds, 35-40 reptiles, 16 crabs, at least three types of prawns and several fish species. Though insect life in mangroves has not been adequately researched in India, a number of butterflies and moths are commonly found in the ecosystem. Among those documented are the tiny cream-colored butterfly Salmon Arab and the teak moth *Hyblaea puera*, in which the latter one was responsible for the destruction of several mangrove stretches in the city during 1998. “They devour certain plants but that seldom causes permanent harm to the ecosystem,” reassures Kulkarni (Nitya Kaushik, 2008). Ramadevi *et al*. (2008) studied the insect and plant relationship with reference to herbivory in the mangroves of Karnataka, and a total of 8,638 individual insects belonging to 13 orders and 305 species have been identified. The order Coleoptera represented the maximum diversity at species level followed by Lepidoptera, Orthoptera and Diptera. The effect of herbivory on the mangrove plants varies with species and the effect of herbivores is significantly site specific for *A. officinalis* and *S. alba* but not significantly different for *R. mucronata*.

Work by Veenakumari *et al*. (1997) on the entomofauna of the mangroves in Andaman and Nicobar islands has helped to dispel the belief that the mangroves do not support a distinct insect fauna. Despite this, work on the insect community of mangroves in the Indian mainland, especially in the mangroves along the west coast, was very patchy and only few references are available on this subject. From the mangroves along the west coast, the number of insect species so far reported is less than 10 (Santhakumaran *et al.,* 1995). Raji (2003) reported 340 species of insects belonging to 11 orders in the west coast of South India, out of this only 201 species could be authentically identified and listed. This was the first comprehensive list of mangrove insects found along the west coast of South India in which 22% of the insects belong to Coleoptera, 19% belongs to Lepidoptera and the Hemiptera 17%. Kathiresan (2003) reported few insect species which attacks the mangroves in Pitchavaram mangrove forests, south coast of India. The predominant insect species reported are the leaf mining moth (*Phyllocnistis* sp.), leaf gall species (*Stephaniella falcaria*, *Monolepta* sp.), caterpillars (*Dasychira* sp., *Capua endocypha* and *Odites* spp.) and scale insects (*Aspidiotus destructor*). He also reported that the *Avicennia* species suffer more leaf damage than the *Rhizophora* species. Jugale *et al*.(2010) recorded two major pests i.e the fruit borer *Hypsipyla robusta* and *Attacus atlas* the defoliator on *Xylocarpus granatum*, a critically endangered mangrove species of Maharashtra. Shwetha *et al.* (2019) reported 422 insects belongs to 41 families, in addition to the checklist of insects of Indian mangrove ecosystem reported earlier during 2008 by different authors. It include, 212 insects belongs to the order Lepidoptera, followed by Hemiptera having 69 insect species.

The defoliating pests cause regular defoliation and seasonal outbreaks on the mangroves of Mumbai region particularly in Airoli creek of Navi Mumbai areas. *H. puera* commonly known as the teak defoliator is prevalent during the post monsoon period and infesting *A. marina* severely. In this context, the Mangrove cell, Maharashtra Forest Department approached the Institute of Wood Science and Technology (IWST) for the suitable control measures to be adopted for the control of defoliators in the mangroves of Thane District. Though a reasonable literatures on the pest status of mangrove species are available, no information on the status of defoliating pests and its impact on mangrove species in the state of Maharashtra is available. Therefore a research project was formulated to study the pest status of defoliating pests of the

mangrove species, their host range, occurrence and abundance, influence of biotic and abiotic factors predisposing the hosts and their effective management strategies, etc.

2. OBJECTIVES

- To survey and identify the defoliating pests of Mangroves in Maharashtra
- To determine the most potential defoliators and assessing their host range and damage potential.
- To study the bionomics of the potential defoliators and identify the predisposing factors.
- To evolve suitable management strategies by using non chemicals and plant based products.

3. REVIEW OF LITERATURE

Mangroves are forests found on coastal lowlands of tropical and subtropical intertidal region and near river mouths. This system occupies about one quarter of world's coastal line covering an area of 1,90,000 to 2,40,000 km^2 (Upadhyay *et al*., 2002). These forests comprises taxonomically diverse, salt tolerant trees and other plant species, which thrive in the inter tidal zones along the sheltered shores, lagoons, marshes and mud flats. They are open ecosystem which exchange matter and energy with adjacent marine, fresh water and terrestrial ecosystems. They act as an interface between land and sea and are the most productive of the world's forests (Lugo and Snedaker, 1974).

In the total global cover, Indian mangroves comprise of 3.3 percent and distributed along the maritime states, except Lakshadweep, covering an area of about 4921 sq. km along the 7,500 km long Indian coastline (FSI report, 2017). The Sundarban mangroves occupy very large area followed by Andaman-Nicobar Islands and Gulf of Kutch in Gujarat in the distribution of mangroves on the Indian coastlines. Rest of the mangrove ecosystems are comparatively smaller. There are about 55 mangrove species belongs to 22 genera under 18 families have been recorded in the Indian Ocean region (Singh *et al*., 2012).

For many years, the research on mangroves has been mostly centered on the plant species of the ecosystem. Till recently, most of the workers were of the view that mangrove forests do not support a unique faunal composition. Insect herbivory was much lower in mangrove forests compared to adjacent or similar terrestrial ecosystems (Huffaker *et al*., 1984, Robertson and Duke, 1987). The research on Indian mangroves was also of the same nature and very little work has been initiated on the faunal components (Veenakumari *et al*., 1997). The invertebrate fauna, especially the insects of the mangrove forests, is richer than the vertebrate community (Murphy, 1990), but only less than 200 species of insects have been reported from the mangroves in Indian mainland, mostly restricted to the Sundarbans (Mandal and Nandi, 1989). Raji (2003) reported 340 species of insects belonging to 11 orders in the west coast of South India, out of this only 201 species could be authentically identified and listed and it forms the first comprehensive list of mangrove insects found along the west coast of South India. Remadevi *et al.* (2008) reported

the entomofaunal checklist which comprises of a total of 752 insect species belongs to 155 families of 16 orders, from the mangroves of India including Andaman and Nicobar Islands. In this 514 insects were described upto the species level. About 112 insects species belonging to 51 families of 7 orders were reported from the mangroves of Muthupet, east coast of India (Oswin and Kannadasan 1998). Fourteen species of insect borers of mangroves in the Bay island have been studied from Andaman and Nicobar islands (Das *et al*., 1988). Sundararaj *et al*. (2014) reported the invasion of the spiraling whitefly *Alerurodicus dispersus* on many mangrove plants in South India. The mealy bug *Dysmicoccus brevipes* was recorded as a host species on the mangrove species *Xylocarpus* sp. (Veenakumari *et al.,* 1997). Mehlig and Menezes (2005) reported that in Brazil the attack of *Hyblaea puera* is severe on 'monospecific' *Avicennia* stands, while multi species areas of mangroves are less affected. Menezes and Peixoto (2009) reported widespread defoliation and necrosis of *Avicennia schaueriana* trees by *H. puera* population explosion in Rio de Janeiro State. Leaf galls caused by Cecidomyiid (Diptera) on *A. marina* and leaf fold galls caused by microlepidoptern insects on *S. apetala* were reported for the first time from mangrove swamps of Vikhroli, Maharashtra. (Sharma *et al.,* 2003). Similar type of galls were recorded from Andaman Island also (Sharma *et al.,* 1983). Janzen (1988) reported that caterpillars of insects alone consume more leaves in forests particularly in tropical forests than all other animals combined. Insects which affect the growth of very large trees by causing damage (Mazanec, 1967). Raja Rishi *et al*. (2019) reported *D. brevipes* as pest of *A. marina*, *A. officinalis*, *S. alba* and *S. apetala* in the mangroves of Airoli and Vashi creek of Thane district of Maharashtra for the first time.

Different kinds of management practices were reported by many of the researchers to control the defoliating pests of agricultural importance. In some extent very few research were done on the forestry tree species, but not much information on mangrove species. The use of bio-insecticides either separate or in combination in IPM systems is increasingly becoming important (Adams and Bonami, 1991; Cherry *et al*., 1997). Satpathi *et al.* (1991) tested the extract of *Nerium oleander, Pongamia pinnata* and *Thevetia nerifolia* on *Corcyra cephalonica* and recorded 80%, 86.6% and 88.3 % mortality respectively. Meshram (1995) reported parthenium extracts of 5% causing 13.3% mortality on *Eutecona machaeralis* at 24 hr. Durairaj (2010) tested the extracts of *Parthenium hysterophorus* on *H. puera* and reported 100 percent mortality

on the early instar larvae at 48 hr. Extract of *Jatropha curcas* and *Azadirachta indica* were tested for their antifeedant property against the larvae of *Papilio demoleus* (Joshi *et al*., 1993). Several researchers have reported the presence of numerous active ingredients in neem (Schmutterer, 1990,1995 and Bashir, 1994). Entomopathogenic fungi were used as a biocontrol agent worldwide for controlling different insect pests (Liu and Li, 2004). They affect the insects by penetrating in to the body make use of extracellular cuticle-hydrolyzing enzymes of proteases, lipases and chitinases (St. Leger *et al.,* 1986). The native EPF, *Beauaveria bassiana* was evaluated earlier to control *H. vitessoides* in laboratory condition and spore concentration of 2.4×10^{10}, 2.4×10^{8} and 2.4×10^{6} spores/ml were found effective (Rishi and Pandey, 2014). The influence of three cultivars of *Sorghum bicolor* (L.) on the activity of the fungus *M.anisopliae* on the stem borer *Chilo partellus* was investigated in the field and laboratory (Maniania *et al*., 1998). Twenty five different isolates of an entomopathogenic fungus, *Metarhizium anisopliae* were tested for their efficacy against *H. puera* (Remadevi *et al.,* 2013). Arti Prasad (2010) reported 86.7 percent larval mortality on *Helicoverpa armigera* by *B. bassiana* at the concentration 1.25 $x10^{8}$ conidia/ml. Balu *et al.* (1998) reported *B.bassiana* as a promising biocontrol agent on the bark feeding borer, *Indarbela quadrinotata*. Management of pests by using Nuclear Polyhedrosis Virus (NPV) as one of the microbial pesticide presently has received greater attention (Kamiya *et al*., 2004; Tang *et al*., 2011). Reports were available on the effect of Nuclear Polyhedrosis Virus (NPV) on the teak defoliator in laboratory as well in field condition on teak (Ahmed, 1995). Similar reports are available on the management of *H. puera* mainly by the use of HpNPV and few studies on using the biocontrol agents like *Bacillus thuringiensis*, *B. bassiana* and some botanicals (Sudheendrakumar, 1988). Narendrakumar *et al.* (2017) reported the effect of baculovirus with adjuvants against *H. armigera* on cotton with different instars in controlling the pest. Karma *et al*., (2012) described different methods of production of improved formulations and evaluation of NPV of *Spodoptera litura*. Control of *H. armigera* successfully with NPV along with the adjuvants having phagostimulant properties to confirm that the larvae ingest sufficient amount of virus to causes mortality and also UV-protectant properties (LodayaJalpal and Borad, 2014, Liu *et al*., 2010).

4. MATERIALS AND METHODS

4.1 FIELD SURVEY

Field surveys were carried out during the period from 2017- 2019, in different locations of Thane district of Maharashtra having mangrove plantations and natural mangroves and investigated the defoliating in pest attacks.

4.2 SELECTION OF MANGROVE PLANT SPEICES FOR STUDIES:

The common and dominant mangrove species like *A. marina*, *A. officinalis, S. apetala, S. alba* and *R. mucronata* found in the mangroves of Thane district of Maharashtra were selected for the pest studies. The Phenology of the mangrove plant species were recorded during the study period.

4.3 IDENTIFICATION AND ASSESSMENT OF INSECT PEST INCIDENCE :

The defoliating pests recorded during the field visit were documented and identified by sending the specimens to the taxonomic experts. Based on the incidence and intensity of insect pest attack computation was made as per the prescribed methods of assessment of insect pest incidence in plantations (George Mathew, 1990; Prasanth Jacob *et al*., 2002 and Prasanth Jacob 2008). The collected pests were categorized in to major and minor pests in mangroves and the pest calendar was prepared based on the intensity of defoliating pest attack and the damage caused.

Assessment of pest incidence:

Plants/trees were tagged randomly and therein assessed for defoliating pest incidence. 50 plants in each mangrove plant species at random were counted and tagged. The number of plants infested and uninfested in each block area were counted and average percentage of plants infested were calculated.

Defoliation intensity were rated visually by comparing the occurrence of attacked and unattacked leaves in all the plants tagged. The intensity of defoliation/ infestation were classified in to 3 main classes and compared with severity scale (Table-1).

Table. 1 Defoliation score and severity scale.

LEVEL	DESCRIPTION	
	% Defoliation	Severity Scale
Severe (H)	**61 - 100**	**Severely attacked** Attacked leaves dominate
Medium(M)	**26 - 60**	**Moderately attacked** Equal occurrence of attacked & unattacked leaves
Negligible(L)	**0 - 25**	**Unattacked** Attack symptoms negligible/Nil

4.4 PREPARATION OF PEST CALENDAR

Periodicity of incidence, nature of damage/injury and intensity of pest attack by the pests on the mangrove species was monitored regularly and documented to develop a pest calendar.

4.5 STUDIES ON THE BIOTIC AND ABIOTIC FACTORS :

The biotic factor mainly the natural enemy complex such as the larval and pupal parasites, predators and the microbes (entomopathogenic fungi, bacteria) operating in the nurseries, plantations and in natural mangroves were collected, identified and documented. Abiotic factors like Temperature and Rain fall were collected during the study period and correlated with the population level, infestation, intensity of insects pests in natural mangroves and in plantations raised in different locations in Thane district of Maharashtra.

The statistical analysis was done using Microsoft office Excel 2007 to find out the correlations between the incidence of pests in relation to Rainfall and Temperature.

4.6 MANAGEMENT OF KEY PESTS :

4.6.1 LABORATORY STUDIES:

Mass rearing of targeted insect larvae

Larvae of the targeted defoliating insects were reared in the semi synthetic diet developed for rearing of lepidopteran larvae WHICH was further improvised with addition of some more ingredients and standardized the method for rearing of defoliators.

Method for preparation of semi synthetic diet for defoliators:

Channa (100 g) soaked in 405 ml of distilled water for 8-12 hours, overnight, was boiled and homogenized in a blender. With this, yeast tablet 30g, Weason's salt 7g, Methyl parahydroxy benzoate 2g, Sorbic acid 1g were added, mixed them and blended. Agar powder (13 g) was boiled in 405 ml of distilled water separately. After dissolution of agar. cooled slightly and added to the other ingredients including Cellulose -5 g and dried leaf powder (10 g) of concerned plant species preferred by the host insect in blender and homogenized well. Finally Ascorbic acid, multivitamin drops 3g, formalin 2ml, Choline chloride and Streptomycin 40mg were added and homogenized well. Then poured the content into a plastic or in a glass container and kept the diet open for 24 hours to solidify and subsequent use.

Bioassay studies:

The bioassay studies were conducted by using the biological control agents like the entomopathogenic fungi, a native strain of *Nomuraea rileyi* which was isolated and subcultured from the infected cadavers, *Metarizhium anisophilie*-Ma4 (strain of NBAIR), commercial product of *M. anisophilie* and a native pathogenic bacteria *Myroides odoratus* and the biopesticides *viz*; Neem oil, Azadiractin 0.03% (Nimbicidine) and Hy-ACT (IFGTB (Institute of Forest Genetics and Tree Breeding, Coimbatore, product derived from the seeds of *Hydnocarpus pentandra*) against the major key pests in laboratory condition to standardized the dosage for the effective control of the pest.

Preparation and evaluation of entomopathogenic fungal spore suspension:

The efficacy of the entomopathogenic fungi *N. rileyi* (Natural strain) *M. anisopilae* (strain of NBAIR) were evaluated against the targeted major defoliating pests of Mangrove species in laboratory condition. The entomopathogenic fungi were subcultured in Sabouraud dextrose agar medium (SDA; Himedia, Mumbai, India) to obtain a pure culture. Then the conidia were harvested by scraping the surface of an 8-10 days old fungal culture with a sterile loop in 10 ml of distilled water. A drop of 0.01% Tween 80 was added. The spore suspension was then filtered through muslin cloth to remove mycelia. Spore count was calculated using an improved Neubauer haemocytometer (Rabindra and Jayaraj 1998).

Estimation of spores

A. Dilution: One ml of the purified stock fungus suspension was made up to 10 or 100 ml with water containing 0.1% wetting agent (Tween-80). This solution ensured thorough mixing and uniform distribution of fungal spores. There were two dilution factors: 1 ml made up to 10 ml = 10 times; 1 ml made up to 100 ml = 100 times.

B. Counting: To one part fungal suspension, 10 parts distilled water containing 0.1% teepol or liquid soap were added using a Thoma white cell pipette. The spores were counted in about 25 1/400 mm^2 squares with the help of a research microscope under 40X magnification. Spore suspensions of known concentration were prepared from the stock solution by suitable dilution with distilled water.

C. Estimation of spore concentration:

If the number of spores counted from 25 of 1/400 sq.mm squares is X and the original dilution is 100 times, then the spores.ml is calculated as follows:

$$\text{Spores in 1 Sq.mm} = \frac{X \times 400}{25}$$

To calculate the spores in 1 cu.mm, the depth of the suspension in between the haemocytometer and the coverslip, which is 0.1 mm or the depth factor is 10.

$$\text{Spores in 1ml} = \frac{X \times 400 \times 10 \times 1000}{25}$$

Taking into consideration the dilution factor:

$$\text{The spores in 1 ml} = \frac{X \times 400 \times 10 \times 1000 \times 100 \times 10}{25}$$

Then the concentration will be $X \times 10^{10}$ Spores/ml.

Four spore suspension concentrations (2.4×10^{10}, 2.4×10^{8}, 2.4×10^{6} and 2.4×10^{4}) were prepared and a pathogenicity test was conducted under laboratory and field conditions on the targeted defoliating pests. Healthy larvae reared in the laboratory were first surface sterilized with 1-5% sodium hypochlorite and sprayed with the fungal inoculae along with the feeding material (leaves of different mangrove species or in artificial diet). The freshly prepared spore suspensions were sprayed evenly on different larval instars. Four treatments, namely T1 –T4, corresponding to 2.4×10^{10}, 2.4×10^{8}, 2.4×10^{6} and 2.4×10^{4}, were applied. The sprayed larvae and the feeding materials were air dried on filter paper. The larvae sprayed with inoculum (10 - 20 larvae) were released into 100 ml plastic/glass containers. A control (T5) sprayed with 0.1%

Tween 80 in sterile distilled water was also maintained. Each treatment was replicated five times with 10-20 insects in each replicate. Observations were made every 24 h. Mortality was assessed up to 5 days when the highest concentration yielded 100 percent mortality or maximum percentage of mortality. The infected larvae were collected and maintained in Petri dishes lined with moist blotting paper for sporulation of the fungal pathogens.

Testing the safety of entomopathogenic fungi (*N.rileyi)* against beneficial insect *Trichogramma chilonis:*

The EPF *N.rileyi* was tested for their safety to egg parasitoids *T. chilonis* in laboratory condition. The higher concentration 2.4×10^{10} Spores/ml. of the fungal spore suspension was prepared and tested against the egg parasitoids *T. chilonis*.

Corcyra eggs mounted on cards (5 x 2 cm) @ 100 eggs/card procured from National Bureau of Agricultural Insect Resources (NBAIR), Bengaluru were dipped in EPF suspension for a few seconds, air-dried and introduced into the glass tubes. Twenty newly emerged adult parasitoids (*T.chilonis*) were released into each glass tube in five such replicates with suitable controls and incubated at 25°C. Parasitoids were allowed to parasitize the eggs for 48h and then removed to individual tubes provided with 10 percent honey droplets as adult feed. *Corcyra* larvae hatching out from unparasitised eggs were removed daily. Percent parasitisation, number of parasitoids emerged were recorded for two generations after the EPF treatment.

Evaluation of native pathogenic bacteria *Myroides odoratus*:

The native pathogenic bacteria *M. odoratus* isolated from the naturally infected larvae of *Ptyomaxia syntaractis* was subcultured in Nutrient Agar media and evaluated on the larvae of the *P. syntaractis* at the concentrations 2.6×10^8 CFU/ml, 2.6×10^6 CFU/ml and 2.6×10^4 CFU/ml in lab condition. The pathogen was sub cultured and stock solution was prepared. The stock solution of the pathogen was serially diluted from 10^{-1} to 10^{-9} and effective colony forming dilutions of 2.6×10^8 CFU/ml, 2.6×10^6 CFU/ml and 2.6×10^4 CFU/ml were determined. Five replicates with 10 larvae each were maintained for each experiment. Another set of 10 larvae were fed with fresh leaves treated with teepol mixed sterile distilled water and served as the control. Observations on larval mortality was recorded at 24 hrs intervals.

Evaluation of native Baculovirus (The nuclear polyhedrosis virus (HpNPV) against *Hyblaea puera*:

The native nuclear ploy hedrosis virus isolated from the naturally infected larvae of *H. puera* (HpNPV) was cultured and purified and evaluated on the fresh larvae of the *H. puera* at the concentrations 4.05×10^6 PIB/ml 4.05×10^7 PIB/ml and 4.05×10^8 PIB/ml in lab condition. Five replicates with 10 larvae each were maintained for each experiment. Another set of 10 larvae were fed with artificial diet, treated with teepol mixed sterile distilled water and served as the control. Observations on larval mortality was recorded at 24 hrs intervals for 5 days.

Counting and standardization of NPV using the Improved Neubauer Haemocytometer

Successful control of pests with NPV depends on the use of appropriate dose of virus and hence it is ascertained the strength of polyhedral occlusion bodies in the virus suspension before it is applied.

