NBAII: Vision 2030

NATIONAL BUREAU OF AGRICULTURALLY IMPORTANT INSECTS
(Indian Council of Agricultural Research)
Bangalore 560 024, Karnataka

Vision 2030

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FOREWORD

The diverse challenges and constraints as growing population, increasing food, feed and fodder needs, natural resource degradation, climate change, new parasites, slow growth in farm income and new global trade regulations demand a paradigm shift in formulating and implementing the agricultural research programmes. The emerging scenario necessitates the institutions of ICAR to have perspective vision which could be translated through proactive, novel and innovative research approach based on cutting edge science. In this endeavour, all of the institutions of ICAR, have revised and prepared respective Vision-2030 documents highlighting the issues and strategies relevant for the next twenty years.

The National Bureau of Agriculturally Important Insects (NBAII), Bangalore focuses on conservation and utilization of insects, the organisms with most species on earth. A large number of insects are herbivores capable of decimating our food supplies. An equally large or even larger number however are capable of keeping these insects in check. They protect our crops from the ravaging hordes of herbivorous insects. Many others are important as pollinators, seed dispersers and soil builders. The NBAII endeavours to harness the power of insects to serve the cause of sustainable agriculture.

It is expected that the analytical approach and forward looking concepts presented in the '*Vision 2030*' document will prove useful for the researchers, policymakers, and stakeholders to address the future challenges for growth and development of the agricultural sector and ensure food and income security with a human touch.

(S. Ayyappan)

Dated the 9th June, 2011
New Delhi

Preface

The human population of our country is growing and will continue to grow in the coming decades. It is incumbent on the agricultural fraternity of our country to meet the food and nutritional security. While pests and diseases take a significant toll on our production, pesticides are being used extensively in this effort, there is a need for sustainable food production, food and environmental safety.

All forms of agriculture are human interventions that disturb and disrupt natural ecosystems. If the objective of every agriculturist / farmer was to preserve nature in its pristine state then we would have to be hunter–gatherers. No cultivation would be possible and it would be impossible to support the burgeoning human population of the world to which our country is no mean contributor. In our efforts to increase productivity, a variety of circumstances has come together to produce a looming national and global crisis. From an entomological perspective this crisis comes from the widespread reliance on chemicals to control pests. There is thus an urgent need to search for alternative approaches to pest management that while maintaining the ecological balance of the environment will aid in the production of adequate food. In this search for sustainable food production it is becoming increasingly clear that the more agro-ecosystems mimic natural ecosystems the greater the stability of the system and the lesser the pest problems are likely to be. It goes without saying that under these circumstances the ecosystem remains least damaged thus permitting the unfettered activity of pollinators and other beneficial organisms leading to enhanced food productivity.

The National Bureau of Agriculturally Important Insects (NBAII) seeks to achieve higher food production by acting as the hub of a network of institutions spread across the length and breadth of our country to harness the rich biodiversity of useful insects, nematodes and other associated macro- and micro-organisms for enhancing the productivity of Indian agriculture. Placing the powerful tools in the arsenal of the newer technologies like molecular biology, nanotechnology and information technology in the hands of taxonomists the NBAII will document the staggering diversity of insects of agricultural importance.

While the 'Perspective Plan 2025' was formulated within the perspective of the earlier *avatar* of the NBAII as the Project Directorate of Biological Control, the current document NBAII Vision 2030 aims to tackle the problem of pests as well as utilize the services and goods offered by insects to meet the growing demand for food.

30 June, 2011
Bangalore

Director
National Bureau of Agriculturally Important Insects (NBAII)
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Preamble

India is one of the top seventeen mega diversity countries of the world. While plant diversity is discussed at length, insects which form nearly 75% of all animals comprising tremendous diversity remain poorly explored and documented. They far outnumber all other terrestrial animals and occur practically everywhere. Several hundred thousand different kinds have been described- three times as many as there are in the rest of the animal kingdom- and some authorities believe the total number of different kinds may approach 30 million. More than a thousand kinds may occur in far-sized backyards, and their populations often number many millions per acre (Borror *et al.*, 2005).

Although efforts at the discovery and documentation of our insect fauna have been going on for at least the last century and a half, we have not been able to document even half of the estimated fauna. It is to be noted in this context that many of the insects described so far are not known to be of direct value to agriculture while they play a vital role in food chain and ecosystem.

When the All India Coordinated Research Project on Biological Control of Crop Pests and Weeds was initiated by the ICAR in 1977, the focus was on the natural enemies of agricultural pests *sensu lato*. Even when this project was upgraded to the Project Directorate of Biological Control (PDBC) in 1993, the mandate remained the same. However, in 2009 the PDBC was transmuted to the National Bureau of Agriculturally Important Insects (NBAII) enlarging the mandate and the focal insect groups to be studied. Accordingly, major focus in the coming years is to strengthen the traditional and molecular taxonomic base for effective identification of agriculturally important pests and bioagents, develop a national laboratory to facilitate molecular systematics of insects, nematodes, mites, spiders and mandated organisms in agricultural realm, initiate work on RNA interference (RNAi), structural and functional genomics, develop a state of the art containment facility and establish new laboratories for work on insect physiology, pheromones, storage pest management, pollinators, spiders, etc. While mapping the diversity of entomopathogenic nematodes (EPN), new line of work on management of nematodes under protected cultivation and biodiversity of animal parasitic nematodes will be initiated. NBAII proposes to initiate a network project on management of sucking pests and insect vectors of crops encompassing all agricultural and horticultural crops. Insects, spiders and mites in their varied roles as pollinators, nutrient cyclers, bio-indicators and producers of goods of value to man are to be studied in addition to the parasitoids and predators. Insects as regulators of pests and weeds cannot be ignored and continue to get attention as they are the ones that can be used effectively in ecofriendly ways to minimize pest damage to crops. Species diversity and the role of our native insect pollinators and nutrient cyclers remain poorly studied. It is also important that ecological and behavioural studies on these groups are given higher emphasis to enhance their effectiveness in agro-ecosystems contributing to sustained food production.

Despite the numerous hazards that chemical pesticides cause, we continue to be dependent largely on them for the management of pests. Broad based studies on beneficial insects could lead to solutions for pest management that could minimise the use of chemicals in pest control.

As we make inroads into the 21st century, there is a need to focus more on basic research that over time translates to applied research. Keeping in view the economic and ecological needs of the country as a whole and the farmers in particular, thus, NBAII in its Vision 2030 document envisages a blend of basic and applied research keeping in view short term and long term research needs of our country in entomology and related disciplines for the next twenty years to come.