Counting of POB (Polyhedra occlusion bodies):

Counting of POB in the virus suspension is done by the use of a Neubauer Haemocytometer, which is a glass slide carrying calibrations in two replicates. A small volume of test suspension is introduced to both halves of the slide chamber from a pipette, usually 5 – 10µl. The haemocytometer have been cleaned perfectly and dried before introducing the suspension and confirmed whether the introduced suspension filled the calibrated area in the haemocytometer. To see the cover slip is fixed correctly watched for the interference pattern of Newton's Rings seen under the part of the cover slip directly in contact with the counting chamber slide and ascertained that the rings were seen on either side of the actual counting area.

Only the specially thickened cover slips designed for use with haemocytometers were used. The haemocytometer was cleaned perfectly and dried before introducing the suspension. Allowed polyhedra to settle down for 5 to 10 minutes and counted the OB seen under x400-x600 phase contrast illumination. The count was made at least 300 OB per count to obtain a statistically valid sample and made sure that the OB were not clumped. The most common technique is to count the contents of 10 of the larger double ruled squares each of which contain 16 small squares giving a total of 160 squares counted. The larger squares were chosen on a pattern sampling both across and down the grid. This was done by counting the polyhedral inside

the squares as well as the polyhedral on the top and left side lines only of each square. Three separate counts on three sub-samples from the NPV concentration were counted and arrived the average to get the final count.

To calculate the number of polyhedra per ml:

$$\text{Number of polyhedral per ml} = \frac{D \times X}{N \times K}$$

Where

D = dilution factor

X = total number of polyhedral counted

N = Number of squares counted

K = Volume above one small square in cm^3

Area of each small square is 1/44 mm^2 = 0.0025 mm^2

Depth of chamber is 0.1 mm.

Volume of liquid about a single small square is 0.0025 mm^2 × 0.1 mm = 0.00025 mm^3

To convert to cm3 multiply by 1/1000 to get a volume of 2.5 × 10-7 cm^3

Evaluation of the biopesticide Hy-ACT:

The botanical bio pesticide Hy-ACT was evaluated for its efficacy and effectiveness against the different instar larvae of the defoliators *P.syntaractis*, *Hypocala* sp., and *H.puera* (III instar). Four concentrations of 0.25%, 0.50%, 0.75% and 1% were used. Five replications were maintained in each treatment (T1 – T4) with 10 larvae. Control was maintained separately (T5). Observations on the mortality of larvae was taken after every 24 hours interval.

Testing the safety of Hy-ACT against beneficial insect *Trichogramma chilonis:*

The biopesticide Hy-ACT was tested for their safety to egg parasitoids *T. chilonis* in laboratory condition. The higher concentration i.e 1% of the biopesticide suspension was prepared and tested against the egg parasitoids *T. chilonis* as per the procedure mentioned in EPF treatment for safety test.

Evaluation of the biopesticide Neem oil:

The biopesticide Neem oil was evaluated for its efficacy and effectiveness against the defoliators. Four concentrations of 2%,3%,4% and 5% were evaluated on the defoliating insect pests *P.syntaractis, Hypocala* sp., and *H.puera*. Five replications were maintained in each treatment (T1 – T4). Control was maintained separately (T5) with 10 larvae. Observations on the mortality of the defoliator were taken after every 24 hours interval.

Evaluation of the biopesticide Nimbecidine (*Azadirachtin* 0.03%):

The biopesticide Nimbecidine (Azadirachtin 0.03%) was evaluated for its efficacy and effectiveness against the defoliators. Four concentrations of 0.25%, 0.50%, 0.75% and 1% were evaluated on the defoliating insect pests *P.syntaractis*, *Hypocala* sp., and *H.puera*. Five replications were maintained in each treatment (T1 – T4). Control was maintained separately (T5) with 10 larvae. Observations on the mortality of the defoliator were taken after every 24 hours interval.

Observations on the larval mortality of insects were recorded at different time duration at different concentrations and percent larval mortality was calculated using Abbott's formula (Abbott, 1925).

$$\text{Percentage larval mortality} = \frac{\text{\% treated mortality - \% control mortality}}{\text{100 - \% control mortality}} \times 100$$

All the data were subjected to analysis of variance (ANOVA) and significance of various treatments was evaluated by F test ($p<0.05$) by calculating CD values.

4.6.2 FIELD STUDIES:

Evaluation of entomopathogenic fungi against the key defoliating pests:

The efficacy of the entomopathogenic fungi *N. rileyi* (Native strain) *M. anisopilae*-Ma 4 (strain of NBAIR) were evaluated against the targeted major defoliating pests *P.syntaractis* and *Hypocala* sp., in field condition with different concentration of fungal solutions viz. 2.4×10^{10}, 2.4×10^{8}, 2.4×10^{6} and 2.4×10^{4} Spores/ml. The larvae sprayed with fungal inoculum were released on to the leaves of mangrove plants. Five treatments (T1 – T5) were maintained to test

the targeted pests. T5 was treated as control. Each treatment was replicated 5 times in completely randomized design with 5 larvae in each replicate. The fungal pathogens sprayed leaf bunches were tagged properly. Observations were taken at every 24 hours interval. The larval mortality was observed up to 5 days after spraying.

Evaluation of native pathogenic bacteria *Myroides odoratus*:

The efficacy of native pathogenic bacteria *M. odoratus* was evaluated against the targeted pest *P. syntaractis* in field condition. Three different concentrations i.e 2.6×10^8 CFU/ml,2.6×10^6 CFU/ml and 2.6×10^4 CFU/ml were evaluated against the III instar larvae. Five replications maintained with 10 larvae in each replication. Control was maintained separately. Larval mortality percent were recorded after every 24 hours interval.

Evaluation of native Baculovirus (The nuclear polyhedrosis virus (HpNPV) against *Hyblaea puera*:

The native nuclear ployhedrosis virus isolated from the naturally infected larvae of *H.puera* (HpNPV) was evaluated on the larvae of *H. puera* in field condition at the concentrations standardized in the laboratory studies. Five replicates with 10 larvae each were maintained for each experiment. Control was maintained separately. Observations on larval mortality was recorded at 24 hrs intervals for five days.

Evaluation of the biopesticide Hy-ACT:

The botanical bio pesticide Hy-ACT was evaluated for its efficacy and effectiveness against the larvae of the defoliators *P.syntaractis*, *Hypocala* sp., and *H.puera* (III instar) in field condition. The concentrations standardized in the laboratory studies *viz;* 0.25%, 0.50%, 0.75% and 1% were used. Five replications were maintained in each treatment (T1 – T4) with 10 larvae each were used for each replication. Control was maintained separately (T5). Observations on the mortality of larvae was taken after every 24 hours interval.

Evaluation of the biopesticide Neem oil:

The biopesticide Neem oil was evaluated for its efficacy and effectiveness against the defoliators *Hypocala* sp., and *H.puera* in field condition with the four concentrations of 2%,3%,4% and 5% standardized in the laboratory experiments. Five replications were

maintained in each treatment (T1 – T4)with 10 larvae. Control was maintained separately (T5). Observations on the mortality of the defoliator were taken after every 24 hours interval.

Evaluation of the biopesticide Nimbecidine (*Azadirachtin* 0.03%):

The biopesticide Nimbecidine (Azadirachtin 0.03%) was evaluated for its efficacy and effectiveness against the defoliators *P.syntaractis*, *Hypocala* sp., and *H.puera* in the field condition with the four concentrations of 0.25%, 0.50%, 0.75% and 1% standardized in laboratory experiments. Five replications were maintained in each treatment (T1 – T4). Control was maintained separately (T5) with 10 larvae. Observations on the mortality of the defoliator were taken after every 24 hours interval.

All the data were subjected to analysis of variance (ANOVA) and significance of various treatments was evaluated by F test ($p<0.05$) by calculating CD values.

5. RESULTS

5.1 FIELD SURVEY

Periodical survey at various mangrove areas in Thane district and Gorai mangrove areas was undertaken during 2017-2019 to diagnose the insect pest probelms. Three plantations in Thane district *viz.*, Airoli plantations,Gothivali Plantation, Ghansoli Plantation and two natural mangroves one each at Airoli in Thane District and Gorai mangrove areas in Mumbai suburban District of Maharashtra were selected for the present study (Table 2) (PLATE 1- i to iv) (Map. Fig.1).

5.1.1 STUDY LOCATIONS IN MAHARASHTRA

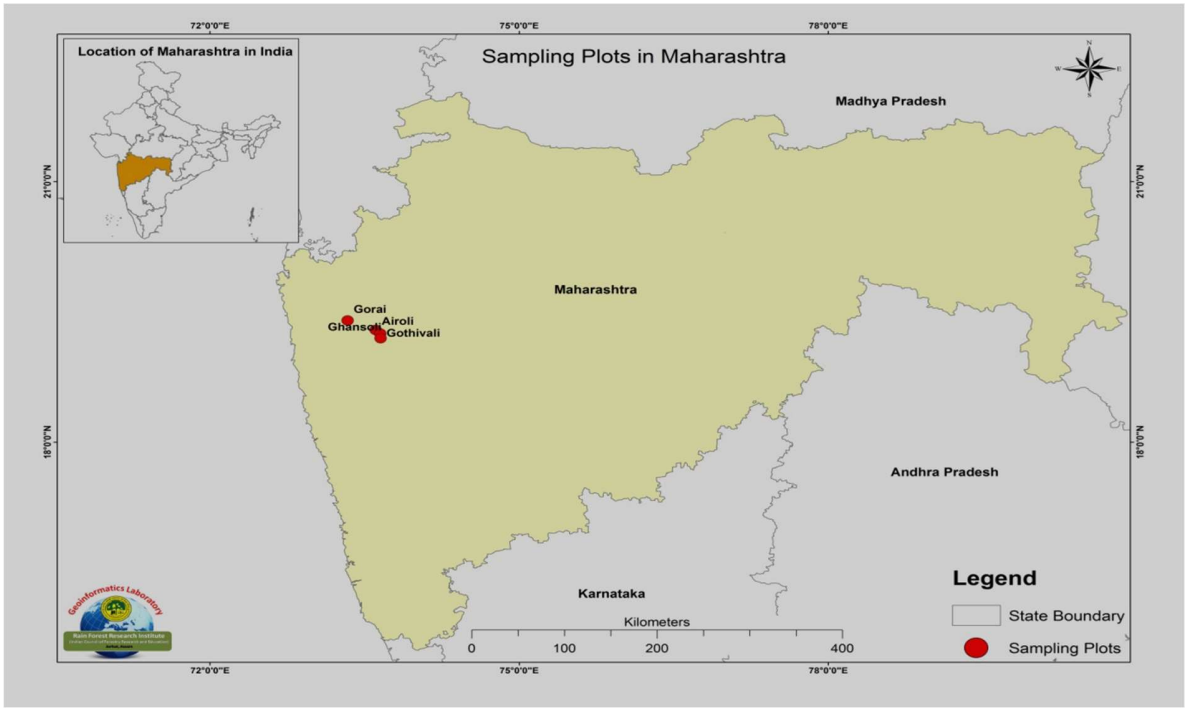
Natural mangroves

Airoli (N 19° 14′ 76.5" E 072° 98′ 43.9") and Gorai (N 19° 24′ 04.8" E 072° 80′ 08.8").

Table. 2 Plantations selected for survey

S. No.	Area selected	District	Control Division	GPS reading Latitude/longitude
1.	Airoli	Thane	Mangrove cell , Maharashtra State Forest Department	N 19º 14′76.5" E 072º 98′43.9"
2.	Gothivali	Thane	Mangrove cell , Maharashtra State Forest Department	N 19º 14′07.9" E 072º 99′38.5"
3.	Ghansoli	Thane	Mangrove cell , Maharashtra State Forest Department	N 19º 11′50.9" E 072º 99′17.3"

Fig.1 MAP OF STUDY AREAS OF MANGROVES IN THANE DISTRICT OF MAHARASHTRA



Study area in Airoli

Study area in Ghansoli

PLATE -1

(i) Mangroves in Airoli

(ii) Mangrove plantation in Gothivali

(iii) Mangrove plantation in Ghansoli

(iv) Mangroves in Gorai

5.2 SELECTION OF MANGROVE PLANT SPEICES FOR STUDIES

The common and dominant mangrove species like *A. marina*, *A. officinalis, S. apetala, S. alba* and *R. mucronata* found in the mangroves of Thane district of Maharashtra were selected for the studies on pest problems. The Phenology of the plant species were also recorded during the study period.

#**Scientific Name** : ***Avicennia marina*** (Forssk.) Vierh. (PLATE 2 -ii)

Vernacular Name : Tivar

Family : Avicenniaceae

Description **:** Most common mangrove species in Maharashtra**.** Leaves dark green, shinning above and white beneath. Fruits yellow in colour, more or less heart shaped, hairy and smooth. Propagation through fruits. Flowers yellow in colour. Budding took place in January, February, November and December. Flowering occurs during the months from March to July and fruiting from July to September.

#**Scientific Name** : ***Avicennia officinalis*** L. (PLATE 3 -i)

Vernacular Name : Tivar

Family : Avicenniaceae

Description **:** Widely distributed mangrove species in Maharashtra but not as common as *A. marina.* Leaves dark green above and yellowish green or bluish grey beneath. Leaves not pointed as in *A.marina* but more rounded. Flowers and fruits yellowish orange in colour. Fruits ovoid, hairy, wrinkled about 3cm long. Budding occurs during December to March and flowering in the months of April to June and fruiting from July to August.

#**Scientific Name** : ***Sonneratia apetala*** Buch. Ham. (PLATE 3 -ii)

Vernacular Name : Chipi

Family : Sonneratiaceae

Description **:**Distributed in Thane, Mumbai and Raigad districts rarely found in Southern districts of Ratnagiri and Sindhudurg (south of Alibaug). Leaves narrow, dense crown and slender drooping branches. Petals absent, fruit very small in size of 2cmm dia. Budding occurs during February to April, flowering occurs from April to June, fruiting from June to July.

#**Scientific Name** : ***Sonneratia alba*** Sm. (PLATE 3 -iii)

Vernacular Name : Pandhari Chipi

Family : Sonneratiaceae

Description : Distributed in all coastal districts of Maharashtra. Leaves are oval to round shape, flowers are white, calyx cup shaped. Fruit green in colour and large , shaped like an apple . Propagation through seeds. Budding occurs during November to January, flowering from February to April. Fruiting from May to August.

#**Scientific Name** : ***Rhizophora mucronata*** Lam. (PLATE 3 -iv)

Vernacular Name : Kandal

Family : Rhizophoraceae

Description : Distributed throughout Maharashtra. Long prop/stilt roots that seems to elevate the tree from the ground. Leaves are leathery to touch. Long propagule, dull green brown 50cm length, calyx pale yellow. Budding occurs from December to January, April to June and September. Flowering from September to April, fruiting from January to March and May to June and August.

5.3 STUDIES ON THE INCIDENCE AND INTENSITY OF INSECT PEST ATTACK

Based on the regular survey in the natural mangroves, nurseries and plantations the following insect pests were recorded in the selected mangrove species *A. marina*, *A. officinalis, S. apetala, S. alba* and *R. mucronata.* Around 50 to 100 plants in each block were tagged for each mangrove species and were assessed for regular pest incidence. Insects pests were collected by manually, using insect net, light trap etc. The collected insects were brought to laboratory for rearing and identification and for experimental purposes (PLATE 4 &5). 20 pests including 2 snails were recorded on the selected mangrove species. Based on the frequency of incidence and extent of damage caused, insect pests were classified as (i) Occasional (occurring occasionally), (ii) Regular (most frequently occurring) and (iii) Seasonal (occurring at a particular season of the year). The description of the pest, pest occurrence and the damage caused by the insects were described and the details given below.

PLATE -2

(i) Mangrove species in nursery and demo plot in Airoli

(ii) *Avicennia marina*

PLATE -3

(i) *Avicennia officinalis*

(ii) *Sonneratia apetala*

(iii) *Sonneratia alba*

(iv) *Rhizophora mucronata*

PLATE – 4
Collection of insect pests in the field

(i) Tagging of mangorve plants for observation

(ii) Insect pests collection in the field in Airoli

PLATE – 5

(i)Insect pests collection in the field in Ghansoli

(ii) Collection of *H. puera* in Airoli

(iii) Collection of *H. puera* in Gorai

(iv) Fixing of light tarp in the field

5.3.1 INSECT PESTS UNDER THE ORDER LEPIDOPTERA

Euproctis sp. (Lymantriidae) (PLATE 6 –i & ii)

Pest recorded on: *Sonneratia apetala*

Pest status: Occasional and Miner pest.

Description: Adult moths are 10-14mm long and pale yellow in colour**.** Moth lays the eggs in groups, usually on the leaves and they remain covered with hairs discharged from the body by the female. The eggs will hatch with in 5 to 10 days. The larva grows to a maximum length of 35-40mm. The larvae are dark coloured possesses red head with tufts of dark or pale hairs. The larval period last for about 17 to 25 days. It pupates in a silken cocoon in leaf folds for 10 to 20 days.

Damage caused: The hairy caterpillar larva feed on the leaf and cause defoliation in nurseries, young plantations and in natural mangroves.

Period of occurrence: June to August

Alternate host : Feeds on potato, coffee, red gram, castor, cauliflower, apricot trees and many other plant species.

Hyblaea puera Cramer (Hyblaeidae) (PLATE 6 –iii to v, PLATE 7 –i & ii)

Pest recorded on: *A. marina* and *A. officinalis*

Pest status: Regular, seasonal and Major pest.

Description and Biology: *H. puera* moths are small, with a wing span of 3 to 4cm. Forewing is greyish brown and the hind wings had black and orange-yellowish markings. The eggs are more or less elliptic and flat and laid singly near the veins on the lower side of the leaves. About 400-450 eggs are laid by a female moth on the leaves. During rearing of this moth in laboratory condition they lay eggs on the thin cloths. The young larva is greenish with a black head, but the body colour darkens on maturity to bluish black with black spec, bearing the setae. The under surface is lighter or olive green in colour. The full grown larva was stout and fleshy, almost black or dark greyish green with faint longitudinal lines or black with a broad dorsal orange coloured band and lateral longitudinal white and black lines. They make a shelter by folding over a part of the leaf and spinning silk. The larva retreats from danger by passing through a hole to

the other side of the leaf or by dropping on a silk thread. The pupation takes place on the leaf in a triangular leaf fold and also on the branches. It completes its life cycle with in 28 to 35 days depending mainly on the climatic condition.

Damage caused: The larva of caterpillar feed on entire part of leaf and cause complete defoliation and affect the growth of the plant. Epidemics of the pest completely denude the nurseries and young plantations of the species.

Natural enemies : Predatory spider *Oxyopes shweta,* Predatory pentatomid bug *Tipulparra pseudoversicolor,* Common House crow *Corvus splendens,* Nuclear polyhedrosis virus HpNPV

Period of occurrence: July to December

Alternate hosts : *Tectona grandis* (Teak)**,** *Sonneratia caseolaris, Casuarina equisetifolia, Khaya senegalensis*

Hypocala sp. (Erebidae) (PLATE 7 –iii & iv)

Pest recorded on: *Avicennia marina* and *A.officinalis*

Pest status: Regular and Major pest.

Description and Biology: The dark brownish adult moths are having 35 to 40mm wing span. Antennae ciliated in male. Thorax and abdomen scaled smoothly. Forewings with slightly arched costa towards rectangular apex. Larva greenish in colour having five instar stages before pupation. The matured larva ranges from 35 to 40 mm in length. The larval period was about 17 to 18 days. Pupation takes place on the leaf folded. The average duration required to complete the life cycle ranged from 35 to 37 days.

Damage caused: The larva feed on entire part of leaf and cause complete defoliation in nurseries, young plantations and in natural mangroves.

Period of occurrence: July to December

Alternate host : *Diospyros* spp., *Quercus leucotrichophora*

Hypomecis sp. (Geometridae) (PLATE 7 –v & vi)

Pest recorded on: *Avicennia marina*

Pest status: Regular and Minor pest.

PLATE -6

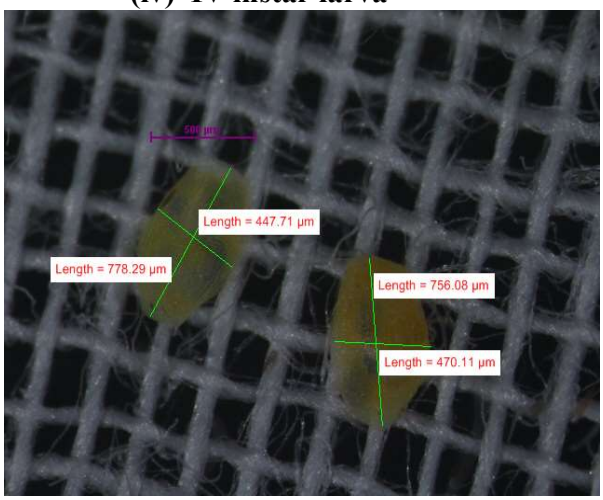
(i) *Euproctis* sp. larva on *Sonneratia apetala*

(ii) Pupa and adult moth of *Euproctis* sp.

Biology of *Hyblaea puera*

(iii) Defoliation on *Avicennia marina*

(iv) IV instar larva



(v) Eggs

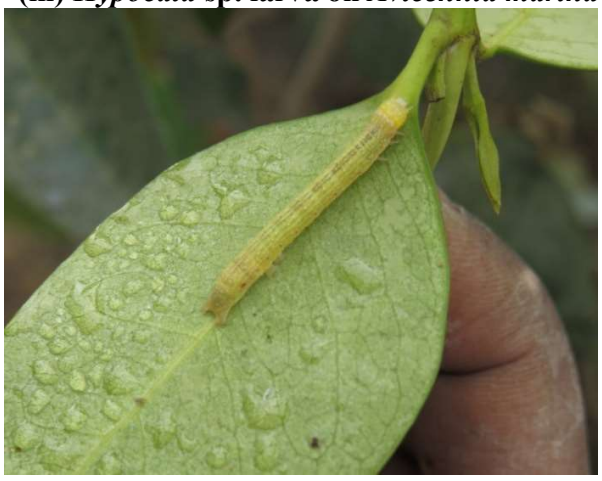
PLATE -7

(i) Pupae of *H.puera*

(ii) Adult moth of *H.puera*

(iii) *Hypocala* sp. larva on *Avicennia marina*

(iv) Pupa and adult moth of *Hypocala* sp.



(v) *Hypomecis* sp. larva on *Avicennia marina*

(vi) Adult moth of *Hypomecis* sp.

Description and Biology: The polyphagous adult moths are brown in colour having 38 to 42mm wing span. Larva greenish brown in colour having five instar stages before pupation. The matured larva ranges from 38 to 40 mm in length. Pupation takes place on the leaf folded. The average duration to complete the life cycle ranged from 36 to 40 days.

Damage caused: The semi looper larva feed on entire part of leaf and cause complete defoliation in nurseries, young plantations and in natural mangroves.

Period of occurrence: August to October

Alternate host : *Aleurites montana, Castanopsis fissa, Cinnamomum zylanicum* and *Hevea* sp.

Hypomecis transcissa Walker, 1860 (Geometridae)(PLATE 8 –i & ii)

Pest recorded on: *Avicennia marina*

Pest status: Regular and Minor pest.

Description and Biology: The polyphagous adult moths are light to dark brown in colour having 40 to 45mm wing span. Linear forewing postmedial with a subcostal angle and zig-zag. Larva brown in colour having five instar stages before pupation. The matured larva ranges from 40 to 43 mm in length. Pupation takes place on the leaf folded or between two leaves. The average duration of the life cycle ranged from 38 to 42 days**.**

Damage caused: The semi looper larva feed on entire part of leaf and cause complete defoliation in nurseries, young plantations and in natural mangroves.

Period of occurrence: August to October

Alternate hosts: *Aleurites montana, Castanopsis fissa, Cinnamomum zylanicum*, *Hevea* sp., *Nephelium lappaceum*, *Theobroma caca, Quercus leucotrichophora*(oak) and *Vernicia fordii.*

Phyllocnistis sp. (Gracillariidae) (PLATE 8–iii & iv)

Pest recorded on: *Avicennia marina*

Pest status: Regular and Miner pest.

Description : Adult moths are minute with a wingspread of 5mm. White and silvery iridescent scales on the forewings with several black and white markings. The hind wings are pale colour with scales from the hindwing margins. The head is smooth scaled and whitish pale colour.

Larve are minute 3 to 4mm length, translucent greenish yellow and located inside the leaf mine. The pupa is in a pupal cell at the leaf margin.

Damage caused: The larva mines the leaf and feed on the leaf and cause defoliation in nurseries, young plantations and in natural mangroves.

Period of occurrence: June to August

Alternate hosts: Citrus - may not be in mangrove area: known to inpest Citrus (Pandey 1964)

Pteroma sp. (Psychidae) (PLATE 8 –v)

Pest recorded on: *Rhizophora mucronata*

Pest status: Regular and Miner pest.

Description : Larva inhabits in portable smooth bags constructed out of silk and plant materials. The bagworm which grows to a size of 2 to 3cm. The male has a wingspan of 14–16 mm. It is a brownish black moth. Female is wingless and found within a case with a sclerotized posterior part. The fully grown larva is about 10–12 mm long present inside a movable case. After mating, female lay eggs within its case.

Damage caused: The bag worm larva feed on the leaf and cause defoliation in nurseries, young plantations and in natural mangroves. Scorched leaf appearance is common during heavy infestation.

Period of occurrence: January, June to July and December.

Alternate host : *Acacia nilotica, Bambusa nutans, B. tulda.*

Ptyomaxia syntaractis Turner,1904 (Pyralidae) (PLATE 9 – i to iii)

Pest recorded on: *Avicennia marina* and *A. officinalis*

Pest status: Regular and Major pest.

Description and Biology: The grayish, pale white adult moths are having 22 to 28mm wing span. The full grown larva is bluish green in colour. Larval period is 13 to 15 days. Pupation occurs in a cocoon between the leaves. Life cycle completes with in one month period.

Damage caused: The larva feed on the young shoots and skeletonize the leaf and cause defoliation in nurseries, young plantations and in natural mangroves.

Period of occurrence: June to January

Alternate host : *Rhizophora* sp.

Streblote helpsi Holloway (Lasiocampidae) (PLATE 9 – iv and PLATE 10 -i to iii)

Pest recorded on: *Avicennia marina*

Pest status: Occasional and Minor pest.

Description and Biology: The adult males are 20 to 23 mm wing span and the females are 30 to 37 mm. The males are dark brown in colour with the hindwing distal margin straight to convex rather than slightly concave. There is a faint antemedial posterior to the cell and a pale dash at the centre of the costa. The females are lacking pale fasciae on the wings or having them more pronounced. Full grown caterpillars are pale brown in colour with small black spots on each segment and long lateral tufts of ochreous hair. Larvae when fully grown pupate in cocoons on leaves. Female lays the eggs in patches and the eggs are oval with the length of about 1.3mm to 1.5mm and width 1.8mm to 2 mm. The eggs are whitish gray in colour with pigmented. The average duration required to complete a life cycle ranged from 50 to 55 days.

Damage caused: The larva of hairy caterpillar feed on entire part of leaf and cause complete defoliation in nurseries, young plantations and in natural mangroves.

Alternate host : *Casuarina equisetifolia* and *Sonneratia caseolari.*

Trabala vishnou (Lefebvre, 1827) (Lasiocampidae) (PLATE 10 – iv & v)

Pest recorded on: *Sonneratia apetala* and *S.alba*

Pest status: Regular and Miner pest.

Description and Biology: The pale green colour adult male moths are having 40 to 47mm wing span. Antennae ochreous brown. The disk of the forewing and the inner margin of the hind wing are pale or whitish. Forewings with a faint pale antemedial line curved below the costa. Both wings have a series of small submarginal dark spots. The female moths are yellowish green. Lines and spots of both wings are enlarged and blackish having 55-60 mm wing span. Larva has a yellow head spotted with red and its body colour is brownish grey with long lateral tufts on each somite.

PLATE - 8

(i) *H. transcissa* larva on *Avicennia marina*

(ii) Adult moth of *H. transcissa*

(iii) Leaf miner *Phyllocnistis* sp. attack on *Avicennia marina*

(iv) Adult moth of *Phyllocnistis* sp.

(v) *Pteroma* sp. on *Rhizophora mucronata*

PLATE - 9

(i) Larva of *P. syntaractis* on *Avicennia marina* and *A. officinalis*

(ii) Adult moth *P. syntaractis*

(iii) Adult moth *P. syntaractis* (enlarged)

Biology of *Streblote helpsi*

(iv) Defoliation by *S. helpsi* on *Avicennia marina*

PLATE - 10

(i) Eggs of *S. helpsi*

(ii) Pupa of *S. helpsi*

(iii) Adult moth of *S. helpsi*

(iv) *T. vishnou* larva on *S. apetala*

(v) Adult moth *T. vishnou*

Pupation takes place on the leaf folded in a cocoon. The average life cycle period ranged from 45 to 48 days.

Damage caused: The hairy caterpillar larva feed on the leaf and cause defoliation in nurseries, young plantations and in natural mangroves.

Period of occurrence: May to August

Alternate host : *Populus* sp., castor, jamun, pomegranate, rose and sandalwood plants.

5.3.2 INSECT PESTS UNDER THE ORDER COLEOPTERA

Alcidodes sp. (Curculionidae) (PLATE 11– i)

Pest recorded on: *Avicennia marina*

Pest status: Occasional and Minor pest.

Description: The brownish weevil with pale white dots on the dorsal, 5-6mm long usually hide below the leaf. They lay eggs in soil and grubs hatch out, feed on the roots of plants and grasses and survive.

Damage caused: Adult weevil feed on the leaf margin and defoliate the young shoots.

Period of occurrence: January, July and August

Myllocerus dentifer (Fabricius) (Curculionidae) (PLATE 11– ii)

Pest recorded on: *Avicennia marina* and *A. officinalis*

Pest status: Occasional and Minor pest.

Description: The adult weevil measure about 6-8mm long, small and elongate with long and slender legs. Grey to grayish brown with long antennae. Elytra is broader than thorax, constricted apically.

Damage caused: The adult feeds on the foliage, severe feeding resulting in partial defoliation of tender foliage of the young shoots.

Period of occurrence: November to January

Myllocerus discolor Boheman (Curculionidae) (PLATE 11– iii)

Pest recorded on: *Avicennia marina*

Pest status: Occasional and Minor pest.

Description: The brownish black weevil with fawn and pale markings, 6 mm long usually hide below the leaf. They lay eggs in soil and grubs hatch out, feed on the roots of plants and grasses. Female lays on an average of 300 eggs over a period of 24 days. Eggs hatch with in 3–5 days. Grub period is 1–2 months, pupation takes place in soil inside earthen cells and pupal period is about 7–10 days. Life cycle period will be completed in 6–8 weeks.

Damage caused: The weevils can inflict heavy injury on young shoots and branches, can occur in large number and devours young tender leaves from the edge inwards but on older leaves eat only the soft tissues between the veins. Adult weevil feed on the leaf margin and defoliate the young shoots.

Period of occurrence: November to February

Alternate hosts: Pearl millet, maize, sorghum, ragi, mulberry, mango, guava.

5.3.3 INSECT PESTS UNDER THE ORDER ORTHOPTERA

Aiolopus thalassinus (Fabricius, 1781) (Acrididae) (PLATE 11– iv)

Pest recorded on: *Avicennia marina* and *Avicennia officinalis*

Description: Medium sized grasshopper, tegmina and wings fully developed, head acutely conical, antennae filiform, as long as or longer than head and pronotum together, fastigium of vertex elongate angular, slightly concave, with well developed lateral carinulae, frons oblique; frontal ridge flat, pronotum slightly tectiform and slightly constricted in prozona, median carina weak, medial area of tegmen with intercalary vein well developed , hind femur slender, hind tibia longer than external one with inner pair of spines, external apical spine absent, arolium of small size, frontal ridge of uniform width with nearly parallel margins, hind tibia coloured with a dark ring before the middle and without the bluish median part. The total duration of *A. thalassinus* from first nymphal instar to adults ranged between 86-102 days for males and 99 to 122 days for females.

Damage caused: The numph and adult grasshopper browse and feed on leaves of tender leaves and cause damage to the plants in nurseries, young plantations and in natural mangroves.

Period of occurrence: May to September.

Alternate hosts : Lucerne (alfalfa), Cabbage.

Cyrtacanthacris sp**.** (Acrididae)(PLATE 11– v)

Pest recorded on: *Avicennia marina* and *Avicennia officinalis*

Description: Body yellow colour with brown and white markings. Both the sides of the occiput having a dark colour stripe. Cheeks sometimes with indefinite dark spots. Velvet blackish brown band on both sides of the pronotum. Tegmina with dense and thick reticulation. Wings hyaline. Hind tibiae yellowish below. Hind tarsi red.

Damage caused: The numph and adult grasshoppers browse and feed on leaves of tender leaves and cause damage to the plants in nurseries, young plantations and in natural mangroves.

Period of occurrence: June to August

Alternate hosts : Tapioca, cotton.

Holochlora sp**.** (Tettigoniidae) (PLATE 12– i)

Classification

Class: Insecta

Order: Orthoptera

Family: Tettigoniidae

Pest recorded on: *Sonneratia apetala*

Pest type/status: Regular and Miner pest.

Description and Biology: Adults are pale green in colour. Hind wings are little longer than forewings and the tips of the wings are pointed. Ovipositor long. Hind femora prominently attenuate, lateral lobes or pronotum longer than deep. slightly concave in the antero-dorsal with pointed postero-dorsal tip projected relatively upward.

Damage caused: The green grass hopper feed on the leaf and cause defoliation in nurseries, young plantations and in natural mangroves.

Period of occurrence: June to August

Phlaeoba panteli Bolívar, 1902 (Acrididae) (PLATE 12– ii)

Pest recorded on: *Avicennia marina* and *Avicennia officinalis*

Description: Medium size grasshopper; ensiform antennae, shorter than head and pronotum together, brown at apex; pronotum truncated in front, obustly angulated behind; head and pronotum very rugose, wings narrow, bluish hyaline, nervures greenish; ferruginous brown colour with scattered black dots.

Damage caused: The numph and adult grass hoppers browse and feed on leaves of tender leaves and cause damage to the plants in nurseries, young plantations and in natural mangroves.

Period of occurrence: June to August and January.

Alternate hosts : Wheat, Paddy, Maize, Grass.

Trilophidia annulata (Thunberg, 1815) (Acrididae) (PLATE 12– iii)

Pest recorded on: *Avicennia marina* and *Avicennia officinalis*

Description: Body brown with black markings. Antennae slightly thickened. Pronotum rugosa, with a median carina, which forming two teeth in front with lateral carinae. Grey Tegmina; wings are yellow at the base, black beyond. Pale colour outside hind femora, with brown spots. The hind tibiae are brown and pale band towards the base and slight pale band beyond the middle.

Damage caused: The numph and adult grass hoppers browse and feed on leaves of tender leaves and cause damage to the plants in nurseries, young plantations and in natural mangroves.

Period of occurrence: June to August and January.

Alternate hosts : Paddy, Maize, Wheat, Sugarcane, Grass Gram, Millet, Oat, Brinjal, Grass Tomato, *Calotropis,* cotton,

5.3.4 MOLLUSCAN SNAILS **(Pulmonata/ Ellobiidae)** AFFECTING MANGROVES

Melampus ceylonicus (Petit,1843) (PLATE 12– iv and v)

Pest recorded on: *Avicennia marina*

Description and distribution: The snails are air breathers. These are gregarious and occur under the bark and crevices in the roots of mangrove plants. Shell is small up to 9-10mm height and 4-5mm width , yellowish brown in colour, with dark brown spiral striation and growth lines. It is a major and serious pest particularly in rainy season causing damage to the mangrove

PLATE – 11


(i) *Alcidodes* sp. on *Avicennia marina*


(ii) *M. dentifer* **(iii) *M. discolor***


iv) *A. thalassinus* **(v) *Cyrtacanthacris* sp.**

PLATE – 12

(i) *Holochlora* sp.

(ii) *P. panteli*

(iii) *T. annulata*

(iv) *M. ceylonicus* feeding on *Avicennia marina*

(v) *M. ceylonicus* ventral and dorsal view

PLATE – 13

(i) *M. pulchellus* feeding on *Avicennia marina*

(ii) *M. pulchellus* ventral and dorsal view

species *A. marina* completely eliminate the young leaf and shoots. Distributed in Maharashtra (Bombay), Andhra Pradesh and Orissa in India.

Melampus pulchellus (Petit,1843) (PLATE 13– i & ii)

Pest recorded on: *Avicennia marina*

Description and distribution: The snails are air breathers and small in size. These are gregarious and occur under the bark and crevices in the roots of mangrove plants. Shell is small up to 9-10mm height and 4-5mm width , whitish to yellowish brown in colour, with dark brown spiral bands or transversal bands. Glossy surface with some spiral striation and growth lines. The periostome is light brownish. It is a major and serious pest particularly in rainy season causing damage to the mangrove species *A. marina* completely eliminate the young leaves. Distributed in Maharashtra and West Bengal in India and also in Philippines.

5.3.1 CATEGORIZATION OF MAJOR AND MINOR PESTS RECORDED

The recorded pests were categorized in to major and minor pests based on the intensity and injuries caused by insect pest of selected mangrove species. 5 insects pests of defoliators including 2 snails were categorized as major pests and 15 other insect pests were categorized as minor pests. The results were given below (Table 3).

Table. 3 List of pests recorded and status of the pest

S.No.	Mangrove Tree species	Pests recorded	Order/Family	Status of the pest
1.	***Avicennia marina***	*Aiolopus thalassinus*	Orthoptera / Acrididae	Minor
		Alcidodes sp.	Coleoptera/ Curculionidae	Minor
		Cyrtacanthacris sp.	Orthoptera/ Acrididae	Minor
		Hyblaea puera	Lepidoptera/ Hyblaeidae	**Major**
		Hypocala sp.	Lepidoptera/ Erebidae	**Major**
		Hypomecis sp.	Lepidoptera/ Geometridae	Minor
		Hypomecis transcissa	Lepidoptera/ Geometridae	Minor
		Melampus ceylonicus	Phylum : Mollusca	**Major**

			Pulmonata/ Ellobiidae	
		Melampus pulchellus	Phylum : Mollusca Pulmonata/ Ellobiidae	**Major**
		Myllocerus dentifer	Coleoptera/ Curculionidae	Minor
		Myllocerus discolor	Coleoptera/ Curculionidae	Minor
		Ptyomaxia syntaractis	Lepidoptera/ Pyralidae	**Major**
		Phyllocnistis sp.	Lepidoptera/ Gracillariidae	Minor
		Phlaeoba panteli	Orthoptera/ Acrididae	Minor
		Streblote helpsi	Lepidoptera/ Lasiocampidae	Minor
		Trilophidia annulata	Orthoptera/ Acrididae	Minor
2.	***Avicennia officinalis***	*Aiolopus thalassinus*	Orthoptera / Acrididae	Minor
		Cyrtacanthacris sp.	Orthoptera/ Acrididae	Minor
		Hyblaea puera	Lepidoptera/ Hyblaeidae	Minor
		Hypocala sp.	Lepidoptera/ Erebidae	**Major**
		Myllocerus dentifer	Coleoptera/ Curculionidae	Minor
		Phlaeoba panteli	Orthoptera/ Acrididae	Minor
		Ptyomaxia syntaractis	Lepidoptera/ Pyralidae	Minor
		Trilophidia annulata	Orthoptera/ Acrididae	Minor
3.	***Sonneratia apetala***	*Euproctis* sp.	Lepidoptera/ Lymantriidae	Minor
		Holochlora sp.	Orthoptera/ Tettigoniidae	Minor
		Trabala vishnou	Lepidoptera/ Lasiocampidae	Minor
4.	***Sonneratia alba***	*Trabala vishnou*	Lepidoptera/ Lasiocampidae	Minor
5.	***Rhizophora mucronata***	*Pteroma* sp.	Lepidoptera/ Psychidae	Minor

5.3.2 INTENSITY OF PEST INFESTATION DURING THE STUDY PERIOD

The intensity of infestation was assessed based on the level of incidence of the insect pest and percentage of the damage/extent of damage caused. The tagged plants of each mangrove species were assessed for the pest incidence and the severity, the average percentage of plants infested was

calculated. The intensity was rated visually by comparing the occurrence of attacked and unattacked leaves in all the tagged plants. The percentage of intensity was classified as Negligible (Low intensity and the percentage of infestation less than 25%), Medium (Moderate intensity and the percentage of infestation between 26 to 60%) and Severe (High intensity and the percentage of infestation between 61 to 100%). Moderate level of infestation by *S. helpsi* (30-35%) recorded on *A. marina* during the months of June and July (Chart 1). The semilooper larvae *H. transcissa* caused moderate level of infestation (25 to 55%) during the months of August to October on *A.marina* (Chart 2). The looper larvae *Hypomecis* sp. caused moderate level of infestation (35%) on *A.marina* during the month of September (Chart 3). The major defoliator *Hypocala* sp. caused severe level of infestation (65%) on *A. marina* and *A. officinalis* during the month of September (Chart 4). Moderate level of infestation caused by the hairy caterpillar *Trabala vishnou* (30-40%) during the months of July to September on *S. apetala* and *S. alba* (Chart 5). The *Phyllocnistis* sp. (Leaf miner) caused moderate level of infestation (35%) during the month of August on *A. marina* (Chart 6). The defoliating skeletonizer, shoot feeder *Ptyomaxia syntaractis* caused severe level of infestation (64 to 70%) during the months of September to November on *A. marina* (Chart 7). *H. puera* was observed as a seasonal and important pest infesting *A. marina* plants heavily during the rainy season particularly during the period from June to December. The level of infestation was peak during the month of July to September. During the year 2018, the infestation level of attack was recorded as moderate (40% in August and September), where as in the year 2019 an epidemic level of infestation was recorded during the period from July to October and total defoliation was recorded during the month of September to October(Chart 8). The only grasshopper *Aiolopus thalassinus* causes moderate level of defoliation during the months of August to October and the average intensity percentage level was between 30 to 40% (Chart 9). The two snails of *Melampus ceylonicus* and *M. pulchellus* caused severe level of infestation (70%) during the months of June and July on *A. marina* (Chart 10).