Contents

Insects of Agricultural Importance: An Overview

Insects are the most abundant of all life on earth. The estimated world totals of described, living species in the 29 orders of the class Insecta amount to 1, 004, 898 (Adler and Foottit, 2009). The figure of four million has been accepted as the most commonly cited figure based on recent publications for the total number of species. Among all arthropods, spiders are probably the best known and Platnick (2005) lists 38, 834 described species of spiders in *The World Spider Catalogue*. The estimated size of the world spider fauna is about 50,000 to 70,000 (Chapman, 2005). Halliday *et al.* (2000) estimated that there were 48,200 described species of Acarina and a total fauna of about 0.5 million. India, with 2 per cent of global space, is among the top ten mega diversity nations in the world in terms of insect diversity, with about 7.10 per cent of the world insect fauna. Ghorpade (2010) provided an estimate of 54,346 described species of insects in 27 orders from India, with nearly as many species yet to be discovered. Parallel estimates by the Zoological Survey of India and others are much higher, ranging from 62,000 to 80,000 described species. For research and development of sustainable pest management system to combat pest induced losses in tropical agriculture, sound biosystematic knowledge of pests and their natural enemies is of fundamental importance.

A great many insects are extremely valuable to humans, and society could not exist in its present form without them. By their pollinating activities, they make possible the production of many agricultural crops, including many fruits, nuts, clovers, vegetables, and fibre; they provide us with honey, beeswax, silk and other products of commercial value; they help keep harmful animals and plants in check; they have been useful in medicine and in scientific research; and people in all walks of life look on them as interesting animals. A few insects are harmful and cause enormous loss each year to agricultural crops and stored products. Some insects transmit diseases that seriously affect the health of plants, humans and animals.

Insects have lived on this earth for about 350 million years, compared to less than 2 million for *Homo sapiens*. During this time, they have evolved in many directions to life in almost every habitat (with the notable and puzzling exception of the sea) and have developed many unusual, picturesque, and amazing features.

Insect pests are an impediment to successful food production. While many are direct pests of crops/animals, some cause extensive damage to crops, animals and human beings as vectors of many pathogens. History is replete with examples where the course of civilization has been altered by some of the insect transmitted diseases. Other insects in the form of natural enemies minimize crop losses by preying on insect pests and keeping them under check. These natural enemies also offer opportunities for use by enhancement of their numbers in specific pest situations enabling us to keep pests and weeds at low levels so that they do not cause significant damage to crops and food grains. In addition to their use in biological pest control as benefactors to humans, insects play a major role in pollination and nutrient cycling in agro-ecosystems. They are also valuable sources of chemicals and medicines. Sericulture, apiculture and lac farming are enterprises that are indulged in solely for the produce of insects.

Insects provide many services like the natural suppression of agricultural and medical pests and weeds, pollination of agricultural and silvicultural crops as well as the decomposition and recycling of organic matter. It is only when these services break down that the value of insects is appreciated. Insect diversity itself is a service, as it acts as a genetic resource for biological control programmes and as a pool for biochemical products.

SERVICES FROM INSECTS

(i) **Natural Control of Pests**

Natural enemy conservation is an effective method of crop pest management in agricultural ecosystems. All insect pests are hosts to a range of predators and parasitoids, many of which are host specific. Greater dependence on natural pest controls and a concomitant reduction in the use of chemical pesticides will result in the long term suppression of pests and a cleaner environment.

The efficacy of generalist predators in reducing pest populations has not as yet received the attention that it deserves in our country. Habitat management in field and strip cropping have been found to enhance the effectiveness of polyphagous predators and parasitoids.

(ii) **Genetic Resource for Biological Control**

Both classical and augmentative biological controls envisage the use of natural enemies in the management of crop pests and weeds. Invasive pests like the papaya mealybug and alien weeds like *Salvinia* are being suppressed by introduction of natural enemies from their areas of origin.

India is home to many insect bioagents which have been used successfully in the management of insect pests in other countries. Over 46 bioagents of Indian origin have permanently established in other countries with some having successfully contained the target pests against which they were released.

(iii) **Pollination**

Cross pollination is essential for the realization of the potential yields in many field and horticultural crops, for enhancing the production of hybrid seeds and for the conservation of some endemic species.

About a hundred species of honey bees are native to India. Honeybee diversity in India is very high. India is the centre of origin of *Apis* - six (*A. cerana, A. florea, A. laboriosa, A. dorsata, A. andreniformis* and *A. koschevnikovi*) of the eight known species are found here. *Apis mellifera*, the European honeybee, a seventh species has been introduced to our country.

About 80 per cent or more of the crop plants depend on or are benefitted by insect pollination. Over 55 million hectares, accounting for about one-third of the cropped area, is under pollinator dependent-crops. In the years to come, as agriculture becomes both intensified and diversified, the services of pollinators will assume greater significance in the enhancement of the productivity of both natural and agro-ecosystems. In addition to the bees and other Hymenoptera, important pollinators occur in Coleoptera, Lepidoptera, Diptera, Hemiptera and Thysanoptera. It is probable that many more species of insects are important in pollination than is currently known.

(iv) **Nutrient Cycling**

In hot, wet tropical ecosystems like those prevailing in our country, insects play a vital role in decomposition and nutrient cycling along with a host of other organisms. Collembola, termites, and beetles dominate the decomposition processes in tropical ecosystems like ours. They not only consume from a fifth to a quarter of the litter production through their burrowing and nesting habits but also expose considerable amounts of organic matter to the action of bacteria, fungi and other decomposers. The high diversity of dung beetles in India ensures that cattle and other mammalian dung does not accumulate thus obviating the problem of the release of large quantities of unwanted methane and nitrogen into the atmosphere. In man–made habitats, the potential exists for utilizing insects to help reduce the accumulation of organic wastes.

(v) **Indicators of environmental change**

The use of chemical pesticides and habitat destruction result in the loss of biodiversity. Non–pest insects may be used to monitor the undesirable effects of insecticides in the environment. As these insects are susceptible to pesticides and are easy to sample, their abundance over a period indicates the extent to which the environment has been altered by anthropogenic influences.

GOODS FROM INSECTS

(i) **Insect Products**

Lac, beeswax, honey and silk are the few products obtained from insects. Of the nine genera and over 90 species of lac insects reported from around the world, two genera and 19 species occur in India. True lac is produced by species of the genus *Kerria*. *Kerria lacca* is the most important and widely exploited lac insect in India. India leads the world in lac production. Deforestation is the major threat to lac production in our country.

India has one of the largest silkworm (*Bombyx mori*) germplasm resources in the world. This includes indigenous, introduced (from 13 countries) and bred accessions. There is a great scope to enrich the silkworm germplasm with accessions from other geographical regions.

India is also home to the major genera of saturnine moths that produce ‘wild’ silks, namely, species of *Antheraea* producing Tasar and Muga silks, and *Samia* from which Eri silk is obtained. 'Wild' silk in our country is mainly produced by the tribals of Central and Northeastern India and this serves to augment their meagre incomes.

Beekeeping in hives is an ideal low cost, eco-friendly, non-land based enterprise that does not compete for the resources of farming systems. It provides sustainable livelihood to rural households and can easily be adopted by the landless and by women. It is well suited for integrated agriculture and generates employment for rural youth and women. Even farmers with small or no land holdings can supplement their incomes through bee keeping.