Chart 1: Intensity percentage level of *Streblote helpsi* on *A. marina*

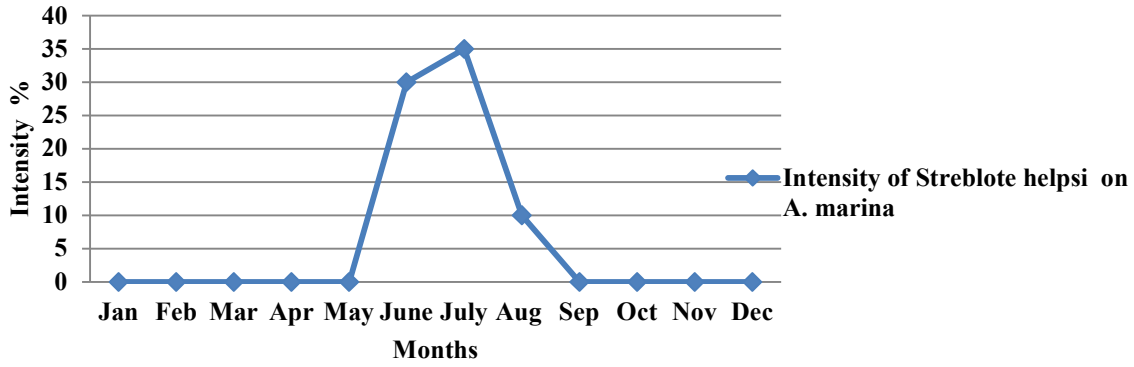


Chart 2: Intensity of on *Hypomecis transcissa* on *A. marina*

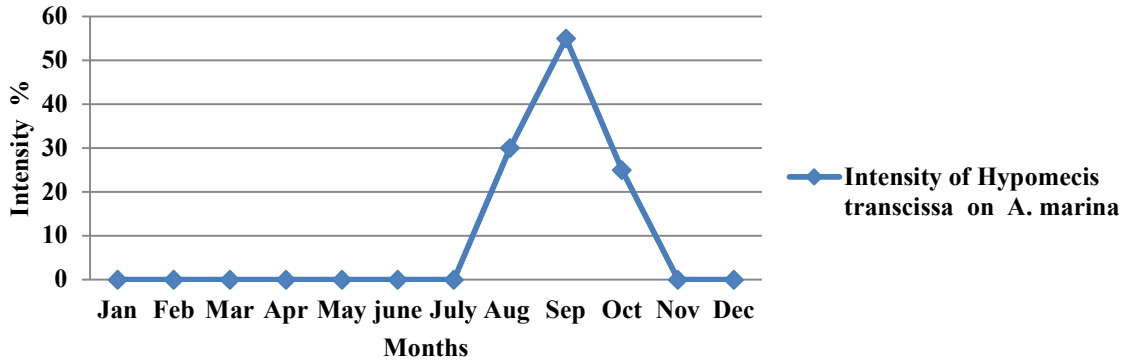


Chart 3: Intensity of *Hypomecis* sp. looper on *A. marina*

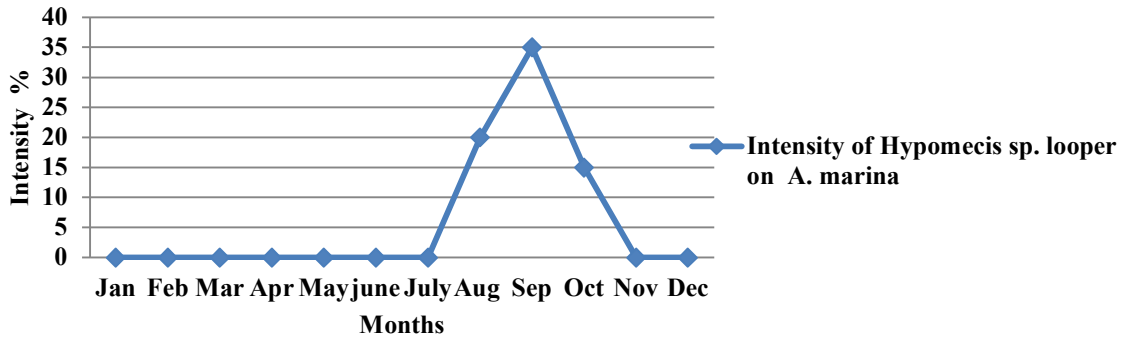


Chart 4: Intensity of *Hypocala* sp. on *A. marina* and *A. officinalis*

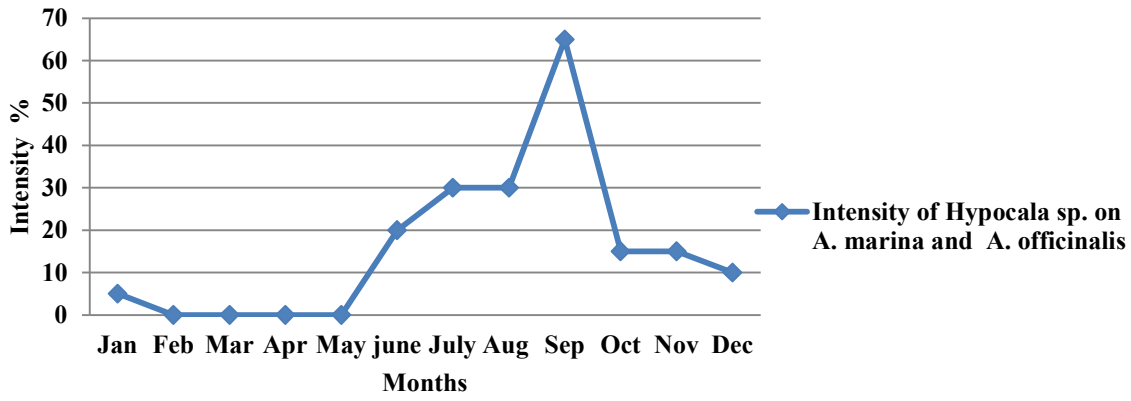


Chart 5:Intensity of *Trabala vishnou* on *S. apetala* and *S. alba*

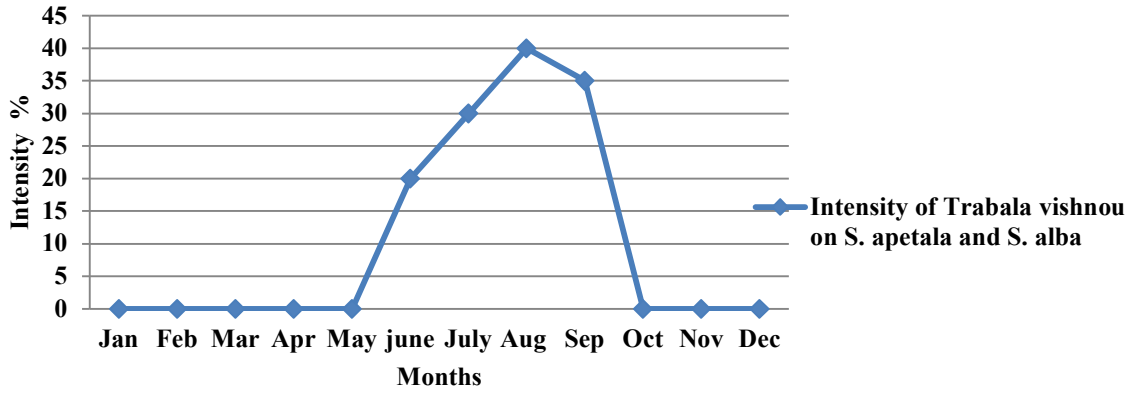
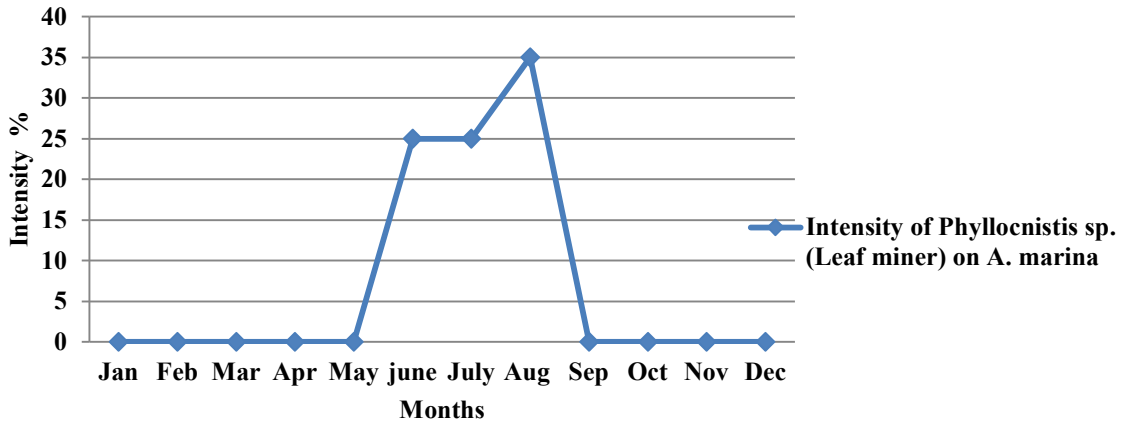


Chart:6 Intensity of *Phyllocnistis* sp. (Leaf miner) on *A. marina*



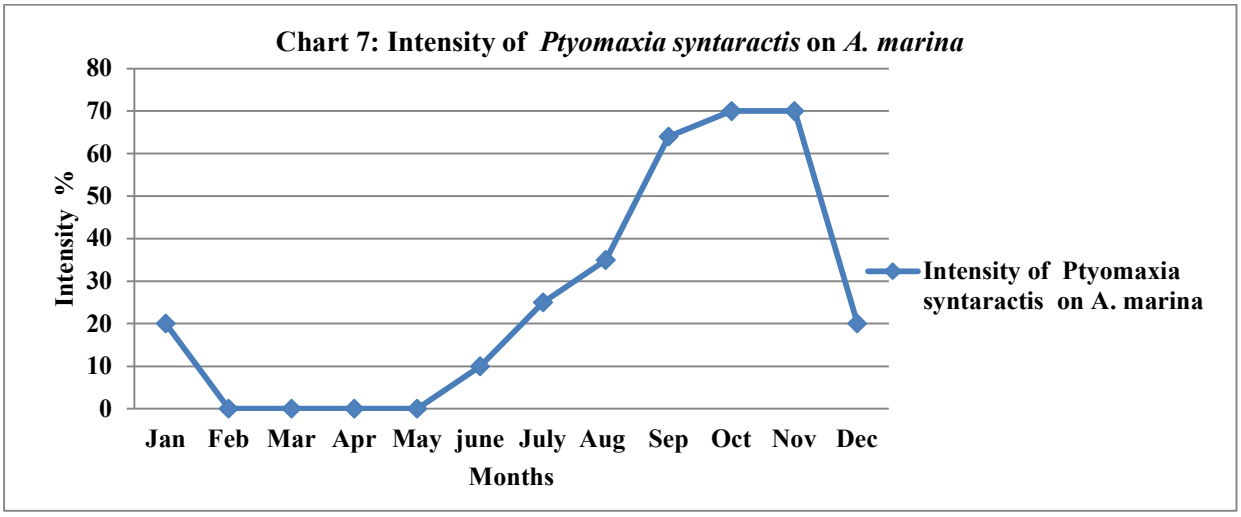


Chart 7: Intensity of Ptyomaxia syntaractis on A. marina
Intensity %
80
70
60
50
40
30
20
10
0
Jan Feb Mar Apr May june July Aug Sep Oct Nov Dec
Months
Intensity of Ptyomaxia syntaractis on A. marina

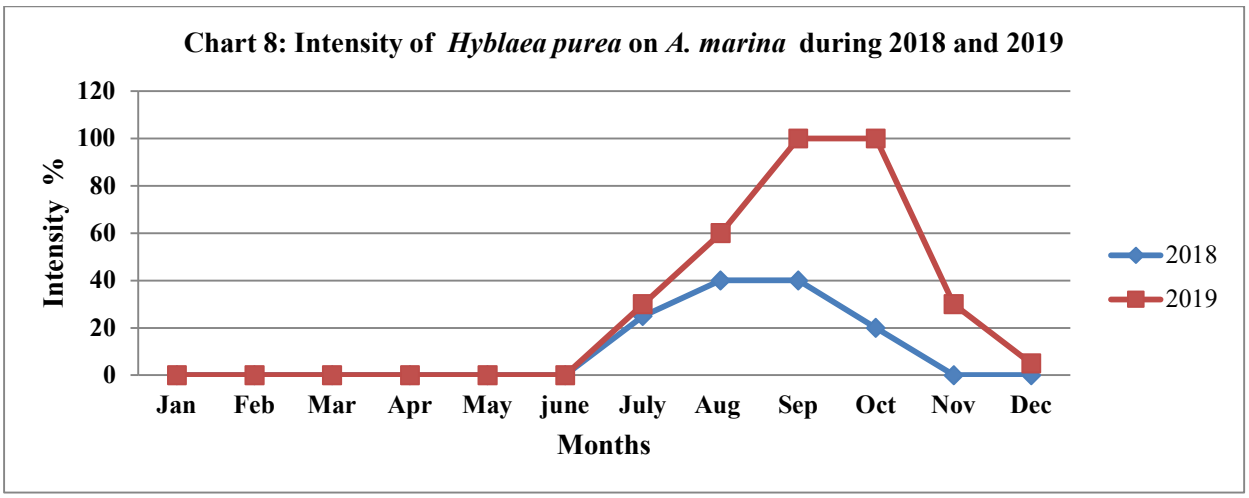


Chart 8: Intensity of Hyblaea purea on A. marina during 2018 and 2019
Intensity %
120
100
80
60
40
20
0
Jan Feb Mar Apr May june July Aug Sep Oct Nov Dec
Months
2018
2019

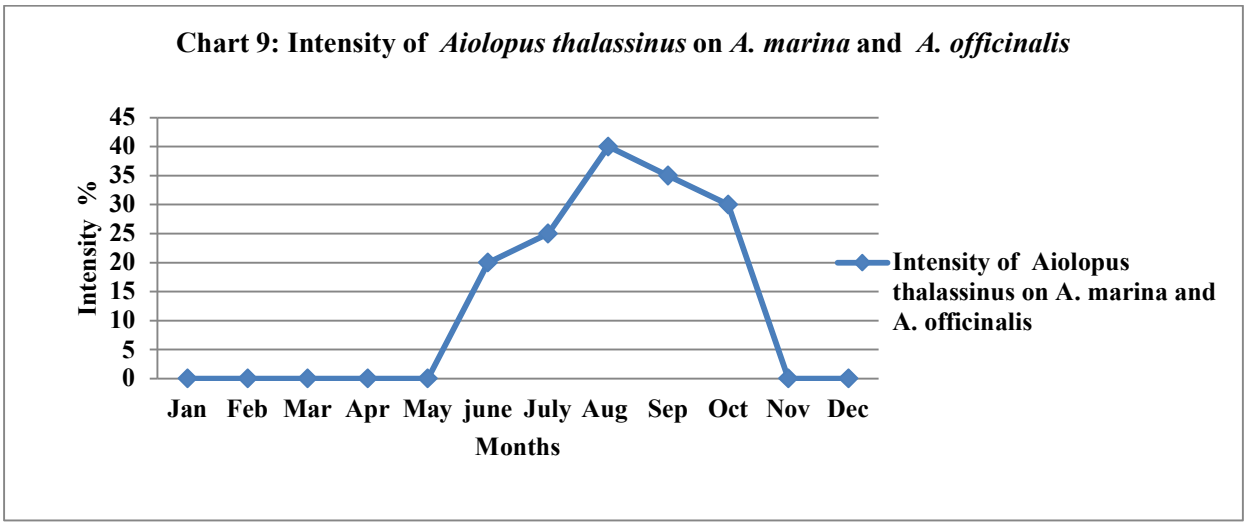
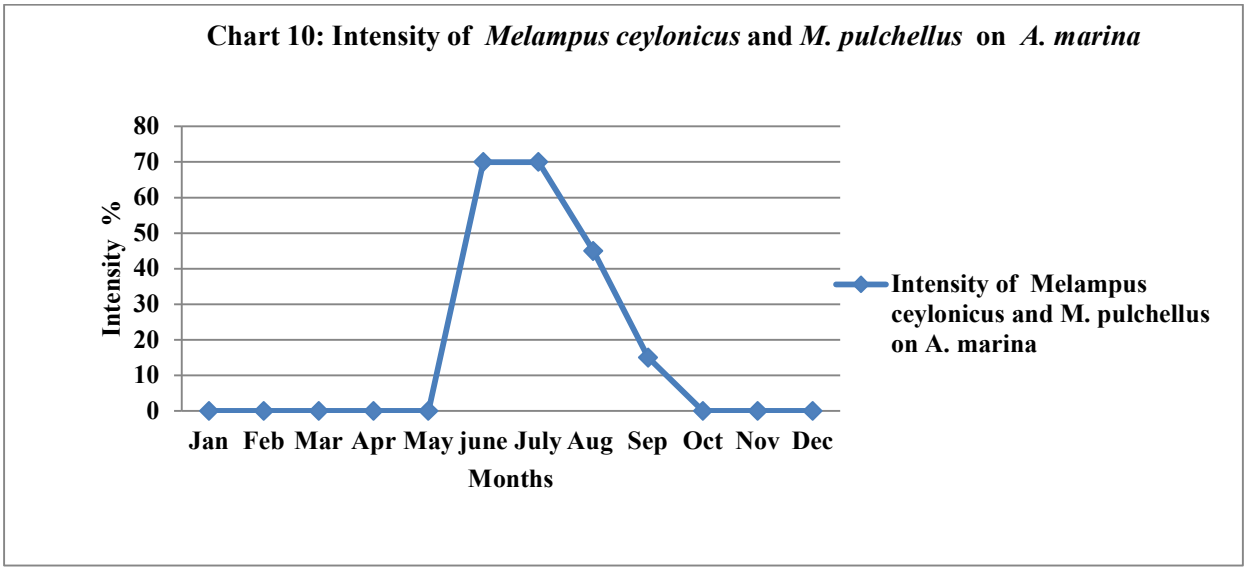


Chart 9: Intensity of Aiolopus thalassinus on A. marina and A. officinalis
Intensity %
45
40
35
30
25
20
15
10
5
0
Jan Feb Mar Apr May june July Aug Sep Oct Nov Dec
Months
Intensity of Aiolopus thalassinus on A. marina and A. officinalis



5.4 STUDIES ON THE BIOTIC AND ABIOTIC FACTORS :

5.4.1 NATURAL ENEMIES RECORDED

The natural enemies such as the predators, pupal parasitoids and the microbes like entomopathogenic fungi, entomopathogenic bacteria and NPV operating in the nurseries, plantations and natural mangroves were collected, identified and documented. One pupal parasitoid, five predatory spiders, one predatory pentatomid bug and the microbes one entomopathogenic fungus, one entomopathogenic bacteria and the NPV (Nuclear polyhedrosis virus) were recorded as natural biocontrol agents.(Table 4) (PLATE 14 to 16 ii).

Table.4 Natural enemies recorded in the nurseries and plantations against the pests.

Sl. No	Natural enemy	Insect host	Tree species	Parasite/Predator/ Microbes
1.	***Brachymeria* sp.**	*P. syntaractis*	*A. marina* and *A. officinalis*	Pupal parasitoid
2.	***Carrhotus decorata***	*Hypomecis* sp., *H. transcissa,*	*A.marina*	Predatory spider
3.	***Corvus splendens***	*H. puera*	*A. marina*	Common House crow -Predator

4.	**HpNPV**	*H. puera*	*A. marina*	Nuclear polyhedrosis virus
5.	***Myroides odoratus***	*P. syntaractis*	*A. marina* and *A. officinalis*	Entomopathogenic bacteria
6.	***Neoscona* spp.**	*Hypocala* sp.	*A. marina* and *A. officinalis*	Predatory spider
7.	***Nomuraea rileyi***	*Hypocala* sp.	*A.marina* and *A.officinalis*	Entomopathogenic fungus
8.	***Oxyopes javanas***	*H. puera, P. syntaractis*	*A. marina* and *A.officinalis*	Predatory spider
9.	***O. shweta***	*H. puera*	*A.marina*	Predatory spider
10.	***Tipulparra pseudoversicolor***	*H. puera*	*A. marina*	Predatory pentatomid bug

5.4.2 WEATHER PARAMETERS (Temperature and Rainfall)

Abiotic factors like Temperature and Rainfall were recorded during the period 2018 and 2019 and arrived the average monthly mean in the district of Thane in Maharashtra. It shows that the average monthly mean Temperature (^{o}C) in Thane district, the minimum of 26^{o}C during the month of January and the maximum of 34^{o}C during the month of October during 2018. Where as during the year 2019, the minimum and maximum average temperature ranges between 27^{o}C and 34^{o}C in the month of September and April respectively. The average monthly mean Rainfall (mm) in Thane district shows that the maximum rainfall recorded as 357.32 mm in the month of July and the minimum rainfall recorded as 0.31 mm in the month of March and no rain during the months of December to February during the year 2018. Where as the maximum rainfall recorded as 1073.1 mm in the month of July and the minimum rainfall recorded as 0.4 mm in the months of March and April. There was no rain during the month of February during the year 2019 (Table 5& 6). The Temperature and Rainfall recorded during the year 2018 was correlated with population level of infestation, intensity of defoliating insect pests *H.purea, H. transcissa***,** *Hypocola* sp., *P. syntaractis, T. vishnou* and the snails *M. ceylonicus* and *M. pulchellus.* The statistical analysis was worked out using Microsoft office Excel 2007 to find out the correlations between the pests vs Rainfall and Temperature. In case of *H. purea*, average mean temperature exhibited significant negative correlation, and the average rainfall

exhibited significant positive correlation with the intensity of pest in the year 2019. While in the year 2018, average temperature exhibited non-significant negative correlation, and the average rainfall exhibited significant positive correlation. With respect to *H. transcissa* the average temperature exhibited significant negative correlation and average rainfall exhibited significant positive correlation with the intensity of pest in the year 2018. For *Hypocala* sp. the average temperature exhibited significant and negative correlation, and the average rainfall mean exhibited significant positive correlation with the intensity of pest in the year 2018. Whereas in case of *P. syntaractis*, both average temperature and average rainfall exhibited significant positive correlation with the intensity of pest in the year 2018. In case of *T. vishnou*, the average temperature exhibited significant negative correlation but the average rainfall exhibited non-significant positive correlation with the intensity of pest in the year 2018. Where as for *Melampus*, the average temperature exhibited significant and negative correlation, but the average rainfall exhibited non-significant positive correlation with the intensity of pest in the year 2018 (Table 7).

Table. 5 Average monthly mean Temperature (°C) and Rainfall in Thane district of Maharashtra during 2018.

Weather parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (°C)	26	28	29	30	31	30	27	27	27	34	33	29
Rainfall (mm)	0	0	0.31	0.39	1.24	206.79	357.32	268.2	31.06	21.1	27.6	0

Table.6 Average monthly mean Temperature (°C) and Rainfall in Thane district of Maharashtra during 2019.

Weather parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (°C)	29	30	32	34	33	31	29	29	27	29	30	29
Rainfall (mm)	0.9	0	0.4	0.4	1.3	385.9	1073.1	669.2	715.1	216.7	37.4	5.6

Source: Temperature and rainfall : www.worldweatheronline.com

Table. 7 Regression equation and correlation coefficient of various pests against Temperature and Rainfall

Pest	Temperature	Rainfall
H.purea (2019)	y = -12.57x + 406.4 R^2 = 0.415 R= -0.644*	y = 0.054x + 12.87 R^2 = 0.272 R= 0.522*
H.purea (2018)	y = -2.069x + 70.95 R^2 = 0.1 R= -0.316	y = 0.067x + 5.276 R^2 = 0.272 R= 0.522*
H. transcissa (2018)	y = -1.062x + 40.23 R^2 = 0.021 R= -0.147*	y = 0.010x + 8.337 R^2 = 0.005 R= 0.0764*
***Hypocala* sp.** (2018)	y = -2.142x + 78.09 R^2 = 0.089 R= -0.298*	y = 0.065x + 10.45 R^2 = 0.211 R= 0.459*
P. syntaractis (2018)	y = 3.846x - 86.66 R^2 = 0.124 R= 0.352*	y = 0.011x + 24.94 R^2 = 0.002 R= 0.0542*
T.vishnou (2018)	y = -3.241x + 105.2 R^2 = 0.254 R= -0.504*	y = 0.098x + 2.949 R^2 = 0.595 R= 0.77
M. ceylonicus and ***M. pulchellus*** (2018)	y = -3.516x + 119.5 R^2 = 0.096 R= -0.311*	y = 0.210x + 0.647 R^2 = 0.887 R=0.942

*Significant at 0.05 level

5.4. NEW HOST RECORD

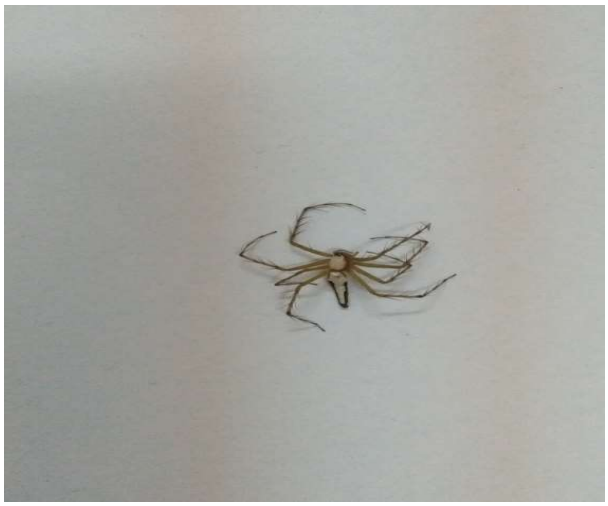
During the course of investigation new hosts have been recorded for five insect pests. They were *Hypocala* sp. on *A. marina* and *A. officinalis*, *H. transcissa* on *A.marina, S. helpsi* on *A. marina, T. vishnou* on *S.alba* and *S. apetala, M. dentifer* on *A.marina* and *A.officinalis.* The two snails *M. ceylonicus* and *M. pulchellus* were reported on *A. marina* for the first time.

5.5 PEST CALENDER

DEFOLIATORS -PEST CALENDAR												
PESTS NAME	**MONTHS**											
	JA	**FB**	**MA**	**AP**	**M**	**JU**	**JL**	**AU**	**SE**	**OC**	**NO**	**DE**
Aiolopus thalassinus					L	L	M	M	M			
***Alcidodes* sp.**	L						L	L				
***Cyrtacanthacris* sp.**						L	L	L				
***Euproctis* sp.**						L	L	L				
***Holochlora* sp.**						L	L	L				
Hyblaea purea							M	S	S	S	M	L
***Hypocala* sp.**						L	M	M	S	L	L	L
***Hypomecis* sp.**								L	M	L		
Hypomecis transcissa								M	M	L		
Melampus ceylonicus						S	S	M	L			
Melampus pulchellus						S	S	M	L			
Myllocerus dentifer	L										L	L
Myllocerus discolor	L	L									L	L
Phlaeoba panteli	L					L	L	L				
***Phyllocnistis* sp.**						L	L	M				
***Pteroma* sp.**	L					L	L					L
Ptyomaxia syntaractis	L					L	L	M	S	S	S	L
Streblote helpsi						M	M	L				
Trabala vishnou					L	M	M	M				
Trilophidia annulata	L					L	L	L				

PLATE – 14
Natural enemies

O. javanas



O. shweta

C. decorata

***Neoscona* spp.**

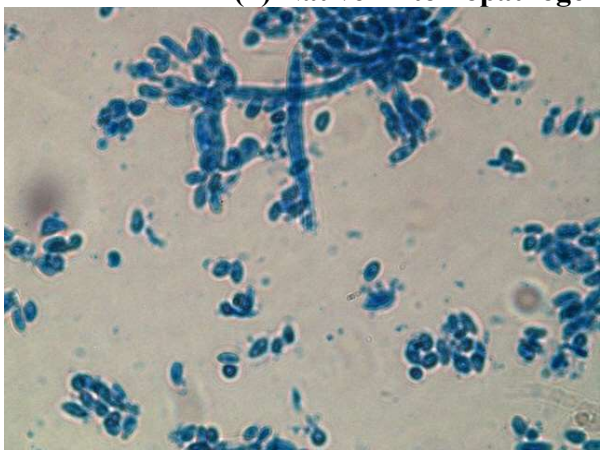
Predatory pentatomid bug
T. pseudoversicolor

Pupal parasitoid *Brachymeria* sp.

PLATE – 15
Natural enemies

(i) Common House crow *Corvus splendens* predating *H. puera* as natural control

(ii) Native Entomopathogenic fungi *N. rileyi*

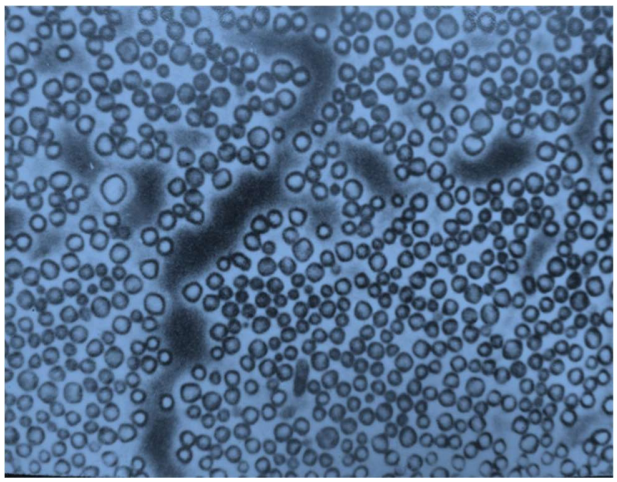


(iii) Conidiospores of *N. rileyi*

(iv) Entomopathogenic bacteria *M. odoratus*

PLATE – 16
Natural enemies

(i) NPV infected larva in the field



(ii) Polyhedral inclusion bodies

ARTIFICIAL DIET PREPARATION

(iii) Artificial diet for rearing the larvae of different defoliators of mangroves

(iv) Rearing the *H. puera* larvae in artificial diet

5.6 MANAGEMENT OF KEY PESTS :

5.6.1 LABORATORY STUDIES:

Mass rearing of targeted insect larvae:

The method for rearing of defoliators in laboratory condition was standardized.

Standardized method for preparation of semi synthetic diet for defoliators:

Channa (100 g) soaked in 405 ml of distilled water for 8-12 hours, overnight, was boiled and homogenized in a blender. To this, yeast tablet 30g, Weason's salt 7g, Methyl parahydroxy benzoate 2g, Sorbic acid 1g were added, mixed them and blended. Agar powder (13 g) was boiled in 405 ml of distill water separately. After dissolution of agar. cooled slightly and added to the other ingredients including Cellulose -5 g and dried leaf powder (10 g) of concerned plant species preferred by the host insect in blender and homogenized well. Finally Ascorbic acid, multivitamin drops 3g, formalin 2ml, Choline chloride and Streptomycin 40mg were added and homogenized well. Poured the content into a plastic or in a glass container. Kept the diet open for 24 hours to solidify and subsequent use (PLATE-16 iii & iv).

Evaluation of entomopathogenic fungi:

The bioassay studies were conducted by using the biological control agents like a native strain of *Nomuraea rileyi* an entomopathogenic fungi isolated and subcultured from the infected cadavers, *Metarizhium anisophilie* (strain Ma4- of NBAIR), commercial product of *M. anisophilie* and *B.bassiana* were evaluated against the targeted pests *P.syntaractis* and *Hypocala* sp., with different concentration of fungal solutions viz. 2.4×10^{10}, 2.4×10^{8}, 2.4×10^{6} and 2.4×10^{4} Spores/ml. The larvae sprayed with fungal inoculum were released on to the leaves for feeding in the containers. Five treatments (T1 – T5) were maintained to test the targeted pests. T5 was treated as control. Each treatment was replicated 5 times in completely randomized design with 10 larvae in each replicate. Observations were taken at every 24 hours interval. The mortality was observed up to 5 days after spraying. The native strain of *N. rileyi* showed highest level of mortality of 82 % and 90% in the concentration of 2.4×10^{8} and 2.4×10^{10} spores.ml respectively on *P.syntaractis*. Where as the strain of *M. anisopliae* –Ma 4 of NBAIR was also performed well in controlling the pest of *P.syntaractis* and caused 80% larval mortality (Table 8 & Chart 11). The native strain of *N. rileyi* showed highest level of mortality

of 96 % and 100% in the concentration of 2.4× 10^8 and 2.4 × 10^{10} spores.ml respectively on *Hypocala* sp. Where as the strain of *M. anisopliae* of NBAIR was also performed well in controlling the pest of *Hypocala* sp. and caused 82% larval mortality (Table 9 & Chart 12) (PLATE -17).

Table.8 Effect of different concentrations of Entomopathogens against the mortality percentage of *Ptyomaxia syntaractis* in laboratory condition.

Entomopathogens	2.4 x 10^{10} Spores/ ml	2.4 x 10^8 Spores/ ml	2.4 x 10^6 Spores/ ml	2.4 x 10^4 Spores/ ml
Nomuraea rileyi	90±3.17 [a]	82±2.00 [a]	72±2.00 [a]	62 ±2.00 [a]
M. anisopliae (NBAIR)	80±3.17 [b]	68±3.74 [b]	54±2.45 [b]	38±2.00 [b]
M. anisopliae (com)	52±3.74 [c]	38±3.74 [c]	32±2.00 [c]	20±3.17[c]
B. bassiana (com)	28±2.00 [d]	22±2.00 [d]	12±2.00 [d]	6±2.45 [d]
Control	0.0 [e]	0.0 [e]	0.0 [e]	0.0 [e]

Values are means ±SE of 5 replications. In each column, means followed by same letter under each treatments are not significantly different at 5% level of significance.

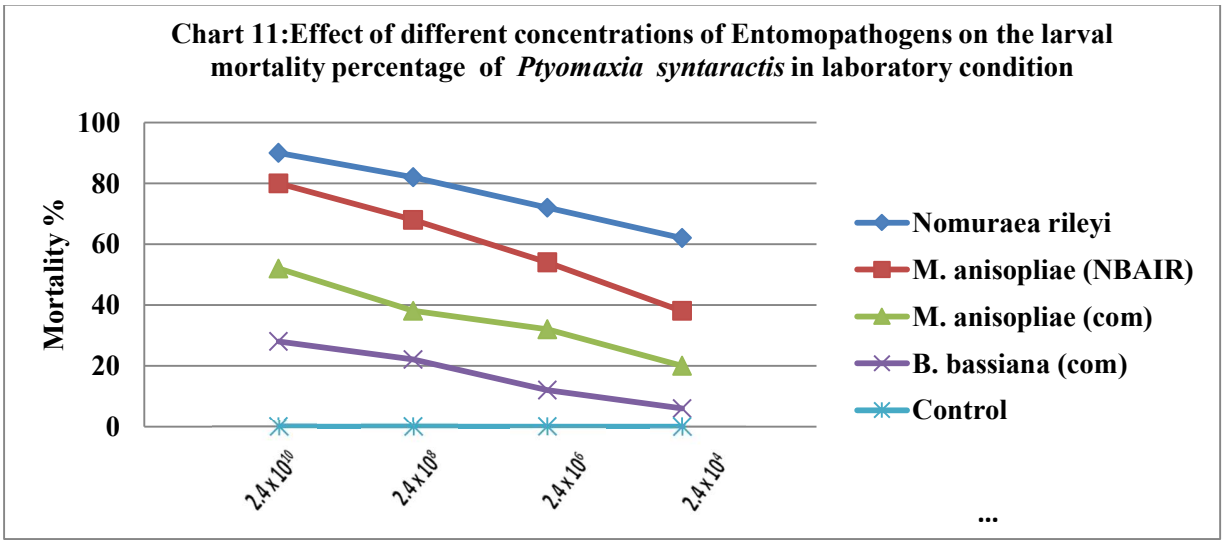
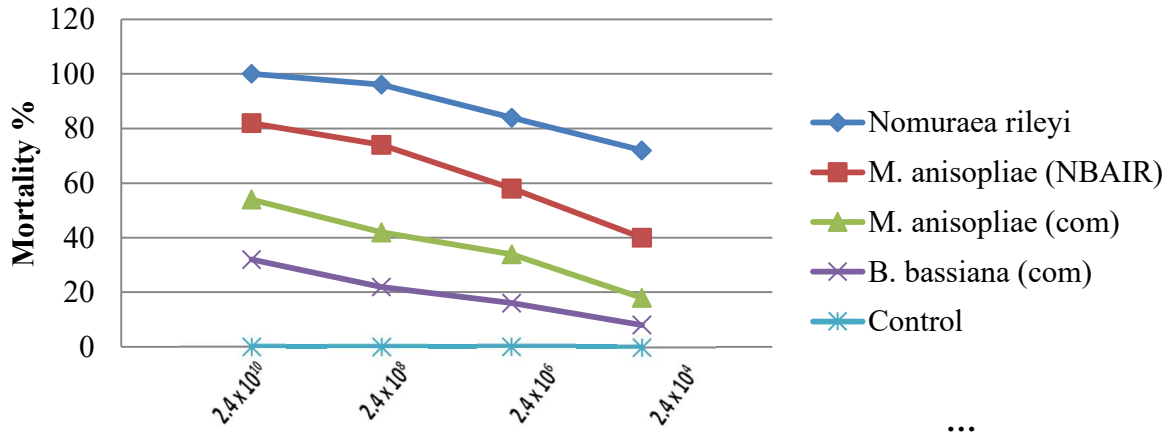


Table. 9 Effect of different concentrations of Entomopathogens against the mortality percentage of *Hypocala* sp., in laboratory condition.

Entomopathogens	2.4 x 10^{10} Spores/ ml	2.4 x 10^{8} Spores/ ml	2.4 x 10^{6} Spores/ ml	2.4 x 10^{4} Spores/ ml
Nomuraea rileyi	100 [a]	96±2.45 [a]	84±2.45 [a]	72 ±2.00 [a]
M. anisopliae (NBAIR)	82±2.00 [b]	74±2.45 [b]	58±2.45 [b]	40±3.17 [b]
M. anisopliae (com)	54±2.45[c]	42±2.00 [c]	34±2.45 [c]	18±2.00[c]
B. bassiana (com)	32±2.00 [d]	22±2.00 [d]	16±2.45[d]	8±2.00 [d]
Control	0.0 [e]	0.0 [e]	0.0 [e]	0.0 [e]

Values are means ±SE of 5 replications. In each column, means followed by same letter under each treatment are not significantly different at 5% level of significance.

Chart 12:Effect of different concentrations of Entomopathogens on the larval mortality percentage of *Hypocala* sp. in laboratory condition



Testing the safety of EPF *N.rileyi* against beneficial insects:

The EPF *N.rileyi* was tested for their safety to egg parasitoids *Trichogramma chilonis*. EPF spore suspension of different concentrations such as 2.4 × 10^{10}, 2.4× 10^{8}, 2.4 × 10^{6} and 2.4 × 10^{4} Spores/ml as a surfactant was tested. The results revealed that the EPF was found very safe to the beneficial insects and causing no adverse effect of parasitisation of the parasitoids *T. chilonis* for the two generations tested (Plate 19-iii to v).

Evaluation of native pathogenic bacteria *Myroides odoratus*:

The efficacy of native pathogenic bacteria *M. odoratus* was evaluated against the targeted major pest *P. syntaractis* in lab condition. Three different concentrations i.e 2.6 × 10^{8}

CFU/ml,2.6 × 10^6 CFU/ml and 2.6 × 10^4CFU/ml were evaluated against the III instar larvae. After 24 hrs of treatment the larvae fed on leaves treated with bacterial suspensions were observed to be pale. Subsequently, larval feeding was arrested and change of coloration and spread to the entire body surface, by which time the larvae were dead. Though feeding in the treated larvae was not affected in the first 24 hrs, it was drastically reduced at 48 hrs with significant loss in body weight and larval mortality observed in all the cases as compared to control. Rate of larval mortality of the pest with the pathogenic bacteria, the larvae of *P. syntaractis* showed 100 percent mortality in the 48 hrs in the 2.6 × 10^8 CFU/ml, whereas the concentration 2.6 × 10^6 CFU/ml showed 70 % larval mortality. (Table-10) (PLATE-18 -i).

Table. 10 Effect of native pathogenic bacteria *Myroides odoratus* strain on the IIIrd instar larvae *P. syntaractis* in lab condition.

Conc. Tested	Larval mortality (%) of IIIrd instar	
	24 hrs	48hrs
2.6 × 10^4CFU/ml	0	42±3.74
2.6 × 10^6 CFU/ml	0	70
2.6 × 10^8 CFU/ml	0	100
Control	0	0

n=10 Values are means ±SE of 5 replications .

Evaluation of native Baculovirus (The nuclear polyhedrosis virus -HpNPV) against *Hyblaea puera* in lab condition:

The native nuclear ploy hedrosis virus isolated from the naturally infected larvae of *H.puera* (HpNPV) was cultured and purified and evaluated on the fresh larvae of the *H. puera* at the concentrations 4.05 × 10^5,4.05 × 10^6, 4.05 × 10^7 and 4.05 x 10^8 PIB/ml in lab condition. Five replicates with 10 larvae each were maintained for each experiment. Another set of 10 larvae were fed with artificial diet, treated with teepol mixed sterile distilled water and served as the control.

Daily observation of mortality was recorded up to five days so that the maximum percent of mortality arrived in the higher concentration tested. The result of the experiment conducted on the III instar larvae revealed that the concentrations 4.05 × 10^8 PIB/ml and 4.05 × 10^7 tested was pathogenic to the larvae and resulting 100 percent mortality after a period of

five days, where as the concentrations 4.05 × 10^6 and 4.05 × 10^5 PIB/ml exhibited only 70 and 30 mean percent mortality respectively (Table 11 &11.1 Chart 13)(PLATE-18 -ii).