(ii) **Butterfly farms**

Butterfly houses and farms with live butterfly displays have become centres of attraction for the public. While Europe, Canada, USA and Australia have a number of these enterprises, there are only a few in Southeast Asia and India. This is based on captive bred species but unlike other countries only local butterflies are in use in India. These enterprises generate some income for the local populace and more importantly, benefit conservation. Butterfly ranching as practiced in Papua New Guinea, Kenya and other places offers rural employment and augmented incomes. Here food plants are established in a butterfly garden to attract butterflies from the forest. The pupae are harvested and the adults that emerge are sold with the profits going directly to the producers. Butterfly ranching is regarded as beneficial to conservation as it does not deplete wild stocks and high quality specimens are produced that are valued by specialists.

(iii) **Deadstock**

Trade in dead insects is mainly for decorative purposes. If a species' habitat has not been severely reduced, then trade in deadstock does not have an adverse impact on the insect concerned. Lepidoptera are not the only insects used in deadstock trade. Coleoptera, particularly Cerambycidae, Buprestidae and Dynastinae (Scarabaeidae), as well as Phasmida are the other groups of insects popular in the trade of insect deadstock.

(iv) **Insects as food**

The nutritional value of many insects such as locusts, honeybees, housefly pupae and termites is quite high. Many insects contain a good deal of available protein. They also contain useful minerals and vitamins. The only people who use insects as food in our country are some tribes. They collect insects from the wild for consumption. In addition to using insects as human food, there is the potential to use farmed insects as feed for poultry, pigs and fish.

Management of Insect Resources

In the long term it is essential that the diversity of insects is maintained in 'wild' areas as much as in the cultivated areas as there is constant exchange of biota between the two areas. The species poor cultivated areas are dependent on the surrounding natural vegetation in the countryside for the replenishment of faunal and floral elements that are under severe stress in the former areas. Even in the most intensively farmed areas some wildlife, especially insects, survive. It should be our aim to enhance and perpetuate the survival of these species and enrich farmlands with additional species whenever possible. To do this, however, an effective insect monitoring scheme must be put in place. And this is dependent on a sound knowledge of the species level identity of the insects in the area. Unfortunately, countries like ours and others in the tropics which are rich in insect diversity are poor in numbers of insect taxonomists, while the biodiversity-poor temperate regions are where the majority of the world's taxonomists are. In such a situation, it is imperative that there is a need for adequate insect taxonomists that is commensurate to the scientific effort required for the description of our priceless insect resource.

NBAII & NARS

The **National Bureau of Agriculturally Important Insects (NBAII)** established recently by ICAR, New Delhi had its genesis dating back to the year 1977 when the All India Co-ordinated Research Project on Biological Control of Crop Pests and Weeds (AICRP-BC) was initiated under the aegis of the ICAR with funds from the Department of Science and Technology, Government of India. Within two years (1979), the ICAR brought the project under its research umbrella with full financial support. Recognition of the importance of biological control came during the VIII plan period with the upgradation of the centre on biological control to the **Project Directorate of Biological Control (PDBC)** with headquarters at Bangalore with effect from 19 October 1993. The PDBC was further upgraded into the **National Bureau of Agriculturally Important Insects** on 25 June, 2009.

The mandate of NBAII is to act as a nodal agency for collection, characterisation, documentation, conservation, exchange and utilisation of agriculturally important insect resources (including mites, spiders and related arthropods) for sustainable agriculture. The research programmes are developed in consultation with the state agricultural universities according to the prevailing pest problems of regional and national importance. NBAII with its inherent strength, continues to coordinate the AICRP on Biological Control of Pests with 14 centres in the state agricultural universities and six in ICAR institutes.

The research programmes under NBAII are focused on biosystematics, classical biological control of pests and weeds, maintenance of live insect and microbial germplasm, developing protocols for producing insects and insect derived microbials, production and utilization of beneficial macrobials and microbials, understanding the behaviour of parasitoids and predators, selection of improved strains of parasitoids and predators, molecular characterization, gene identification and developing barcodes and digitized inventories of mandated organisms of the Bureau. It is the vision of NBAII to develop a scientific base and human resources in the coming years to address its mandate. Strengthening molecular biosystematics on target organisms that include insects, mites, nematodes, pollinators, etc., new initiatives to develop human resource in traditional systematics in groups such as Coleoptera (Chrysomelidae, Cerambycidae, Bostrichidae, Scolytidae and Scarabaeidae); Lepidoptera (Noctuidae, Pyralidae and microlepidoptera); Hemiptera (Coccoidea, Aleyrodoidea, Pentatomidae and Miridae); Neuroptera (Chrysopidae); Isoptera; Hymenoptera (Ichneumonidea, Apoidea); Orthoptera (Acrididae, Tettigoniidae); Diptera (Tabanidae, Syrphidae, Tachinidae) and spiders, understanding the structural and functional genomics from a vast gene pool of insect genome. NBAII would strive to integrate the knowledge of insect ecology and behaviour to make IPM more sustainable and initiate new research frontiers in areas such as RNAi, barcoding, vectors in epidemiology of plant pathogens, biodiversity of stored grain pests, pollinators, veterinary parasitoids, etc. In short, our vision is to make NBAII a national hub for entomological and nematological research by enhancing human resources and networking through the length and breadth of the country to harness collective wisdom and channelize it for sustainable food production and environmental safety.

Mandate of the NBAII

To act as a nodal agency for collection, characterisation, documentation, conservation, exchange and utilisation of agriculturally important insect resources (including mites, spiders and related arthropods) for sustainable agriculture.

Until the year 2009, the erstwhile PDBC had focussed its attention on biological control of crop pests, diseases and weeds, both classical and augmentative and implemented many successful bio-intensive IPM programmes in farmers' fields. These programmes were supported by both basic and applied research.

Taxonomic studies enabling revision of taxa, identification of new species, synonyms in beneficial, preparation of fact sheets for several bio-agents and designing of web sites. Studies on biosystematics were carried out on 200 predatory coccinellids; An annotated checklist of the Indian subcontinent fauna (excluding Epilachninae) comprising of 418 species under 78 genera and 21 tribes under five subfamilies has been prepared. Biosystematic studies have been carried out on Coccinellidae, Thysanoptera, Trichogrammatidae, Chrysopidae, etc. resulting in the discovery of a number of new species. The misconception regarding the existence of *Chrysoperla carnea* in India has been dispelled with the definitive identification of the species found in India as *C. zastrowi sillemi* through acoustic analysis of mating calls. Websites have been constructed and hosted on the common species of Coccinellidae, and the Aphids of Karnataka. Fact sheets for over 155 species of agriculturally important insects and a data base on 185 biocontrol introductions to India have been hosted at NBAII's website.

Ninety-four natural enemies were studied for use against alien invasive pests, of which 62 could be successfully multiplied in the laboratory and 52 of these could be recovered after release from the field. Six of these natural enemies were effective in managing the pests against which they were released providing economic benefit to the tune of millions of rupees. The most recent success in the classical biological control (CBC) of a pest was that of the management of the papaya mealybug with *Acerophagus papayae*, the imported parasitoid. The management of the sugarcane woolly aphid outbreak in South India by the deployment of indigenous natural enemies was another marked success. *Quadrastichus mendeli* imported for the CBC of the eucalyptus gall wasp has established in the field and suppressing populations of this pest. The biological suppression of the Sugarcane woolly aphid through conservation of the indigenous predators *Dipha aphidivora* and *Micromus* sp. and the re-distribution of the parasitoid *Encarsia flavoscutellum* was a success story in the field of biological control. This was followed by the success of the classical biological control of the Papaya mealybug (*Paracoccus marginatus*) with the imported parasitoids *Acerophagus papaya*e, *Pseudleptomastix mexicana* and *Anagyrus loecki*. Techniques were developed for mass production of novel bio-agents like *Micromus igorotus, Micromus timidus, Blaptostethus, pallescens, Xylocoris flavipes*, etc.

Availability of host insects is important for continuous production of natural enemies by research and commercial units and also for testing host plant resistance, insecticide resistance, etc. Technologies and rearing units have been developed for efficient and economic production of host insects like *Helicoverpa armigera, Spodoptera litura, Spodoptera exigua, Phthorimaea operculella, Corcyra cephalonica,* aphids, scales and mealybugs. Quality bio-agents and rearing units with technologies for production were made available to Government orgaisations, NGOs and private entrepreneurs. Parasitoids and predators (both exotic and indigenous) have been studied for developing production protocols and utilizing against major pests. Improved techniques were developed for the multiplication of 27 egg parasitoids, seven egg-larval parasitoids, 42 larval/nymphal parasitoids, 25 predators and seven species of weed insects. Some important bio-agents for which mass production technologies are available include *Trichogramma* spp., *Goniozus nephantidis*, *Cotesia flavipes*, *Campoletis chlorideae*, *Eriborus argenteopilosus*, *Cryptolaemus*, *Chrysoperla*, *Micromus*, *Cardiastethus*, *Blaptostethus*, *Xylocoris*, Syrphids, etc. Suitable low temperatures for short-term storage of trichogrammatids, *Eucelatoria bryani*, *Carcelia illota*, *Allorhogas pyralophagus*, *Copidosoma koehleri*, *Hyposoter didymator*, *Cotesia marginiventris*, *Leptomastix dactylopii*, *Sturmiopsis inferens*, *Pareuchaetes pseudoinsulata*, *Cardiastethus exiguus*, *Blaptostethus pallescens*, etc. have been determined. The host and host plant preferences and competitive interactions between the bio-agents have been studied. The field validation of the effectiveness of the promising parasitoids and predators has been done at different Agro-ecological zones under the AICRP on Biological control.

Molecular characterization of 104 insects using ITS and CO1 regions of DNA was done. One hundred sequences of endosymbionts of various natural enemies were generated and the sequences generated were submitted to Genbank, NCBI and 125 ID were generated. RAPD and RFLP markers were developed for 44 insects. DNA barcodes based on the mitochondrial cytochrome oxidase I gene have been developed for 31 species of entomophagous insects as well as for the quarantine pest *Brontispa longissima*. This will enable quick and definitive identification of the pest if it enters India. The effects of *Wolbachia*, yeasts and bacteria on the fitness attributes of many species of *Trichogramma*, *Chrysoperla*, *Cotesia plutellae* and *Plutella xylostella* have been studied.

An Endosulfan tolerant strain of *Trichogramma* was developed for the first time in the world, which was transferred to the private sector for large scale production and was used in 29600 acres of vegetables and cotton. Following this strain, multiple insecticide tolerance was developed for tolerance to 7 groups of insecticides. Genetic improvement of *Trichogramma* and *Chrysoperla* for tolerance to abiotic stresses like temperature as well as chemical pesticides was done. Pesticide tolerant strains *T. chilonis* and *C. z. sillemi* was commercialized and revenue of Rs. 6.50 lakhs was generated.

Tritrophic interactions between natural enemies, their hosts and host plants have been studied which will help in development of successful biological control in different crop ecosystems. Identified kairomones from *H. armigera*, *Spodoptera litura*, *Opisina arenosella*, which will be useful for increasing efficiency of their natural enemies. Kairomones from scale extracts of *Helicoverpa armigera* and *Corcyra cephalonica* increased searching efficiency of *Trichogramma chilonis*. Combined treatment of tricosane impregnated septa and limited appliacation of acid hydrolyzed L-tryptophan increased oviposition by *C. z. sillemi* on cotton. Identified plant volatiles through GCMS studies from maize, cotton, chickpea, pigeonpea, sunflower, tomato, marigold and *Solanum viarum* and studied their synomonal activity. More than 20 species of weed flora were recorded in and surrounding fields of rice and extract from rice and flowers *Hyptis suveolens* elicited higher electroantennogram response in the females of *T. schoenobii*. Rice cultivar Triguna showed highest attraction to *T. schoenobii*. Extracts of weed species of *Melia dubia* and *Malvastrum coramandelicum* recorded maximum attraction to *Trichogramma japonicum*. Methyl hexadecanoate, 2-di-butyl phenol, caryophyllene and phytol are major volatiles identified from the rice cultivars which were more attractive to the parasitoids, *T. schoenobii* and *T. japonicum*.

Studies on the polymorphism of pheromone perception of males of *H. armigera* revealed that some geographical populations showed higher electroantennogram and behavioural response to blends 85:15 or 91:9 (Z-11-16-Ald: Z-9-16-Ald) in comparison to the commercially available blend of 97:3. Even in field trials, some populations respond to the 85:15 (Patna population) and 91:9 (Raichur population) in preliminary field trials. Nanoformulations of pheromones and other semiochemicals such as methyl eugenol were evaluated for their efficiency and storage capabilities. The nanoformulations of methyl eugenol is as effective as the particle board formulation of methyl eugenol.

New species and strains of entomopathogenic nematodes (EPN) *Steinernema abbasi, S. tami, S. carpocapsae, S. bicornutum* and *Heterorhabditis indica* have been recorded. Suitable media for mass multiplication of EPN was standardized. *S. carpocapsae* @ 1.25-5 billion/ha proved effective against the brinjal shoot and fruit borer, *Leucinodes orbonalis*. Talc-based and alginate-capsule formulations of *S. carpocapsae* and *H. indica* were effective against *S. litura* in tobacco. A sponge formulation was found suitable for transport retaining 90% viability of *Steinernema* spp. for 3-4 months and 85% viability of *Heterorhabditis* spp. for 2 months. *Bacillus thuringiensis* isolate PDBC-BT1 caused 100% mortality of first instars of *Plutella xylostella*, *Chilo partellus* and *Sesamia inferens*. *Bacillus thuringiensis* isolate PDBC-BNGBT 1 caused complete mortality of *Helicoverpa armigera*. Efficient isolates of *Beauveria bassiana*, *Metarhizium anisopliae* and *Verticillium lecanii* have been identified for the management of sucking pests.