Table.11 Evaluation of Baculovirus against *Hyblaea puera* (III instar) in Laboratory condition

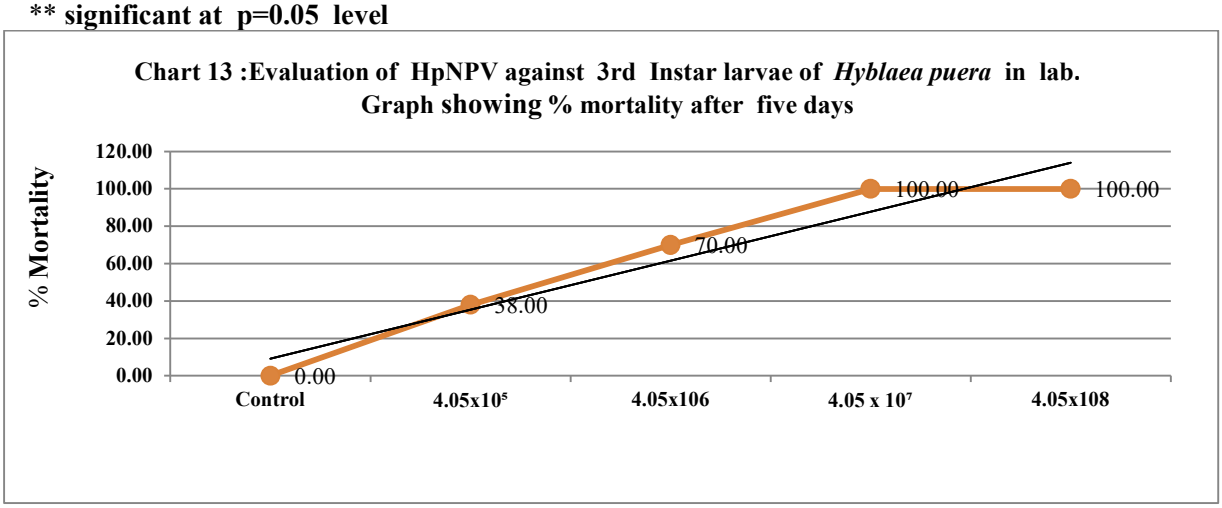
Treatment	Treatment /conc. In PIB/ml	Evaluation of Baculovirus - *Hyblaea puera* Mortality % of (III instar)						
		R1	R2	R3	R4	R5	Treatment Total	Mean
1	T1 4.05 x 10^8	100.00	100.00	100.00	100.00	100.00	500	100.00
2	T2 4.05 x 10^7	100.00	100.00	100.00	100.00	100.00	500	100.00
3	T3 4.05 x 10^6	70.00	70.00	80.00	60.00	70.00	350	70.00
4	T4 4.05 x 10^5	40.00	30.00	30.00	40.00	50.00	190	38.00
5	T5 Control	0.00	0.00	0.00	0.00	0.00	0	0.00
Rep total (R)		310.00	300.00	310.00	300.00	320.00		
Grand total							1540	
Grand mean								61.60

Table. 11.1 Analysis of variance

Source of variation	Degree of freedom	Sum of squares	F calculated	Tabular *F*	
				5%	Significance
Replication	4	56	0.53	3.01	NS
Treatment	4	36856	347.70	3.01	Sig**
Error	16	424			
Total	24	37336			

Coefficient of variation **CV** 8.36 **SED** 2.06 **CD** 3.6

**** significant at p=0.05 level**



Evaluation of the biopesticide Hy-ACT on *H.puera*:

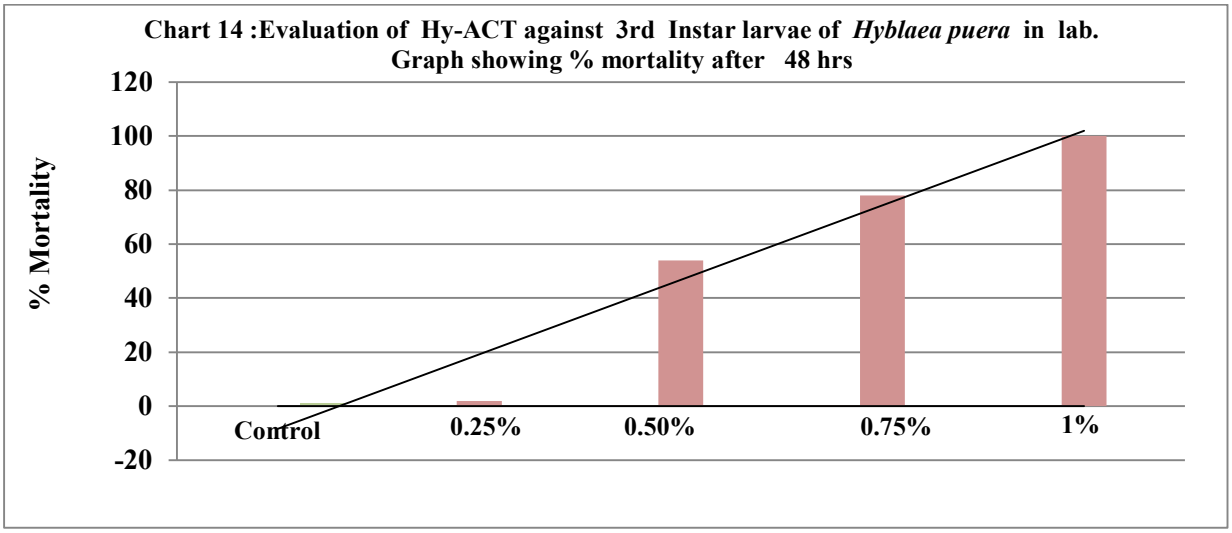
The botanical bio pesticide Hy-ACT (IFGTB (Institute of Forest Genetics and Tree Breeding, Coimbatore) product derived from the seeds of *Hydnocarpus pentandra*) was evaluated for its efficacy and effectiveness against the third instar larvae of the defoliator *H.puera*. Four concentrations of 0.25%, 0.50%, 0.75% and 1% were used. Five replications were maintained in each treatment (T1 – T4) with 20 larvae. Control was maintained separately (T5). Observations on the mortality of larvae was taken after every 24 hours interval. The mortality was observed for 2 days ie. 48 hrs. The biopesticide Hy-Act at the concentration of 1% showed highest level of larval mortality of 100 % on *H.puera* in lab condition. Where as the concentration 0.75% showed 78% larval mortality (Table 12&12.1 Chart 14) (PLATE-18-iii & iv).

Table.12 Evaluation of biopesticide Hy-ACT against defoliator *Hyblaea puera* (third instar) in laboratory conditions.

Treatment	Conc. Tested	Evaluation of Hy-ACT - Mortality % of *H.puera* (third instar)						
		R1	R2	R3	R4	R5	Treatment Total	Mean
T1	1%	100.00	100.00	100.00	100.00	100.00	500	100.00
T2	0.75%	78.00	79.00	78.00	78.00	77.00	390	78.00
T3	0.50%	55.00	50.00	58.00	54.00	53.00	270	54.00
T4	0.25%	2.00	3.00	3.00	1.00	1.00	10	2.00
T5	Control	0.00	0.00	0.00	0.00	0.00	0	0.00
Rep total (R)		235.00	232.00	239.00	233.00	231.00		
Grand total							1170	
Grand mean								46.80

Table.12.1 Test of significance of difference among the treatments of biopesticide Hy-ACT against defoliator *Hyblaea puera* (third instar) in laboratory condition through Analysis of variance.

Source of variation	Degree of freedom	Sum of squares	Mean squares	F calculated	Tabular *F*	
					5%	Significance
Replication	4	8	2	1.00	3.01	NS
Treatment	4	40264	10066	5033.00	3.01	Sig**
Error	16	32	2			
Total	24	40304				
CV: 3.02; SED :0.57; CD: 1.0; ** significant at *P* = 0.05						



Evaluation of the biopesticide Hy-ACT on *P. syntaractis* and *Hypocala* sp.:

The botanical bio pesticide Hy-ACT was evaluated for its efficacy and effectiveness against the third instar larvae of the defoliators *P.syntaractis* and *Hypocala* sp. Four concentrations of 0.25%, 0.50%, 0.75% and 1% were used. Five replications were maintained in each treatment (T1 – T4) with 10 larvae. Control was maintained separately (T5). Observations on the mortality of larvae was taken after every 24 hours interval. The mortality was observed for 2 days ie. 48 hrs. The biopesticide Hy-Act at the concentration of 1% showed highest level of larval mortality of 100 % on *P.syntaractis* and *Hypocala* sp. in lab condition. Where as the concentration 0.75% showed 82% and 86 % larval mortality respectively (Table 13) (PLATE-18-v).

Table:13 Effect of different concentrations of Hy-ACT against the mortality percentage of *P. syntaractis* and *Hypocala* sp. in laboratory condition.

Test insect	Conc. 0.25%	Conc. 0.50%	Conc. 0.75%	Conc. 1%
P. syntaractis	10±3.17 [a]	54±2.45 [b]	82±2.00[a]	100[a]
Hypocala sp.	10±3.17 [a]	60±3.17 [a]	86±2.45 [a]	100[a]
Control	0.0 [b]	0.0 [c]	0.0 [b]	0.0 [b]

Values are means ±SE of 5 replications. In each column, means followed by same letter under each treatment are not significantly different at 5% level of significance.

Testing the safety of Hy-ACT biopesticide against beneficial insects:

The biopesticde Hy-ACT was tested for their safety to egg parasitoids *T. chilonis*. Biopesticide suspenstion of different concentrations such as 0.25%, 0.50%, 0.75% and 1% as a surfactant was tested. The results revealed that Hy-ACT was found very safe to the beneficial insects and causing no adverse effect of parasitisation of the parasitoids *T. chilonis* for the two generations tested (Plate 19-iii,iv & vi).

Evaluation of the biopesticide Neem oil:

The biopesticide Neem oil was evaluated for its efficacy and effectiveness against the defoliators. Four concentrations of 2%,3%,4% and 5% were evaluated on the defoliating insect pests *P. syntaractis, Hypocala* sp., and *H. puera*. Five replications were maintained in each treatment (T1 – T4). Control was maintained separately (T5) with 10 larvae. Observations on the mortality of the defoliator were taken after every 24 hours interval. The mortality was observed for 2 days ie. 48 hrs. The biopesticide Neem oil at the concentration of 5% showed highest level of larval mortality of 70 % on *H.puera*, whereas it showed 54% and 52% on *P.syntaractis* and *Hypocala* sp. respectively in lab condition. (Table 14).

Table: 14 Effect of different concentrations of Neem oil against the mortality percentage of *H. puera*, *P. syntaractis* and *Hypocala* sp. in laboratory condition.

Test insect	Conc. 2%	Conc. 3%	Conc. 4%	Conc. 5%
H. puera	8±2.00 [a]	16±2.45 [a]	48±2.00 [a]	70±3.17 [a]
P. syntaractis	10±3.17[a]	18±2.00 [a]	38±2.00[b]	54±2.45[b]
Hypocala sp.	10±3.17 [a]	20±3.17 [a]	28±2.45 [c]	52±2.00 [b]
Control	0.0 [b]	0.0 [b]	0.0 [d]	0.0 [c]

Values are means ±SE of 5 replications. In each column, means followed by same letter under each treatment are not significantly different at 5% level of significance.

Evaluation of the biopesticide Nimbicidine (Azadirachtin 0.03%):

The commercial biopesticide Nimbicidine (Azadirachtin 0.03%) was evaluated for its efficacy and effectiveness against the defoliators. Four concentrations of 0.25%, 0.50%,0.75% and 1% were evaluated on the defoliating insect pests *P. syntaractis, Hypocala* sp., and *H.*

puera. Five replications were maintained in each treatment (T1 – T4). Control was maintained separately (T5) with 10 larvae. Observations on the mortality of the defoliator were taken after every 24 hours interval. The mortality was observed for 2 days ie. 48 hrs. The biopesticide *Azadiractin* (0.03%) at the concentration of 1% showed highest level of larval mortality of 82 % on *H.puera*, whereas it showed 78% and 76% on *P.syntaractis* and *Hypocala* sp. respectively in lab condition. (Table 15) (PLATE-19-I & ii).

Table:15 Effect of different concentrations of Nimbicidine (Azadirachtin 0.03%)against the mortality percentage of *H. puera*, *P. syntaractis* and *Hypocala* sp. in laboratory condition.

Test insect	Conc. 0.25%	Conc. 0.50%	Conc. 0.75%	Conc. 1%
H. puera	8±2.00 [a]	42±2.00 [a]	58±2.00 [a]	82±2.00 [a]
P. syntaractis	10[a]	32±2.00 [b]	54±2.45[a]	78±2.00[b]
Hypocala sp.	8±2.00 [a]	42±2.00 [a]	56±2.45 [a]	76±2.45 [b]
Control	0.0 [b]	0.0 [c]	0.0 [b]	0.0 [c]

Values are means ±SE of 5 replications. In each column, means followed by same letter under each treatment are not significantly different at 5% level of significance.

5.6.2 FIELD STUDIES:

Evaluation of entomopathogenic fungi:

The efficacy of the entomopathogenic fungi *Nomuraea rileyi* (Natural strain), *Metarizium anisopilae* (strain of NBAIR) and commercial product of *M. anisophilie* were evaluated against the targeted pests *P.syntaractis* and *Hypocala* sp., with different concentration of fungal solutions viz. 2.4×10^{10}, 2.4×10^{8}, 2.4×10^{6} and 2.4×10^{4} Spores/ml. in field condition. The larvae sprayed with fungal inoculum were released on to the leaves of mangrove plants. Five treatments (T1 – T5) were maintained to test the targeted pests. T5 was treated as control. Each treatment was replicated 5 times in completely randomized design with 8 larvae in each replicate. The fungal pathogens sprayed leaf bunches were tagged properly. Observations were taken at every 24 hours interval. The mortality was observed up to 5 days after spraying. The experiments were carried out in the field at Airoli. The native strain of *N. rileyi* showed highest level of mortality of 60 % and 75% in the concentration of 2.4×10^{8} and

2.4 × 10^{10} spores.ml respectively on *P.syntaractis*. Where as the strain of *M. anisopliae* of NBAIR was also performed well in controlling the pest of *P.syntaractis* and caused 65% larval mortality in field condition (Table 16, Chart 15) . The native strain of *N. rileyi* showed highest level of mortality of 92.5 % and 100% in the concentration of 2.4× 10^{8} and 2.4 × 10^{10} spores.ml respectively on *Hypocala* sp. Where as the strain of *M. anisopliae*-Ma4 of NBAIR was also performed well in controlling the pest of *Hypocala* sp. and caused 77.5% larval mortality in field condition (Table 17, Chart 16) (PLATE-20 &21 i to iii).

Table:16 Effect of different concentrations of Entomopathogens against the mortality percentage of *Ptyomaxia syntaractis* in field condition.

Entomopathogens	2.4 x 10^{10} Spores/ ml	2.4 x 10^{8} Spores/ ml	2.4 x 10^{6} Spores/ ml	2.4 x 10^{4} Spores/ ml
Nomuraea rileyi	75±3.94 [a]	60±2.50 [a]	37.6±3.88 [a]	5±3.06 [a]
M. anisopliae (NBAIR)	65±2.50 [b]	52.5±2.50 [b]	32.5±3.06 [a]	0.0 [b]
M. anisopliae (com)	42.5±3.06 [c]	27.5±2.50 [c]	15±2.50 [b]	0.0[b]
Control	0.0 [d]	0.0 [d]	0.0 [c]	0.0 [b]

Values are means ±SE of 5 replications. In each column, means followed by same letter under each treatment are not significantly different at 5% level of significance.

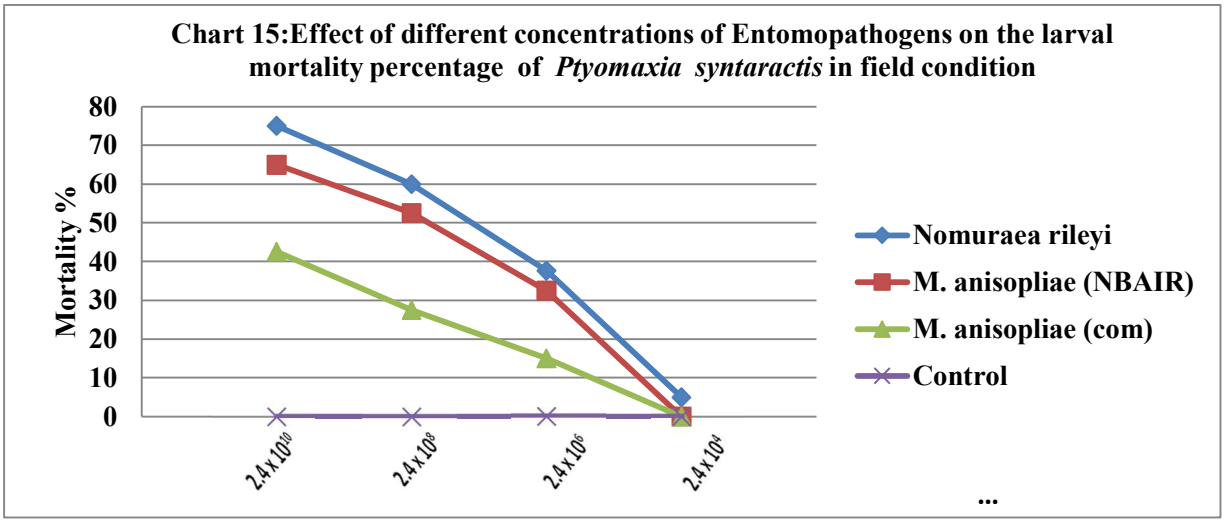
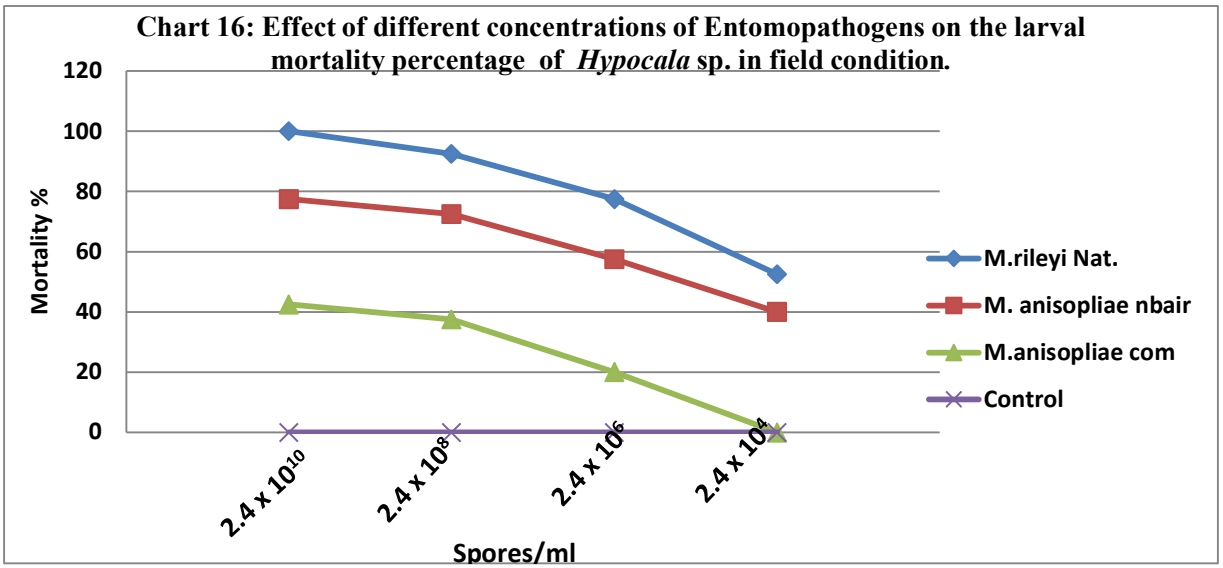


Table:17 Effect of different concentrations of Entomopathogens against the mortality percentage of *Hypocala* sp., in Field condition.

Entomopathogens	2.4 x 10^{10} Spores/ ml	2.4 x 10^{8} Spores/ ml	2.4 x 10^{6} Spores/ ml	2.4 x 10^{4} Spores/ ml
Nomuraea rileyi	100 [a]	92.5±3.06 [a]	77.5±2.50 [a]	52.5 ±2.50 [a]
M. anisopliae (NBAIR)	77.5±2.50 [b]	72.5±2.50 [b]	57.5±3.06 [b]	40±2.50 [b]
M. anisopliae (com)	42.5±3.06[c]	37.5±3.95 [c]	20±3.06 [c]	0.0[c]
Control	0.0 [d]	0.0 [d]	0.0 [d]	0.0 [c]

Values are means ±SE of 5 replications. In each column, means followed by same letter under each treatment are not significantly different at 5% level of significance.



Evaluation of native pathogenic bacteria *Myroides odoratus*:

The efficacy of native pathogenic bacteria *Myroides odoratus* was evaluated against the targeted pest *Ptyomaxia syntaractis* in field condition. Three different concentrations i.e 2.6 × 10^8 CFU/ml,2.6 × 10^6 CFU/ml and 2.6 × 10^4CFU/ml were evaluated against the III instar larvae. Five replications maintained with 10 larvae in each replication. Control was maintained separately. Mortality percent were recorded after every 24 hours interval. Rate of larval mortality of the pest with the pathogenic bacteria, the larvae of *P. syntaractis* showed 100 percent mortality in the 48 hrs in the 2.6 × 10^8 CFU/ml, whereas the concentration 2.6 × 10^6 CFU/ml showed 58% larval mortality. (Table-18) (PLATE-21 iv).

Table.18 Effect of native pathogenic bacteria *Myroides odoratus* strain on the IIIrd instar larvae *P. syntaractis* in field condition

Conc. Tested	Larval mortality (%) of IIIrd instar	
	24 hrs	48hrs
2.6×10^4CFU/ml	0	22±2.00
2.6×10^6 CFU/ml	0	58±2.00
2.6×10^8 CFU/ml	0	100
Control	0	0

n=10 Values represent means ±SE of 5 replicates

Evaluation of native Baculovirus (The nuclear polyhedrosis virus (HpNPV) against *Hyblaea puera* in field condition.

The native nuclear ployhedrosis virus isolated from the naturally infected larvae of *H.puera* (HpNPV) was evaluated on the larvae of the *H. puera* at the concentrations 4.05×10^5,4.05×10^6, 4.05×10^7 and 4.05×10^8 PIB/ml in field condition. Five replicates with 10 larvae each were maintained for each experiment. Control was maintained separately. Observations on larval mortality was recorded at 24 hrs intervals for five days so that the maximum percent of mortality arrived in the higher concentration tested. The result of the experiment conducted on the III instar larvae revealed that the concentrations 4.05×10^8 PIB/ml and 4.05×10^7 tested was pathogenic to the larvae and resulting 100 percent mortality after a period of five days, where as the concentrations 4.05×10^6 and 4.05×10^5 PIB/ml exhibited only 52 and 28 mean percent mortality respectively (Table 19 &19, Chart 17) (PLATE -21 v & vi) .