Two fungal bioagents *Trichoderma harzianum* (PDBC-TH 10) and *T. asperellum* (PDBC-TH 23) and two bacterial isolates *viz*., *Pseudomonas fluorescens* (PDBC-TH 23) and *P. putida* (PDBC-AB 19) were identified to by effective against plant pathogens like *Macrophomina phaseolina, Fusarium, Phytophthora* and *Sclerotium*. Isolates of Trichoderma spp. that produce more chitinase and glucanase had been identified. Isolates of *Trichoderma harzianum* tolerant to carbendazim and salinity with good biocontrol potential against four important plant pathogens have been identified. Addition of chitin in formulation, colloidal chitin (0.02%) or glycerol (3%) in production medium and heat shock at the end of log phase were found to extend the shelf life of liquid fermentation derived formulations of *Trichoderma*. Bioefficacy test for screening talc formulations of fungal antagonists was also standardized. Talc-based formulation of *Bacillus megaterium* has been developed for the management of bacterial wilts of tomato and brinjal caused by *Ralstonia solanacearum*. Bacterial antagonists, particularly *Pseudomonas cepacia* (starin N 24), suppressed successfully *Sclerotium rolfsii* in sunflower rhizosphere as seed inocula.

Suitable media for mass multiplication of EPN was standardized. An easy and rapid technique to screen large number of antagonistic fungi against plant parasitic nematodes has been devised to identify efficient strains. *Paecilomyces lilacinus* was found effective against *Meloidogyne incognita* and *Rotylenchulus reniformis* in red laterite soils and *Verticillium chlamydosporium* was effective in sandy loam soil. An easy and rapid technique to screen large number of antagonistic fungi against plant parasitic nematodes has been devised to identify efficient strains. Molecular identity of native isolates of *P. chlamydosporia* was established through sequencing the β-tubulin gene. Solid state fermentation based production technology for these fungi have been standardized and commercialized.

Databases like 'PDBC – INFOBASE' detailing information on bioagents, their use and availability in the public and private sectors in the country, 'BIOCOT' giving information on biocontrol measures for cotton pests and a CD version of the software 'Helico-info' were developed. A database on 'Vegetable crop pests' has been developed on the pest–natural enemy complex, their distribution and IPM options for brinjal, beans, cabbage, cowpea, tomato and potato. Six video films were produced: (i) on biocontrol based management practices for rice pests, coconut black headed caterpillar and the sugarcane woolly aphid; (ii) on the production and use of coccinellids and trichogrammatids and (iii)on the production and use of *Trichoderma*.

The NBAII is also recognized as a Centre of Excellence for Human Resource Development. Scientists, teachers and state department officials from all over the country have been trained on biodiversity quantification protocols and biological control. Bio-pesticide industry has been supported with training of its staff on mass production, formulation and quality control as well as with supply of nucleus cultures of biocontrol agents. This Bureau has a rich collection of biocontrol agents including several arthropod species and has been supplying these agents to various stakeholders. Thus, besides following its normal mandate of collecting, characterising, documenting, conserving, exchanging and utilising agriculturally important insect resources for sustainable agriculture, NBAII has been popularising mass production and delivery systems of biocontrol agents through linkages with stakeholders.

NBAII -2030

NBAII is a nascent institute with immense responsibilities collection, characterization, documentation, exchange and utilization of insects. In view of the current scenario of changing dynamics of pests and diseases in our country, it was felt essential to prioritise our research programmes for the next 20 years to ensure increased role of conservation, characterization and utilization of agriculturally important insect resources for enhancing crop productivity while ensuring food and environmental safety. Further, the vision is to develop qualified human resource to address present lacunae in systematics, molecular entomology, biodiversity conservation and characterisation, insect vectors and looming dangers of biosecurity. Based on the experience of the last few years and also the emerging challenges of pests and diseases, the perspective plan of NBAII (erstwhile PDBC) has been revised for the current plan period as well as for the period up to 2030 to include additional areas of research.

Vision

A prosperous farming community with assured productivity, food safety and profitability of agriculture and horticulture through conservation and utilization of useful insect genetic resources.

Mission

The main mission of the National Bureau of Agriculturally Important Insects is to explore, identify, characterize, conserve and utilize the biodiversity of beneficial insect and associated microbial resources for cost-effective management of pests, diseases and weeds.

Focus/ Future Research Thrusts

In order to accomplish its vision and mission, the NBAII would focus on the following thrust areas

Systematics

- Strengthening traditional taxonomy & documenting biodiversity of insect orders/ superfamiles/ families, *viz.* Coleoptera (Chrysomelidae, Cerambycidae, Bostrichidae, Scolytidae and Scarabaeidae); Lepitoptera (Noctuidae, Pyralidae and microlepidoptera); Hemiptera (Coccoidea, Aleyrodoidea, Pentatomidae and Miridae); Neuroptera (Chrysopidae); Isoptera; Hymenoptera (Ichneumonidea, Apoidea); Orthoptera (Acrididae, Tettigonidae); Diptera (Tabanidae, Syrphidae, Tachinidae); spiders; pollinators and Veterinary pests and parasites

- To act as a nodal agency for collection, characterization and cataloguing of insects, mites, spiders and other arthropods.

- To develop identification tools and databases on insect resources.

- Documentation and mapping of biodiversity of EPN and microbial biocontrol agents.

Molecular Entomology

- To act as a nodal agency for characterization, diversity analysis, DNA barcoding, phylogeny, development of species specific markers for insects, arthropods and other organisms.
- To develop genomic database and library for insect resources in the country; establish genetic and molecular evolutionary trends in insects, genetic prospecting of insect resources for maintenance, conservation, utilization and improvement and metagenomic analysis of insect derived resources and development of gene barcodes
- Development of databases, software tools and portals for insect resources; development of web consultancy, blogs and e-network for insect resources and workers
- Focus on structural and functional genomics
- Identifying the potential of RNAi in insect pest management. Identification of suitable target genes and delivery method to usher in a new eco-friendly approach that is safe to non-target organisms.

Biosecurity

- To conduct in-depth studies on areas related to quarantine and biosafety of accidentally introduced insects, nematodes, etc.
- Cataloguing of biosecurity threats to the Indian subcontinent; action plan for mitigating accidental introductions; the natural enemy complex across the world for putative threats; development of containment facility; strengthening international collaboration and public/ private sector partnerships.
- Impact of global warming and climate change (increased CO_2) on arthropod biodiversity with focus on pollinator diversity, parasitoids, pests, etc.

Mass production

- Exploration for specific groups of agriculturally important beneficial arthropods and associated organisms to evolve protocols for their mass production.
- Up-scaling mass production, commercialization and participatory rural appraisal (PRA) for performance evaluation.

Ecology

- Documenting insecticide resistance and its impact on natural enemy complex in selected agro-ecosystems.
- Synthesis and evaluation of pheromones for new and major pests
- Field evaluation for persistence and improvement of pheromones/ nano-formulations of sex pheromones and commercialization.
- Ecology of spiders and their role in IPM.

Vector entomology

- Biodiversity of major vectors, *viz.* aphids, whiteflies, thrips, leafhoppers, etc.
- Role of endosymbionts in vector competence and efficiency
- Population dynamics of insect vectors in the epidemiology of the plant diseases transmitted

Microbial biocontrol agents

- Mapping of biodiversity of microbial biocontrol agents in Sub-Himalayan region, Andaman & Nicobar Islands and Northeastern India
- Field evaluation and commercialization
- Gene mining for the identification of genes from microbial agents useful in pest management
- Metabolomics and functional genomics of microbial bioagents

Nematology

- Cataloguing, conservation, utilization and metagenomic analysis of biodiversity of agriculturally beneficial nematode fauna.
- Genome sequencing, EST analysis and miRNA of one representative insect pathogenic nematode, *Heterorhabditis indica* and its bacterial symbionts and a plant parasitic nematode.
- Comprehensive biology and genomic analysis of crop rhizospheres for enhancing natural antagonistic potential and plant health against nematode-wilt and soil borne disease complexes.

Outreach network projects on

- Management of sap sucking insects of major agricultural crops.
- National network project on spiders and other arthropods
- National network project on insect endosymbionts.
- Veterinary entomology, parasitology and documenting the species complexity and diversity.

Harnessing Science

The National Bureau of Agriculturally Important Insects is the nodal agency for harnessing insect and biological control agents for increasing the productivity of the crops. With the advent of organic farming, polyhouse farming, rainfed agriculture, etc., the significance for the use of these natural enemies is assuming more prominence. The new frontiers of science in the 21st century necessitates that a number of dimensions are researched to make plant protection more sustainable and researchable. The Bureau would also evolve mechanisms for accelerating work on genomics, pollinators, soil builders, spiders, mites and insect derived microbes. It would also attempt to realise its commitment for the pest management using insect & biocontrol measures.

In order to make these interventions highly productive and useful, strong scientific understanding and application of priorities will be focussed upon. Innovative and scientific approaches will be adopted in achieving the envisaged goals of the Bureau.

Systematics

Authoritative identification of pests and natural enemies is essential for research, development and successful implementation of IPM, biological control, biodiversity and conservation programmes. While taxonomic expertise in Coccinellidae (Coleoptera); Trichogrammatidae, Microgastrinae, Platygastroidea (Hymenoptera), Cococoidea and Aphidoidea is being built up, expertise in other important groups of agriculturally important insects, nematodes and other insect associated organisms is to be nurtured. The NBAII being the nodal agency in India for the collection, characterization and documentation of agriculturally important insects, will address all issues in this regard through (i) augmentation of existing collections, (ii) biosystematic studies, (iii) cataloguing of arthropod resources, (iv) networking of institutions and human resources, and (v) establishment of identification services.

Effective quarantine measures will also have to be put in place for the ever increasing pool of pest and beneficial species entering the country in this era of globalization.

Agricultural arthropod diversity

Molecular entomology

Molecular entomology has a considerable potential to address many of the challenges posed by large diversity and genome pool of insects. The Bureau will act as a nodal agency for molecular systematics, diversity analysis, DNA barcoding and development of species specific markers. On priority, whole genome sequencing of two insects, *viz., Plutella xylostella* and *Chrysoperla zastrowi sillemi* will be achieved and further would be continued for other insects. A national facility will be set up for insect genomic resources to enable prospecting, conservation and utilization, besides metagenomic analysis of insect derived resources. The focus will be on study of structural and functional genomics and development of related databases. NBAII will strive for identifying the potential of RNAi in insect pest management. Suitable target genes identified for pesticide and temperature tolerance will be utilized to develop their delivery method for eco-friendly pest management strategies. The role of symbionts in fitness attributes, tolerance to temperature and pesticides in natural enemies will be studied for exploitation of host endosymbionts for enhanced efficiency of natural enemies.

Biosecurity

Acerophagus papayae, a parasitoid imported for the classical biological control of papaya mealybug brought out spectacular control

With the opening of world trade regimes, the import and export of agricultural commodities have increased manifold, along with the potential threats for the introduction of destructive invasive pests and obnoxious weeds. The NBAII will put in place a mechanism for risk assessment, surveillance, monitoring and early detection of insects, pathogens, mites and weeds that are likely to invade India, and maintain databases on potential invasives and their candidate natural enemies for possible introduction in the event of their entry. Through a network of collaborators (Australasian, American, African and European) efforts will be made to import biocontrol agents for the management of invasives through classical biological control methods. Guidelines of the National Biodiversity Authority will be followed for the exchange of insect genetic resources.

There is a widespread concern that the increase in CO_2 level by 30% from the pre-industrialisation levels along with the increase in other greenhouse gases may witness detrimental agro-climatic conditions.

Invasive insects are likely to have more tolerance to climate change and have been postulated to increase their spread with more biotic potential and tolerance. The influence of climate change on the bioecology and behaviour of invasive pests will be documented along with the technologies for mitigation. Effect of climate change on pollinators and biological control agents including insect pathogens, antagonists, and weed killers will be studied along with perspective plans to mitigate the effect.

Open top carbon dioxide chambers for climate change studies

Mass production

Systematic surveys conducted in different agro-ecosystems have indicated that clear inter and intra-specific variations exist in populations of insect pests and their natural enemies. Studies have indicated the differences in pest populations with respect to their susceptibility to pesticides, natural enemies, response to abiotic factors, the magnitude of their role as disease vectors, etc. To conduct basic studies on these aspects, it is important to have continuous cultures of these insects. Live cultures of pest insects are also in great demand for students, researchers and private companies. NBAII being the only organisation holding the largest repository of live insect cultures, can actively participate in searching and documenting populations of important groups of insect pests and their natural enemies from different zones.

With the growing awareness regarding the hazards caused by chemical insecticides, there is a clear emphasis on organic means of plant protection and an increasing demand for food free from chemical pesticide residues. At this juncture, NBAII can take up the major task of identifying potential strains / populations of bioagents like trichogrammatids, scelionids, braconids, ichneumonids, coccinellids, anthocorids, chrysopids, predatory mites, etc., develop production protocols and standardise technologies for their utilisation as an integral part of organic farming. It is envisaged that beneficial insects and microbes will have a major role to play in the management of polyhouse and storage pests. The outcome of the above investigations could lead to cost-effective and sustainable methods of pest management.

Ecology

Resistance to insecticides has been documented in species like *Helicovera armigera* (resistance being up to 2000-fold in some geographical populations). Mapping of geographical populations of *Plutella xylostella*, *Bemisia tabaci*, planthoppers and other sucking pests in different agro-ecosystems is essential to develop effective IPM practices to manage these pests. Besides, the basic principles underlying the resistance mechanisms need detailed investigation to evolve effective insecticide resistance management practices.