Table. 19 Evaluation of Baculovirus against *Hyblaea puera* (III instar) in field condition

Treatment	**Treatment /conc. In PIB/ml**	**Evaluation of Baculovirus - *Hyblaea puera* Mortality % of (III instar)**						
		R1	**R2**	**R3**	**R4**	**R5**	**Treatment Total**	Mean
1	T1 4.05×10^8	100.00	100.00	100.00	100.00	100.00	500	100.00
2	T2 4.05×10^7	100.00	100.00	100.00	100.00	100.00	500	100.00
3	T3 4.05×10^6	60.00	50.00	50.00	50.00	50.00	260	52.00
4	T4 4.05×10^5	30.00	30.00	30.00	20.00	30.00	140	28.00

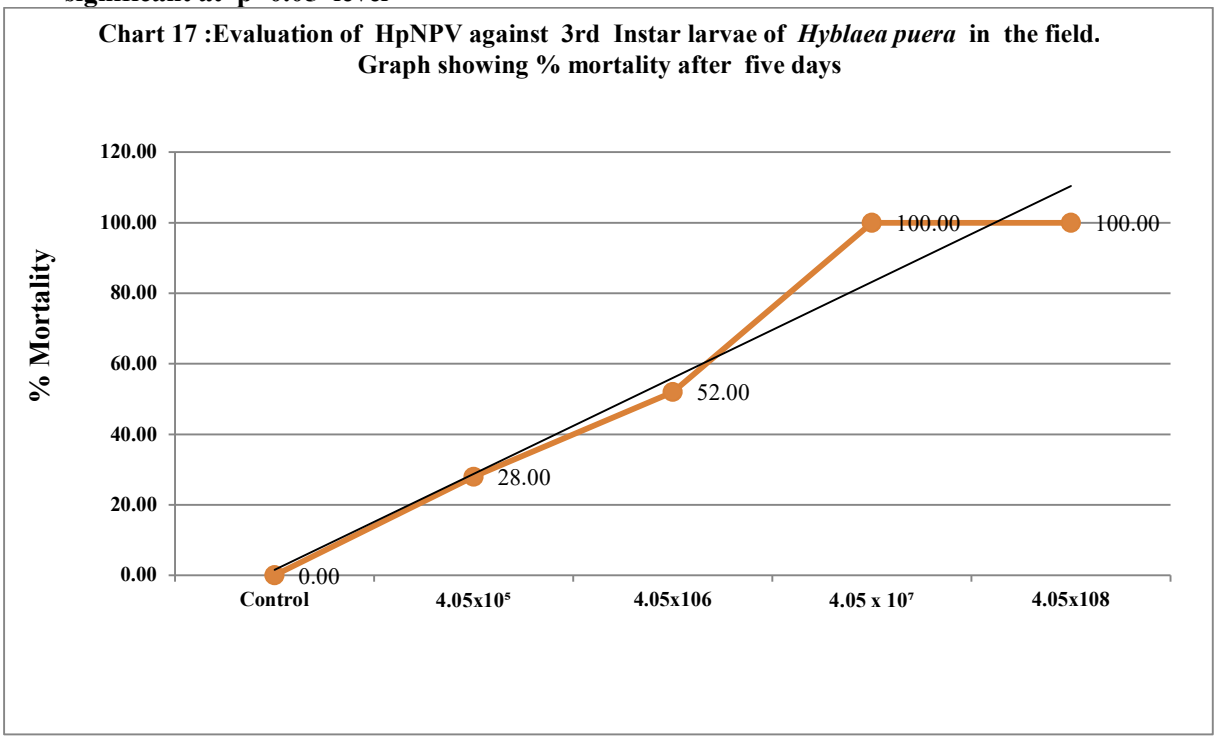
5	T5 Control	0.00	0.00	0.00	0.00	0.00	0	0.00
Rep total (R)		290.00	280.00	280.00	270.00	280.00		
Grand total							1400	
Grand mean								56.00

Table. 19.1 Analysis of variance

Source of variation	Degree of freedom	Sum of squares	F calculated	Tabular *F*	
				5%	Significance
Replication	4	40	1.33	3.01	NS
Treatment	4	39040	1301.33	3.01	Sig**
Error	16	120			
Total	24	39200			

Coefficient of variation **CV** 4.89 **SED** 1.10 **CD** 1.9

** **significant at p=0.05 level**



Evaluation of the biopesticide Hy-ACT on *H.puera*:

The botanical bio pesticide Hy-ACT was evaluated for its efficacy and effectiveness against the larvae of the defoliator *H.puera* (III instar) in field condition. Four concentrations of 0.25%, 0.50%, 0.75% and 1% were used. Five replications were maintained in each treatment (T1 – T4) with 20 larvae each. Observations on the mortality of larvae was taken after every 24 hours interval. The mortality was observed for 2 days ie. 48 hrs. The biopesticide Hy-Act at the concentration of 1% showed highest level of larval mortality of 95 % on *H.puera* in field

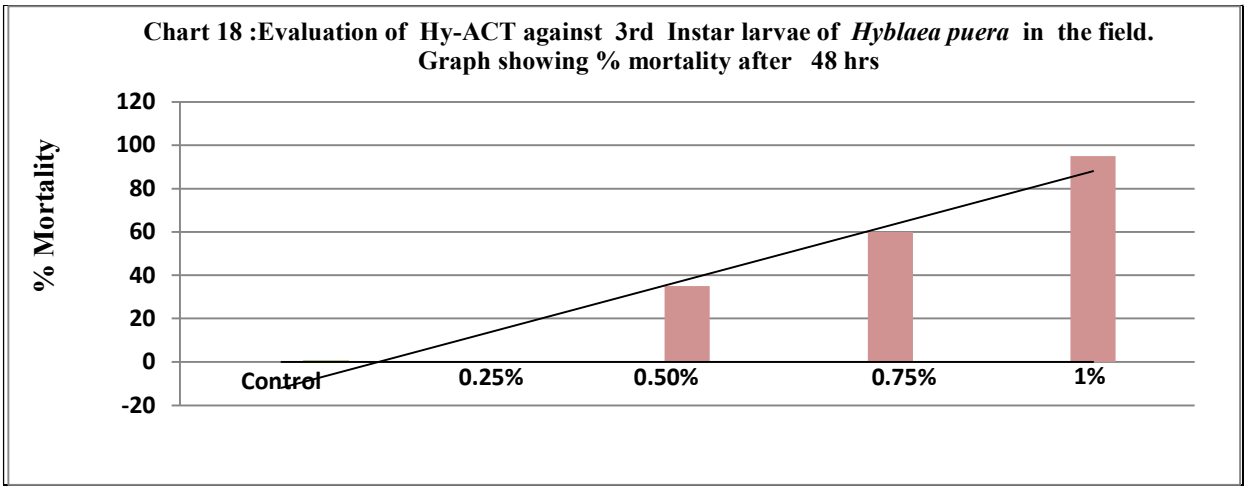
condition. Where as the concentration 0.75% showed 60% larval mortality (Table 20&20.1, Chart 18) (PLATE-22 i &ii).

Table.20 Evaluation of biopesticide Hy-ACT against defoliator *Hyblaea puera* (third instar) in field conditions.

Treatment	Conc. Tested	Evaluation of Hy-ACT - Mortality % of *H.puera* (third instar)						
		R1	R2	R3	R4	R5	Treatment Total	Mean
T1	1%	94.00	96.00	96.00	94.00	95.00	475	95.00
T2	0.75%	62.00	61.00	60.00	59.00	58.00	300	60.00
T3	0.50%	34.00	35.00	37.00	35.00	34.00	175	35.00
T4	0.25%	0.00	0.00	0.00	0.00	0.00	0	0.00
T5	Control	0.00	0.00	0.00	0.00	0.00	0	0.00
Rep total (R)		190.00	192.00	193.00	188.00	187.00		
Grand total							950	
Grand mean								38.00

Table.20.1 Test of significance of difference among the treatments of biopesticide Hy-ACT against defoliator *Hyblaea puera* (third instar) in field condition through Analysis of variance.

Source of variation	Degree of freedom	Sum of squares	Mean squares	F calculated	Tabular *F*	
					5%	Significance
Replication	4	5	1	1.41	3.01	NS
Treatment	4	33150	8288	8959.46	3.01	Sig**
Error	16	15	1			
Total	24	33170				
CV: 2.53; SED :0.38; CD: 0.7; ** significant at *P* = 0.05						



Evaluation of the biopesticide Hy-ACT on *P. syntaractis* and *Hypocala* sp.:

The botanical bio pesticide Hy-ACT was evaluated for its efficacy and effectiveness against the third instar larvae of the defoliators *P.syntaractis* and *Hypocala* sp. Four concentrations of 0.25%, 0.50%, 0.75% and 1% were used. Five replications were maintained in each treatment (T1 – T4) with 10 larvae. Control was maintained separately (T5). Observations on the mortality of larvae was taken after every 24 hours interval. The mortality was observed for 2 days ie. 48 hrs. The biopesticide Hy-Act at the concentration of 1% showed highest level of larval mortality of 96% on *P.syntaractis* and 90 % on *Hypocala* sp. in field condition. Where as the concentration 0.75% showed 64% and 68 % larval mortality respectively (Table 21) (PLATE-22 iii)..

Table. 21 Effect of different concentrations of Hy-ACT against the mortality percentage of *P. syntaractis* and *Hypocala* sp. in field condition.

Test insect	Mortality at different concentrations			
	0.25%	**0.50%**	**0.75%**	**1%**
P. syntaractis	8±2.00 [a]	32±2.00 [a]	64±2.45[a]	96±4.00[a]
Hypocala sp.	6±2.45 [a]	36±2.45 [a]	68±2.00 [a]	90±3.17[a]
Control	0.0 [b]	0.0 [b]	0.0 [b]	0.0 [b]

Values are means ±SE of 5 replications. In each column, means followed by same letter under each treatment are not significantly different at 5% level of significance.

Evaluation of the biopesticide Neem oil:

The biopesticide Neem oil was evaluated for its efficacy and effectiveness against the defoliators *Ptyomaxia syntaractis, Hypocala* sp., and *H. puera*. Four concentrations of 2%,3%,4% and 5% were evaluated on the defoliating insect pest. Five replications were maintained in each treatment (T1 – T4)with 10 larvae. Control was maintained separately (T5). Observations on the mortality of the defoliator were taken after every 24 hours interval. The mortality was observed for 2 days ie. 48 hrs. The biopesticide Neem oil at the concentration of 5% showed highest level of larval mortality of 50 % on *H.puera*, whereas it showed 36% and 34% on *P.syntaractis* and *Hypocala* sp. respectively in field condition (Table 22).

Table. 22 Effect of different concentrations of Neem oil against the mortality percentage of *H. puera*, *P. syntaractis* and *Hypocala* sp. in field condition.

Test insect	Conc. 2%	Conc. 3%	Conc. 4%	Conc. 5%
H. puera	4±2.45 [a]	12±2.00 [a]	38±2.00 [a]	50±3.17 [a]
P. syntaractis	4±2.45[a]	12±2.00 [a]	28±2.00[b]	36±4.00[b]
Hypocala sp.	4±2.45[a]	12±2.00 [a]	22±2.00 [b]	34±2.45 [b]
Control	0.0 [b]	0.0 [c]	0.0 [c]	0.0 [c]

Values are means ±SE of 5 replications. In each column, means followed by same letter under each treatment are not significantly different at 5% level of significance.

Evaluation of the biopesticide Nimbicidine (Azadirachtin 0.03%):

The commercial biopesticide Nimbicidine (Azadirachtin 0.03%) was evaluated for its efficacy and effectiveness against the defoliators in field condition. Four concentrations of 0.25%, 0.50%,0.75% and 1% were evaluated on the defoliating insect pests *Ptyomaxia syntaractis, Hypocala* sp., and *H. puera*. Five replications were maintained in each treatment (T1 – T4). Control was maintained separately (T5) with 10 larvae. Observations on the mortality of the defoliator were taken after every 24 hours interval. The mortality was observed for 2 days ie. 48 hrs. The biopesticide *Azadiractin* (0.03%) at the concentration of 1% showed highest level of larval mortality of 68 % on *H.puera*, whereas it showed 58% on *P.syntaractis* and *Hypocala* sp. in field condition. (Table 23) (PLATE 23 i & ii).

Table. 23 Effect of different concentrations of Nimbicidine (Azadirachtin 0.03%)against the mortality percentage of *H. puera*, *P. syntaractis* and *Hypocala* sp. in field condition.

Test insect	Conc. 0.25%	Conc. 0.50%	Conc. 0.75%	Conc. 1%
H. puera	6±2.45 [a]	26±2.45 [a]	46±2.45 [a]	68±2.00 [a]
P. syntaractis	8±2.00 [a]	16±2.45 [b]	36±2.45[b]	58±2.00[b]
Hypocala sp.	8±2.00 [a]	18±2.00 [b]	38±2.00 [b]	58±2.00 [b]
Control	0.0 [b]	0.0 [c]	0.0 [c]	0.0 [c]

Values are means ±SE of 5 replications. In each column, means followed by same letter under each treatment are not significantly different at 5% level of significance.

PLATE – 17
LAB EXPERIMENTS


Effect of EPF *N. rileyi* against *P. syntaractis*

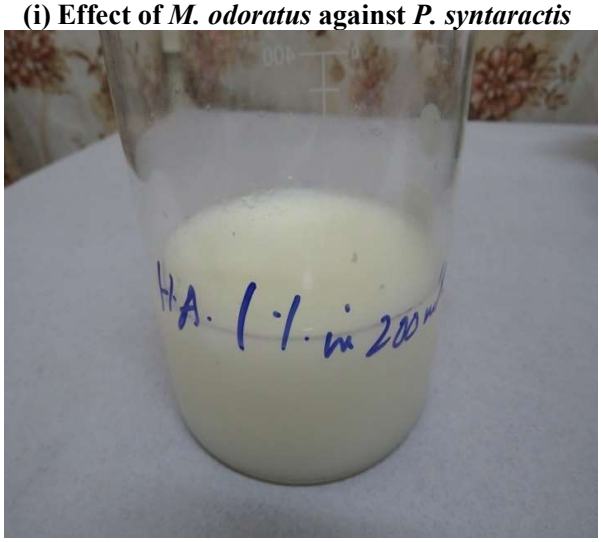

Effect of *M. anisophilie*-Ma4 (NBAIR strain) against *P. syntaractis*


Effect of EPF *N. rileyi* against *Hypocala* sp.

PLATE – 18
LAB EXPERIMENTS

(i) Effect of *M. odoratus* against *P. syntaractis*

(ii) HpNPV infected *H.puera* larvae



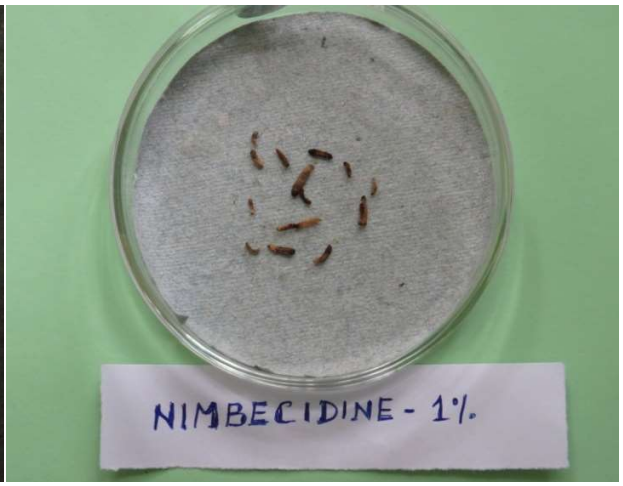
(iii) Bio-pesticide Hy-ACT experiment against *H. puera*

(iv) Effect of Hy-Act against *H. puera*

(v) Effect of Hy-Act against *Hypocala* sp.

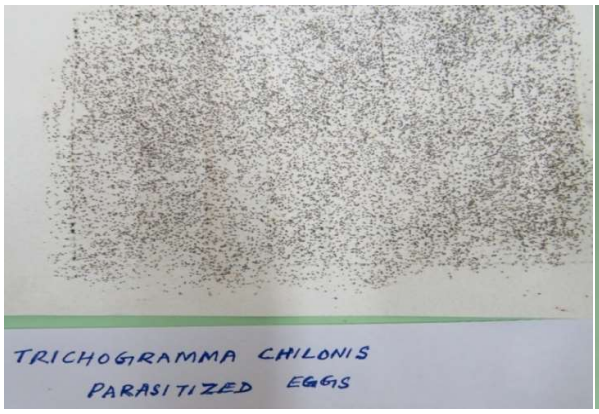
PLATE – 19
LAB EXPERIMENTS

(i) Effect of Azadirachtin 0.03% against *P. syntaractis*



(ii) Effect of Azadirachtin 0.03% against *Hypocala* sp.

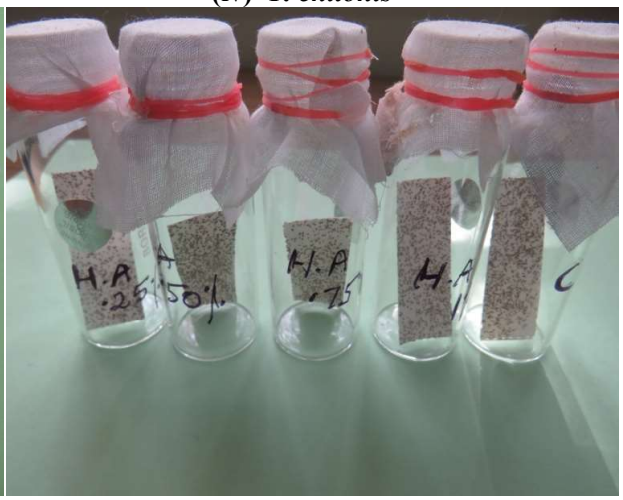
SAFETY TESTS OF EPF *N. RILEYI* AND HY-ACT BIOPESTICIDE AGAINST *T.CHILONIS*



(iii) *T. chilonis* egg card

(iv) *T. chilonis*

(v) EPF *N. rileyi* tested on *T. chilonis*



(vi) Hy-ACT tested against *T. chilonis*

PLATE – 20
FIELD EXPERIMENTS

***N. rileyi* strain in Agar media**

***M. anisophilie*-Ma4 strain in Agar media**

Evaluation of EPFs on *Hypocala* sp. in the field

Field application of EPF

PLATE – 21
FIELD EXPERIMENTS

(i) EPF *N. rileyi* infected *P. syntaractis*

(ii) EPF *M. anisophilie* infected *Hypocala* sp.

(iii) EPF *N. rileyi* infected *Hypocala* sp.

(iv) *M. odoratus* infected *P. syntaractis*

(v) *H. purea* attack on *Avicennia marina* in the field

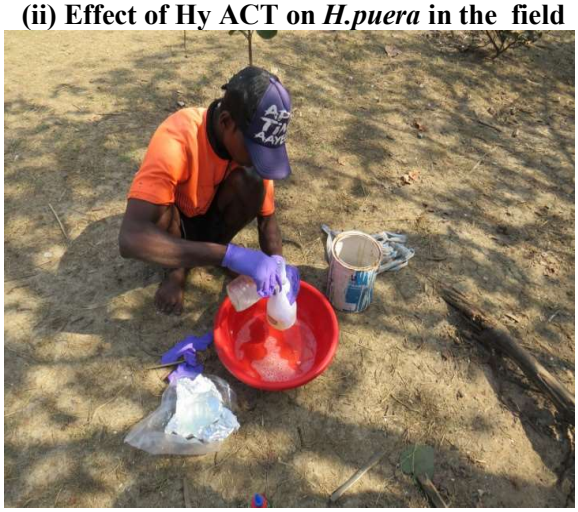
(vi) HpNPV infected *H.puera* larva in the field

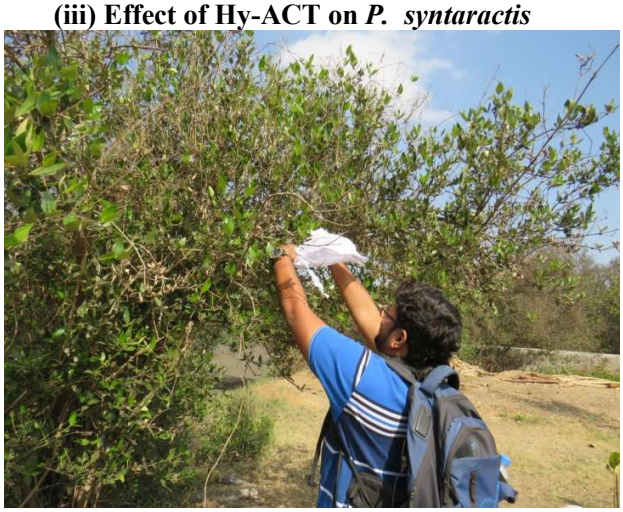
PLATE – 22
FIELD EXPERIMENTS

(i) Pilot scale application of Hy-ACT against *H. purea* in the field at Gorai

(ii) Effect of Hy ACT on *H.puera* in the field

(iii) Effect of Hy-ACT on *P. syntaractis*





(iv) Field experiments conducted at Airoli

PLATE – 23
FIELD EXPERIMENTS

(i) Effect of Azadirachtin 0.03% against *P.syntaractis*

(ii) Effect of Azadirachtin 0.03% against *H.puera*

(iii) Teak trees heavily infested with *H. purea* at Sanjay Gandhi National park

6. DISCUSSION:

Mangroves are often affected by insect pests and nurseries, plantations and natural mangroves are threatened by them. Insects can result in substantial damage and in severe situations can also lead to affect the planting programmes. Swetha *et al*. (2019) check listed the entomofauna of mangroves in India for the period of 10 years from 2009 to 2019, indicated about 516 insects species belongs to 111 families. Raji (2003) reported 340 species of insects belonging to 11 orders in the west coast of South India, out of this 340 species, 201 was authentically identified and listed. This was the first comprehensive list of mangrove insects found along the west coast of South India. During the present study 20 pests including 2 snails were recorded on the selected mangrove species in the District of Thane in Maharashtra State. Among the recorded pests, 6 insects pests of defoliators including 2 snails and 1 grasshopper were categorized as major pests and 14 other insect pests were categorized as minor pests. One of the important defoliating pest of mangroves, the polyphagous insect *H. transcissa* which affects the mangrove species are distributed in several parts of India (Dharmasala, Sikkim, Assam and Nilgris), Bhutan, Sri Lanka, Burma and Java (Hampson, 1895). It occurs in the Indian subregion, from Sri Lanka to Sundaland (Holloway, 1993b). *H .transcissa* is a semilooper and found in Malaysia and Hong Kong (Robinson, 2010). Its prefers many other host plants like *Aleurites Montana* Lour., *Castanopsis fissa* (Champ. ex. Benth.) Rehd. & Wils., *Cinnamomum zylanicum* Blume, *Hevea* sp., *Nephelium lappaceum* L., *Theobroma cacao* L., and *Vernicia fordii* (Hemsl.) (Robinson *et al.,* 2010). *H. transcissa* occurs during the period from August to December in Himachal Pradesh, Maharashtra, Assam, Tripura (Anonymous, 2018d), and Uttarakhand (Sondhi and Sondhi, 2016). *Streblote helpsi*, this moth species was endemic to Borneo infesting *Sonneratia caseolaris* (Joseph Tangah and Arthur Chung, 2017). This was recorded on *Casuarina equisetifolia* as host plant (Holloway, 1998). Chung (2011) recorded this caterpillar on African Mahogany, *Khaya senegalensis* in Sandakan, Sabah. *H. puera* is a polyphagous pest infesting on many tree species including the mangroves species *A. marina* and *A. officinalis*. Teak was considered as the principal host for *H. puera*. (Katagall, 2000). The biology of this pest was studied on different host plants but no information on the mangroves were available (Baksha and Crawley, 1995 ; Loganathan and David, 1998). Arun and Maya (2012) reported the major outbreaks of this pest during the post monsoon period during the year

2006 and 2009 on *A. marina* in Vikhroli mangroves area of Mumbai. They also viwed that these type of outbreaks may promotes mangrove diversity, contribution to the nutrient cycling, enhance fishery resources and provide food sources for birds. *H. puera* is widely distributed in Australian and Oriental regions like India, Sri Lanka and Malaysia and also present in South Africa and many parts of East Africa (Browne, 1968). In the present study revealed the high incidence of the defoliators *H. puera* during July to November. Another important major pest *Hypocala* sp. was recorded on *A. marina* and *A. officinalis* during July to September with high intensity. Where as *P. syntaractis* from August to November and the two snails *M. ceylonicus* and *M. pulchellus* during June to August of the year 2018 and 2019.