Insects use volatile chemicals, often termed semiochemicals, for their intra and inter specific communication. Pheromones for several agriculturally important pests are utilized for monitoring purposes. However, with the variations in pheromone blends for different geographical populations and with little knowledge on the synergists, the pheromone technology for the existing pests needs refinement through development of blend ratios, formulations, including nanoformulations, for effective management of pests through mass trapping and mating disruption. Pheromones of alien invasives and weed biocontrol agents will help in quarantine monitoring and post release evaluation of these organisms respectively. Successful technologies on pheromones and semiochemicals will be available for commercialization and farmers' use. Molecular basis of semiochemical perception will be researched with the objective of utilizing bioinformatic and biotechnological tools for the development of anosmic males and olfacticides for the management of pests.

Understanding tritrophic interactions involving crop-pest-natural enemy will play an important role in the conservation of natural enemies and pollinators. Selection of varieties of oilseeds, pulses and vegetable crops with favourable physical and chemical factors for beneficial insects will help in the conservation of biocontrol agents and pollinators. Creation of suitable habitat diversity, use of kairomones and synomones and provision of shelter and food (refugia) will be explored as useful conservation strategies in crop ecosystems. *In situ* conservation of natural enemies and pollinators will be envisaged through the use of selective weed species.

Impact of climate change on important predators, parasitoids, pollinators and vectors will be examined in detail to mitigate the effect of climate change and thereby increase the productivity of selected oilseeds, pulses and vegetable crops.

Xylocopa sp., an efficient pollinator in pigeon pea

Nanotechnology is likely to witness a boost in coming years with more effective utilisation in crop protection. Nanosensors to detect volatiles from insects (such as pheromones/kairomones) and pathogens or pathogen/insect infested crop plants (synomones) will be used as sensitive detector systems to develop plant protection strategies. Application of nanotechnology for the development of microbial biological control agents with increased shelf life and easy delivery systems will be attempted.

Vector entomology

Strategies for management of vector borne viral diseases of crop plants using symbionts will be developed. At present for the control of vectors we have only chemical methods. Symbionts will be identified that are involved in the transmission of viral diseases in crop plants and their role in transmission will be understood and strategies will be developed for vector and virus management. There will be reduced use of chemicals in vector management. Besides the role of symbionts in virus-vector relationship, molecular characterization and genomics of virus-vector relationship also would be studied.

Microbial biocontrol agents

For minimizing the usage of chemical pesticides in agriculture, microbial biocontrol agents offer an immense scope for alternate management of pests and diseases of crop plants. For this aggressive strains with higher field efficacy have to be identified and their mass production and formulation technologies are to be standardized for large scale uptake by the farming community. Research on these lines of work is being taken in extensive ways at NBAII for development of alternate biocontrol technologies for pests and disease management with sustainable crop production and safety to the environment. Apart from this biodiversity of microbial bioagents from the hotspots will be mapped and useful genes will be identified by gene mining for the effective management of pests and diseases. Novel bacteria including Bt isolated from arthropods toxic to insect pests will be characterized identified and genetically improved. Establishment of gene pool of arthropod derived bacteria and their exploitation in cropping systems would result in reduced use of chemicals and environmental protection.

Nematology

The use of carbamates and chlorinated hydrocarbons for the management of white grubs, other soil insect pests and plant parasitic nematodes has been recorded to have adverse effects on soil health and productivity, besides having limited success in controlling target pests. Dr. M. S. Swaminathan, Chairman, MSSRF, Chennai, rightly attributed the declining soil health as one of the major causes for declining crop productivity, and soil antagonistic potential and soil biodiversity as the prime factors for maintaining soil health. Entomopathogenic nematodes offer an environmentally viable alternative to chemicals for the control of root-grubs and soil insect pests, and maintain and restore the soil health.

It is our vision that the plant parasitic nematodes have been the focus in the diversity analysis as the plant parasitic nematodes remain the main detrimental factor in protected cultivation. Further, studies on nematode biodiversity are envisioned to be expanded to entomopathogenic nematodes, soil nematodes, veterinary helminths, and fish nematode parasites.

With the recent developments in organic farming practices and switch over of states to totally organic cultivation in north-east, Uttaranchal and others, NBAII envisions to generate scientific data on biologically based pest management strategies for soil insect pests polyhouses using antagonists and entomopathogenic nematodes. The following two broad areas of research in nematode research are prioritized.

Biodiversity of nematodes: creation of nematode-resource database at national level for plant parasitic nematodes, entamopathogenic nematodes, veterinary helminths, fish parasitic nematodes, etc., with data on their traditional morphometric, systematic and molecular identification and mechanisms for biosecurity of the country. Further, genomic sequencing, EST analysis and miRNA of a representative insect pathogenic nematode, *Heterorhabditis indica* and its bacterial symbiont and a plant parasitic nematode are contemplated.

Bio-management of plant parasitic nematodes and their associate wilt diseases in protected cultivation and utilization of entamopathogenic nematodes in specific cropping systems including protected cultivation will be aimed at.

IP Generation, Technology Management and transfer

Technologies developed at NBAII will be validated in multi-location trials on cereals, pulses, oilseeds and horticultural crops. Refinement of technologies and constraints in technology adoption will be studied through different sources. The KVKs, TTCs and State Departments will be utilised for the transfer of technology.

Major stress will be on transfer of the technology developed on biological suppression of pests of crops through on-farm demonstration, farmers' melas, exhibitions, slide shows, videos, radio and TV talks, extension bulletins, leaflets and farmer friendly software. This will be done in collaboration with the State Agricultural Universities, Agriculture and Horticulture Departments, KVKs and their functionaries at various levels. Social scientists will be involved at all phases of biological control programmes starting from problem identification and research through solution discovery, evaluation and farmers' training.

Politicians and policy makers in the government should be sensitised and educated about the basic concepts of biological suppression so that the government does not adopt policies that actively discourage the use of biological control. Use of mass media, communication through newsletters, etc. are essential to educate all groups including growers, public, politicians, private enterprises and environmental groups. Encouragement of private entrepreneurs for the production of biocontrol agents will be done to meet the demand for the biological control agents. Institute Technology Management Committee will be responsible for addressing issues of commercialization of transferable technologies and transfer to the farming community to promote the uptake of various technologies.

Human Resource development

Enhancing and upgrading knowledge of human resource is a pre-requisite for implanting research programmes, developing technologies and their utilisation to harness opportunites. Subject matter specialist training will be conducted for scientists, stakeholders and technicians to enhance awareness and uptake of technologies. Long term and short term training programmes on specific areas will empower the researchers and educationists in areas of special interest.

Efforts will be made to encourage students to take up biodiversity, biosystematics and conservation of biological control to enhance their competence through scholarships and post doctoral fellowships in specific areas of research.

Linkages

A comprehensive linkage policy within the country and with the resources of the countries worldwide is envisaged with an emphasis on genomics, bioinformatics, gene/allele mining and other frontier areas of biotechnology. It is important to continuously strive for obtaining potential natural enemies in collaboration with international institutes like CABI, USDA, CSIRO, and several other institutions for the management of alien pests, diseases and weeds. Free exchange of preserved specimens will be envisaged with international organisations for the purpose of carrying out basic taxonomic studies and identification. The network of KVKs and State Departments of Agriculture will be utilised for the dissemination of technologies. The existing network of All India Coordinated Research Projects on honey bees, mites, weeds and other technology assessment units of crop-based ICAR institutes will be suitably utilised for the propagation of technologies.

Private-Public partnerships will be developed with biological control/ biopesticide producers for the development, scale up and commercialisation of technologies.

Strategy and Framework

The NBAII envisages the adoption of the following strategies and framework through the three proposed divisions

Division of Biodiversity, Biosystematics and Biosafety

- Augmentation of existing collections and maintenance of a national repository.
- Biosystematic studies on identified groups of insects using traditional and molecular approaches
- Generation of checklists, catalogues, illustrated field identification guides and digitisation of collections.
- Networking of institutions and individuals working on biosystematics.
- Establishment of a credible and affordable identification service for insects and mites of agricultural importance to cater to national and regional needs.
- Classical biological control through the importation of biological control agents from the country of origin of the pests.
- Biosecurity, threat perception with action-plan for putative accidental introduction of alien pests.
- Biodiversity of nematodes of agricultural and veterinary importance.
- Biosystematics and ecology of spiders in different agro-ecosystems.

Division of Molecular Entomology

- Development of DNA barcodes and molecular phylogeny for important insect pests, mites, nematodes and natural enemies.
- Structural genomics and bioinformatics for selected arthropods.
- Gene mining and allele mining for the selection of genes of specific interest and their utilisation.
- RNAi technology for IPM.
- Genome sequence repository for useful genes.
- Endosymbionts and their role in pest management, virus-vector relationship, and insecticide resistance.

Division of Bioresource Utilisation and Conservation

- Utilisation of agriculturally important arthropods for the management of insect pests.
- Protocols and designs for the establishment of state of art mass production units for important predators, parasitoids, insect microbials, entomophilic nematodes and pathogens for nematodes**.**
- Semiochemicals for invasive pests and weed biological control agents for quarantine and postrelease monitoring.
- Studies on the effect of climate change on the population dynamics, biology, behaviour of pests, vectors and natural enemies to mitigate effects of climate change.
- Studies on role of pollinators in different agro-ecosystems, effect of agro-chemicals and dynamics in crop productivity

Technology dissemination to increase productivity

- Dissemination of scale-up technologies through PPP.
- Large scale demonstration and dissemination through AICRP, KVK, and lab-to-land programmes. Training of extension workers, farmers, rural women and non-governmental officials would be crucial.
- Publication of multimedia resources, technical bulletins, folders, online dissemination through websites, reports, and popular articles for the popularisation of technologies. Success stories will be highlighted with detail of technologies and economics of use.

Monitoring and evaluation

- Monitoring of project output through the Project Monitoring and evaluation cell, Institute Research councils, Research Advisory Committee, AICRP group meeting, QRTs and other technology assessment procedures.
- Impact assessment of technology adoption by private agencies/extension experts for feedback and refinement of technologies.

Linkages with NBPGR and NBAIM to map the biodiversity of insect and microbes utilizing the infrastructure facilities in the respective Bureaus.

Epilogue

The NBAII is resolved to relentlessly pursue the objective of reducing and ultimately phasing out the use of toxic chemicals in pest management to ensure the production of food free of hazardous chemical residues and a crop environment that is clean and benign to humans and other life forms. The pest management strategies envisaged will be based on a profound understanding of the complexity of ecological relationships so as to work in consonance with (by being not disruptive to) natural ecological processes.

Efforts will be made by the NBAII to implement newer, visionary pest management programmes with the active cooperation and involvement of Government and non-Government development agencies, financial institutions and farmers – both large and resource-poor.

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ANNEXURE- I : STRATEGIC FRAMEWORK

Goal	Approach	Performance measures
Systematics Strengthening traditional taxonomy, nodal agency for collections, characterization and cataloguing databases on insect resources and documentation of biodiversity in areas.	Networking of expertise available across the length and breadth of the country. Strengthening of human resource at NBAII	Expertise in number of new insect groups that could be identified. Precision.
Molecular Entomology Diversity analysis, DNA barcoding, phylogeny, development of species specific markers for the insects, genomic database and library for insect resources, gene barcodes data base for insect resources Structural and functional genomics, Web consultancy, blogs and e-net work for insect resources and RNAi in insect pest management	Use of MtCO1 for molecular systematics, barcoding, Gene mining for functional genetics Prioritization of pests and proteins to be directed for gene silencing etc.	Number of insects identified through molecular systematics Identification of biotypes and strains of tradional systematic Analysis of cryptic species, exploration of functional genemics for areas beyond entomology and RNAi in IPM and contribution to basic knowledge of insect molecular biology.
Bio-security Quarantine and bio-safety of accidentally introduced insects, nematodes, mites etc., cataloguing of bio-security threats and action plan for mitigation.	Cataloguing and quarantining of bio safety measures. Action plan for mitigation Data base on natural enemies of accidentally introduced pests across the world. Studies on pollinators diversity, parasitoids and pests in areas subject to climate change	Prevention of accidentally entry of pests into our country, confinement of pest to regions, time taken in mitigating accidental introduction and knowledge in understanding effect of climate change on pollinators and parasitoids.
Mass production Protocols for the mass production, upscaling and commercialization of bioagents.	Laboratory experiments and private and public partnerships in up-scaling. Technology management for commercialization and use of extension agencies for proposal of technology	Number of insects/ organisms for which mass production and upscaling has been developed.

Ecology Insecticide resistance in pests, impact on natural enemies complex, synthesis and evaluation of new pheromone and ecology of spiders and their role in IPM.	Esterase, MFO and other parameters in pests and parasitoids, new pheromones evaluated and data on role of spider in different agro ecosystem	Development of IRM for target pests, conservation of natural enemies, pheromones for major pests and knowledge on spiders
Vector entomology Biodiversity of major vectors, endosymbionts, vector in the epidemiology of the plant viruses and population dynamics.	Survey for major vector across the country Systematic studies on endosymbionts and correlation between vector density and virus diseases	Contribution to virus diseases management based on population density and vectors Understanding the role of endosymbionts on emergence of new biotypes.
Microbial biocontrol agents Bio-diversity of microbial biocontrol agents in sub-himalayan region, Andaman and Nicobar islands and North eastern India, gene mining, microbial agents, metabolomics and functional genomics.	Survey in respective regions and use of molecular tools	Number of new species documented from these regions and contribution of basic knowledge on gene mining, metabolomics and functional.
Nematology Biodiversity of EPN, genome sequencing of EPN and crop rhizospheres for studies nematodes/ disease management.	Survey molecular biology and field experiments to understand rhizospheres nematode diseases	Number of new species collected or identified.
Outreach network projects on Sap sucking insects of major agricultural crops, network projects on spiders, symbionts and biosystematics	Networking of different research institutes and different disciplines Prioritizing the thrust areas and Strengthen action plan	IPM for management of sucking pests Utilization of spiders in IPM Basic knowledge on endosymbionts and new information on biodiversity of veterinary pests and parasitoids