The Temperature and Rain fall recorded during the year 2018 was correlated with population level of infestation, intensity of defoliating insect pests *H.purea, H. transcissa*, *Hypocala* sp., *P. syntaractis, T. vishnou* and the snails *M. ceylonicus* and *M. pulchellus.* The statistical analysis was worked out using Microsoft office Excel 2007 to find out the correlations between the pests vs Rainfall and Temperature. In case of *H. purea*, average mean temperature exhibited significant negative correlation, and the average rainfall exhibited significant positive correlation with the intensity of pest in the year 2019. While in the year 2018, average temperature exhibited non-significant negative correlation, and the average rainfall exhibited significant positive correlation. Whenever the average rainfall level increases the population of the pest *H.puera* increases. It means, high rainfall favour the pest out break in epidemic level. That is why the intensity level of attack was more during 2019 when comparing to the year 2018. In case of *H. transcissa* and *Hypocala* sp. the average temperature exhibited significant negative correlation and average rainfall exhibited significant positive correlation with the intensity of pest in the year 2018. Whereas in case of *P. syntaractis*, both average temperature and average rainfall exhibited significant positive correlation with the intensity of pest in the year 2018. In case of *T. vishnou*, the average temperature exhibited significant negative correlation but the average rainfall exhibited non-significant positive correlation with the intensity of pest in the year 2018. Where as for *Melampus*, the average temperature exhibited significant and negative correlation, but the average rainfall exhibited non-significant positive correlation with the intensity of pest in the year 2018. Overall it indicates that the pest buildup of defoliators are in

increasing trend during the raining period and the population decreases during the summer period.

As an addition, in the present study revealed the fact that when the food resources were exhausted in the teak plantations situated in and around the mangrove areas particularly the areas of Sanjay Gandhi National Park during early in the month of June and July (PLATE 23-iii), the pest *H.puera* might be migrating in to the mangrove plants particularly on *A.marina* to sustain its generations and move back when teak gets new leaves. Thus this insect is probably using mangrove habitat as a carryover habitat.

As far as the control of pest, removal of different stages of life cycle like eggs, larvae and pupae, collection of adults by insect net and light traps and treating them with limited quantity of biocontrol agents like botanical biopesticeds and microbes would not only reduce the population of the insect pests but also avert epidemic out break. In case of *H.puera* infestation, it is important to monitor the mangrove areas carefully during the post monsoon period. Though use of chemical pesticides is not at all possible in the mangroves, application of integrated pest management techniques like tying of parasitoid cards of *T. chilonics* in the field, spraying of biopesticides Hy-ACT, neem based products, spraying of entomopathogenic fungal spore suspension etc., before the initiation of pest attack or in the initial stage is very vital. Once the threshold level of the pest increased to the epidemic level then it is difficult to control the pest population. In the mangrove plantations, allowing the population of the pest uncontrolled will favour the pest to build up its population many folds and damage the entire mangrove plantations. Recently, Roychoudhury and Mishra (2019) reported Spinosad, 45% SC (SPINTOR 45%) a marketed product developed from a soil actinomycete, *Saccharopolyspora spinosa* and evaluated against *H.puera* on teak in laboratory condition concluded that 1250ppm was effective in controlling the pest. Spinosad has been tested extensively against agricultural pests and found effective natural product of management of pests (Thompson *et al*., 1999). Neem oil and neem products are also effective in controlling the pest in field condition. As far as the effect of toxicity of neem is concerned, normally they act through stomach action rather the contact action. For the reason why this interpret, neem products exerted delay in mortality effect on insects which increased with time and concentration as observed in the present study and by others in the previous works (Satti *et al*., 2003; Satti and Nasr, 2006 a,b). Twenty five different

isolates of an entomopathogenic fungus, *Metarhizium anisopliae* were tested for their efficacy against *H. puera* (Remadevi *et al.,* 2013). Studies were reported on the investigations and the effect of Nuclear Polyhedrosis Virus (NPV) on the teak defoliator in laboratory as well in field condition on teak (Ahmed, 1995). Similar studies were reported as management of *H. puera,* involved mainly the use of HpNPV and few studies on using the biocontrol agents like *Bacillus thuringiensis*, *Beauveria bassiana* and some botanicals (Sudheendrakumar 1988). In the present studies the native nuclear ployhedrosis virus (HpNPV) isolated from the naturally infected cadaver of *H.puera* was also evaluated on the larvae of the *H. puera* at different concentrations in field condition and 4.05×10^7 and 4.05 x 10^8 PIB/ml was very much effective in controlling the pest population causing cent percent mortality with in 5 days of interval.

The native strain of *N. rileyi* (isolated from the cadavers of *Hypocala* sp.) caused highest level of larval mortality of 96 % and 100% in the concentration of 2.4×10^8 and 2.4×10^{10} spores/ml respectively on *Hypocala* sp. Where as the strain of *M. anisopliae* –Ma4 of NBAIR was also effective in controlling the pest of *Hypocala* sp. and caused 82% larval mortality in laboratory studies. In field condition *N. rileyi* caused highest level of mortality of 92.5 % and 100% in the concentration of 2.4×10^8 and 2.4×10^{10} spores/ml respectively on *Hypocala* sp. The strain *M. anisopliae*-Ma4 of NBAIR was also performed well in controlling the pest of *Hypocala* sp. and caused 77.5% larval mortality. The biopesticide Hy-ACT also effective in the field condition, and at the concentration of 1% caused highest level of larval mortality of 90 % on *Hypocala* sp. Myco-biocontrol is the use of fungi in biological processes to lower the insect density with the aim of reducing insect activity and consequently damage of plants. The efficacy of native pathogenic bacteria *Myroides odoratus* was evaluated against the targeted pest *P. syntaractis* in field condition and caused 100 percent larval mortality in 48hrs. interval for the concentration 2.6×10^8 CFU/ml, whereas the concentration 2.6×10^6 CFU/ml caused 58% larval mortality. No further studies were carried out by using this bacteria in the field apart from pathogenicity test on the targeted pest, as there were several reports regarding the bacterial pathogen causing infection to the human beings. Infection of this bacteria on *P. syntaractis* for the first time. Vivek *et al*. (2019) reported *M. odoratus* infection in the central nervous system of human beings. Deepa *et al.* (2014) reported *M. odoratus* and *Chryseobacterium indologenes* bacterium causing infection to human beings.

The only grasshopper *A. thalassinus* causes moderate level of defoliation in the mangroves during the months of August to October and the average intensity percentage level was between 30 to 40%. All the grasshoppers are occasional and seasonal pest causing damage to the mangroves particularly on *A.marina* and *A.officinalis*. The grasshopper population in the study areas are kept in control due to the population of natural biocontrol agents already existing in the field itself particularly the availability birds and other predators. The two snails of *Melampus ceylonicus* and *M. pulchellus* caused severe level of infestation (70%) during the month of June and July on *A. marina*. These snails can be effectively controlled by sprinkling of common salt (sodium chloride (NaCl)) on them in the field. Keshav Singh (1996) studied the molluscicidal activity of neem (*Azadirachta indica*) against the snails *Lymnaea acuminate* and *Indoplanoribis exustus* and found the neem based products are effectively control the pest population. Baptista *et al.* (1994) studied the extract of *Euphorbia splendens* as a molluscicide against the vectors of *Schistosoma mansoni*. Oseph Omole *et al.* (2008) studied the effect of varying levels of salt (sodium chloride) on the performance characteristics of snails *Archachatina marginata*. Hand picking and squashing of the slugs and snails is the oldest mechanical control method and was the only measure used adopted during the middle ages (Carman, 1965; Mahrous *et al*., 2002; Shah, 1992). Later, collection of the snails and to kill them with a strong solution of common salt was also adopted (Ahmed Sallam, 2012).

7. SUMMARY OF THE PROJECT

Periodical survey at various mangrove areas in Thane district and Gorai mangrove areas was undertaken during 2017-2019 to diagnose the insect pest probelms. Three plantations in Thane district *viz.*, Airoli plantations,Gothivali Plantation, Ghansoli Plantation and two natural mangroves one each at Airoli in Thane District and Gorai mangrove areas in Mumbai suburban District of Maharashtra were selected for the present study. Twenty different types of defoliating pests were collected from the mangroves. Among the defoliators, ten species of caterpillars (Lepidopterans) such as *Euproctis* sp., *H.puera, Hypocala* sp., *Hypomecis* sp., *H. transcissa*, *Phyllocnistis* sp., *Pteroma* sp., *P. syntaractis*, *S. helpsi* and *T. vishnou*, five species of grass hoppers (Orthopterans) such as *Aiolopus thalassinus*, *Cyrtacanthacris* sp., *Holochlora* sp.,*Phlaeoba panteli* and *Trilophidia annulata*, three species of Coleopteran weevils such as *Alcidodes* sp.,*M. dentifer* and *M.discolor* and two species of snails *M. ceylonicus* and *M.pulchellus* were collected and identified authentically. The recorded pests were categorized in to major and minor pests based on the intensity and injuries caused by insect pests on selected mangrove species. Five insects pests of defoliators including three lepidopterans such as *H.puera, Hypocala* sp., *P. syntaractis* and 2 snails such as *M. ceylonicus* and *M.pulchellus* were categorized as major pests and 15 other insect pests were categorized as minor pests. During the course of investigation **new hosts** have been recorded for five insect pests. They were *Hypocala* sp. on *A. marina* and *A. officinalis*, *H. transcissa* on *A.marina, S. helpsi* on *A. marina, T. vishnou* on *S.alba* and *S. apetala, M. dentifer* on *A.marina* and *A.officinalis.* The two snails *M. ceylonicus* and *M. pulchellus* were reported on *A. marina* for the **first time**. Biology of the key defoliators of the mangrove species were studied in the laboratory condition. Based on the intensity of the pests in different period, a pest calendar was prepared.

Abiotic factors like Temperature and Rainfall were recorded during the period 2018 and 2019 and arrived the average monthly mean in the district of Thane, Maharashtra. It shows that the average monthly mean Temperature (^{o}C) in Thane district, the minimum of 26^{o}C during the month of January and the maximum of 34^{o}C during the month of October during 2018. Where as during the year 2019 the minimum and maximum average temperature ranges between 27^{o}C and 34^{o}C in the month of September and April respectively. The average monthly mean

Rainfall (mm) in Thane district shows that the maximum rainfall recorded as 357.32 mm in the month of July and the minimum rainfall recorded as 0.31 mm in the month of March and there was no rain during the months of January, February and December during the year 2018. Where as the maximum rainfall recorded as 1073.1 mm in the month of July and the minimum rainfall recorded as 0.4 mm in the months of March and April. There was no rain during the month of February during the year 2019. The Temperature and Rainfall for the year 2018 was correlated with the population level of infestation, intensity of the defoliating insect pests *H.purea, H. transcissa*, *Hypocola* sp., *P. syntaractis, T. vishnou* and the snails *M. ceylonicus* and *M. pulchellus.* The statistical analysis was worked out using Microsoft office Excel 2007 to find out the correlations between the pests vs Rainfall and Temperature. In case of *H. purea*, average mean temperature exhibited significant negative correlation, and the average rainfall exhibited significant positive correlation with the intensity of pest in the year 2019. While in the year 2018, average temperature exhibited non-significant negative correlation, and the average rainfall exhibited significant positive correlation. With respect to *H. transcissa* the average temperature exhibited significant negative correlation and average rainfall exhibited significant positive correlation with the intensity of pest in the year 2018. For *Hypocola* sp. the average temperature exhibited significant and negative correlation, and the average rainfall mean exhibited significant positive correlation with the intensity of pest in the year 2018. Whereas in case of *P. syntaractis*, both average temperature and average rainfall exhibited significant positive correlation with the intensity of pest in the year 2018. In case of *T. vishnou*, the average temperature exhibited significant negative correlation but the average rainfall exhibited non-significant positive correlation with the intensity of pest in the year 2018. Where as in case of *Melampus*, the average temperature exhibited significant and negative correlation, but the average rainfall exhibited non-significant positive correlation with the intensity of pest in the year 2018.

The natural enemies such as the predators, pupal parasitoids and the microbes like entomopathogenic fungi, entomopathogenic bacteria and NPV operating in the nurseries, plantations and natural mangroves were collected, identified and documented. One pupal parasitoid, five predatory spiders, one predatory pentatomid bug and the microbes one entomopathogenic fungus, one entomopathogenic bacteria and the NPV (Nuclear polyhedrosis

virus) were recorded as natural biocontrol agents. **The native entomopathogenic fungi *N.rileyi* is reported on *Hypocala* sp. for the first time. The native bacterial pathogen *M. odoratus* is reported on *P. syntaractis* for the first time.**

Management of key pests:

The efficacy of the native entomopathogenic fungi *N. rileyi* (Natural strain), *M. Anisopilae*-Ma4 (strain of NBAIR) and commercial product of *M. anisophilie* were evaluated against the targeted pests *P.syntaractis* and *Hypocala* sp., with different concentration of fungal solutions and found effective on the pests. The concentrations 2.4×10^{10} and 2.4×10^{8} Spores/ml. was found effective for the control of the targeted pests resulting 75 to 100% percent larval mortality respectively in the fifth day after treatment in the field condition. In this study, this is the first report of *N. rileyi* infecting *P.syntaractis* and *Hypocala* sp. under invitro and field conditions. Where as the strain *M. anisopliae*-Ma4 of NBAIR was also performed well in controlling the pest of *Hypocala* sp. and caused 77.5% larval mortality in field condition.

The efficacy of native pathogenic bacteria *M. odoratus* was evaluated against the targeted pest *P. syntaractis* in field condition resulted 100 percent larval mortality in 48 hrs. interval for the concentration 2.6×10^{8} CFU/ml, whereas the concentration 2.6×10^{6} CFU/ml caused 58% larval mortality. No further studies were carried out by using this bacteria in the field apart from pathogenicity test on the targeted pest, as there were several reports regarding this bacterial pathogen causing infection to the human beings.

The native nuclear ployhedrosis virus isolated from the naturally infected cadaver of *H.puera* (HpNPV) was evaluated against *H. puera* . The experiment conducted on the III instar larvae revealed that the concentrations 4.05×10^{8} PIB/ml and 4.05×10^{7} was pathogenic to *H.puera* larvae and resulting 100 percent mortality after a period of five days.

The botanical bio pesticide Hy-ACT was evaluated for its efficacy and effectiveness against the larvae of the defoliator *H.puera* (III instar) in field condition. The biopesticide Hy-ACT at the concentration of 1% caused highest larval mortality of 95 % on *H.puera* in field condition. Where as the concentration 0.75% caused only 60 percent larval mortality.It was also evaluated against the third instar larvae of the defoliators *P.syntaractis* and *Hypocala* sp.

The concentration 1% of the biopesticide caused highest larval mortality of 96% on *P.syntaractis* and 90 % on *Hypocala* sp. in field condition. Where as the concentration 0.75% caused only 64% and 68 % larval mortality respectively.

The biopesticide Neem oil was evaluated for its efficacy and effectiveness against the defoliators *P.syntaractis, Hypocala* sp. and *H. puera*. Among the four concentrations of 2%, 3%,4% and 5% evaluated, the higher concentration 5% caused maximum larval mortality of 50 % on *H.puera*, whereas it caused 36% and 34% on *P.syntaractis* and *Hypocala* sp. respectively in field condition**.** The commercial biopesticide Nimbicidine (*Azadirachtin* 0.03%) was evaluated for its efficacy and effectiveness against the defoliators in field condition. The biopesticide *Azadirachtin* (0.03%) at the concentration of 1% caused highest larval mortality of 68 % on *H.puera*, whereas it showed 58% larval mortality on *P.syntaractis* and *Hypocala* sp. after48 hrs. of interval.

The biopesticde Hy-ACT, and the native entomopathogenic fungus *N. rileyi* were tested for their safety to egg parasitoids *T. chilonis* with different concentrations and found very safe to the beneficial insects and causing no adverse effect on parasitisation of the parasitoids *T. chilonis* for the two generations tested

Based on the results generated in this project, a Technical bulletin was prepared on the topic “Important insect pests in mangroves of Maharashtra and their management”. This will benefit the end users especially the Forest departments and researchers.

8. CONCLUSION

The present study revealed the infestation of five defoliating pests including three lepidopterans such as *H.puera, Hypocala* sp., *P. syntaractis* and 2 snails such as *M. ceylonicus* and *M.pulchellus* among the twenty different pests as major pests. During the course of investigation **new hosts** have been recorded for five insect pests. They were *Hypocala* sp. on *A. marina* and *A. officinalis*, *H. transcissa* on *A. marina, S. helpsi* on *A. marina, T. vishnou* on *S. alba* and *S. apetala, M. dentifer* on *A. marina* and *A. officinalis.* The two snails *M. ceylonicus* and *M. pulchellus* were reported on *A. marina* for the **first time**. The natural enemies such as the predators,pupal parasitoids and the microbes like entomopathogenic fungi, entomopathogenic bacteria and NPV operating in the nurseries, plantations and natural mangroves were collected, identified and documented. One pupal parasitoid, five predatory spiders, one predatory pentatomid bug and the microbes which includes one entomopathogenic fungus, one entomopathogenic bacteria and a NPV (Nuclear polyhedrosis virus) were recorded as natural biocontrol agents. The native entomopathogenic fungi *N.rileyi* identified by the National Facility (NFCCI & FIS), Agharkar Research Institute, Pune, was reported on *Hypocala* sp. for the **first time.** The native bacterial pathogen *M. odoratus* was reported on *P. syntaractis* for the **first time** and the bacterial DNA sequence was deposited to NCBI-GenBank with the accession number: MN104590.

Among the five major pests recorded, *H. puera* is the potential insect pest on *A. marina* in the mangroves. The intensity of the pest was severe in the year 2019 and total defoliation of *A. marina* was recorded in the study area at Airoli and Gorai mangroves during the months of September and October. Eco-friendly approaches such as biological control, application of botanical based biopesticides, entomopathogenic fungi are considered as the best alternatives to chemical pesticides. Foliar spraying of the botanical biopesticide Hy-ACT, at a concentration of 1% gave good control of the defoliating pests in field condition. The native entomopathogenic fungus *N. rileyi* was effective against *Hypocala* sp. and *P. syntaractis*. The snails *M. ceylonicus* and *M. pulchellus* can be effectively controlled by sprinkling of common salt (sodium chloride (NaCl)) on them. Nimbicidine (Azadirachtin 0.03%) a commercial neem product and

the entomopathogenic fungus *M. anisopliae* (NBAIR strain Ma-4) were effective in controlling the defoliating pests in the field.

The present study revealed the fact that when the food resources were exhausted in the teak plantations situated in and around the mangrove areas, the pest *H.puera* might be migrating in to the mangrove plants particularly on *A.marina* to sustain its generations and move back when teak gets new leaves. Thus this insect is probably using mangrove habitat as a carryover habitat. Further studies are required exculvesly for the migration of *H.puera* from the teak grown areas particulary from Sanjay Gandhi National Park towards the mangrove areas. In-depth studies are also required to see the possibility of using Nuclear Polyhedrosis Virus (NPV) in mangrove ecosystem to control *H. puera* in a larger scale. Overall, the study revealed that effective implementation of different techniques of Integrated pest management (IPM) like strict surveillance, cultural operations, use of eco-friendly biocontrol agents and all other available control methods with due consideration to economical viability and environmental safety and right time implementation are the best to keep the pest outbreak in control.

Moreover, it is also viewed that outbreaks of pest incidence may also lead to several beneficial and positive impacts on the ecosystem. This promotes mangrove diversity, contribution to the nutrient cycling and there by enhance fishery resources and allows food sources for birds etc. There fore more studies also required in these aspects to answer the questions raised by the environmentalist whether to control these pests or to be conserved.

9. PUBLICATION(S):

Reviewed journal research papers:

1. Shwetha V, Raja Rishi R, Sundararaj R, Sunayana TP. (2019) Check-List of Entomofauna of Mangrove ecosystem in India. International Journal of Science and Nature. 10(4): 159-172

2. Raja Rishi, R , R.Sundararaj , Shwetha, V, Sunayana TP, Mohan Karnat (2019). A new record of *Streblote helpsi* Holloway (Lepidoptera: Lasiocampidae) as pest on *Avicennia marina* from the mangroves of Maharashtra, India. Journal of Entomology and Zoology Studies. 7(6):1268-1270.

3. Raja Rishi, R , R.Sundararaj . (2020). Record of an epidemic outbreak of *Hyblaea puera* Cramer (Lepidoptera: Hyblaeidae) on *Avicennia marina* in the mangroves of Maharashtra, India. Journal of Entomology and Zoology Studies.8(2): 306-309.

Technical Bulletin:

Raja Rishi, R and Sundararaj, R (2020). "Important insect pests in Mangroves of Maharashtra and their management" . Tech. Bulletin No. IWST/18/2020. IWST, Bengaluru Publication.

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