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ONLINE MAGAZINE TO PROMOTE INSECT SCIENCE

FEATURING

A complete ICT solution for crop health management

Citizen science in studying Lepidoptera biology and conservation

In conversation with Dr. Chandish Ballal

INDIAN ENTOMOLOGIST
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Editorial Board

*Cover page: Photo by Shashidharswamy Hiremath

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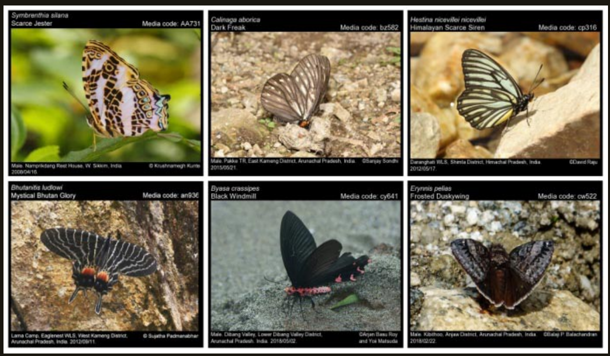


EDITORIAL NOTE

WELCOME TO INDIAN ENTOMOLOGIST

The Entomological Society of India is proud to pioneer this unique activity of publishing online the "Indian Entomologist" with an objective of encouraging the participation of young minds in promoting Entomology as a science. There is a need to provide a forum for informal interactions among the Entomologists in discussing about the current scenario of Entomology as existing in the outputs of such international societies elsewhere. The Society is thankful to the few entomologists who came forward for making this venture feasible. The Society is also pleased to see them in the editorial board for steering this pioneering activity and make it possible.

The scenario in Entomology, especially in terms of publishing activity needs updating and become state of the art. It is necessary that such a forum for informal interactions and expositions by the young minds practicing entomology is made possible. Such interactions will require a different kind of presentation. It is befitting that the "Indian Entomologist" has chosen its contents appropriately. The contents have been designed accordingly with this inspiring motive. The "Feature Articles" "Students Corner" "In Conversation", "Photo Contest" in particular are of unique appeal and will attract young talents in an informal manner, and promote the thoughts in Entomology and make it reverberating in those minds who read these. I am sure the presentations in the "Indian Entomologist" will motivate young upcoming minds especially the students who study and do research in Entomology. Indian Entomologist's blog section is a unique social platform to share new developments related to Entomology for providing an avenue for healthy discussion. Also any content in the "Indian Entomologist" is original and creative, with an objective of open interaction and I am sure it will promote the "genesis of real facts" which are the core of "science"

I am sure this unique venture will sustain itself due to its excellent beginning and the inspiring minds which are behind this.

Dr. V.V. Ramamurthy

Editor in Chief, Indian Entomologist

*e*SAP: A complete ICT solution for crop health management

Aralimarad Prabhuraj

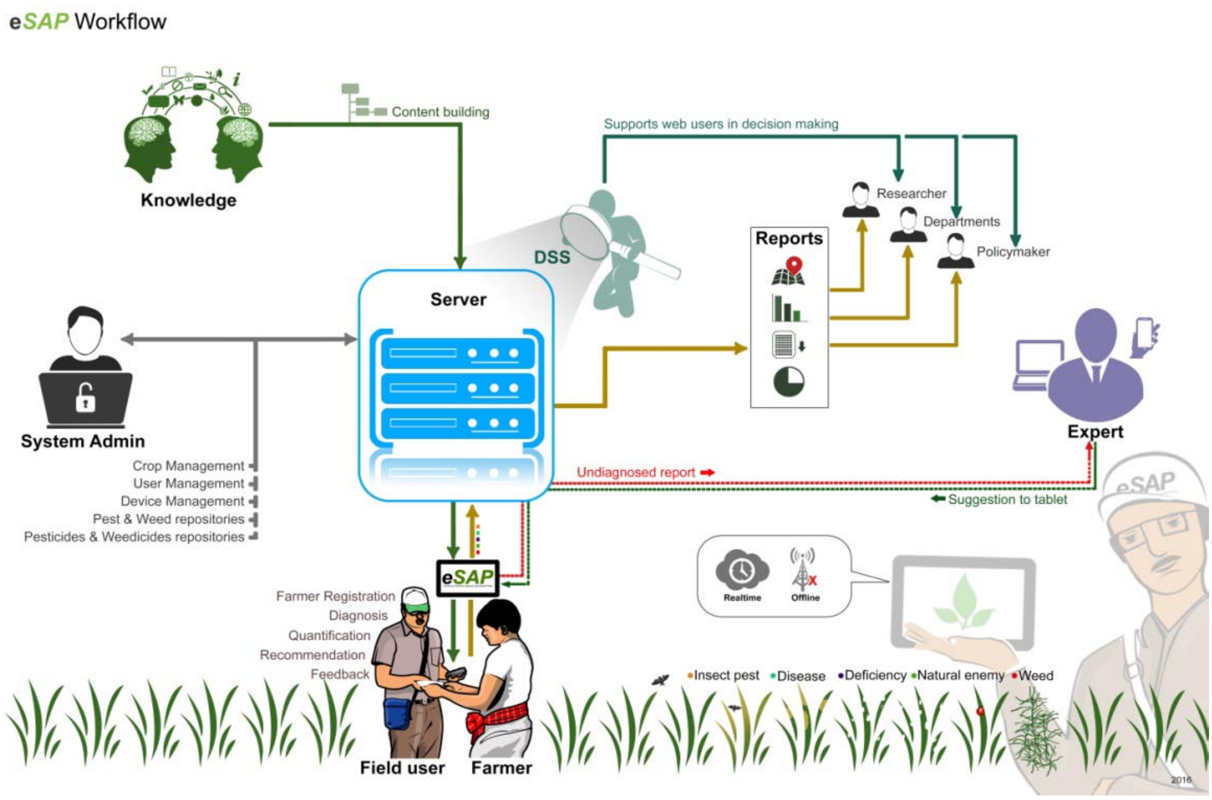
Abstract: eSAP (Electronic Solutions against Agricultural Pests) is an unique product successfully addresses current challenges in agricultural sector by translating expertise into practice at farmers' door step in terms of prescription based plant protection, sustainability of soil and inputs to policy makers for scientific assessment of crop health over a region. It successfully integrates different agricultural sub-systems through an ICT solution leading to effective crop management solutions for farmers of India. It generates rural employment and food security contributing to Sustainable Development Goals. The project has been deployed in Karnataka state involving Agriculture Universities, State departments and ICAR institutions. It was widely appreciated as the most innovative solution in crop health programme with focus on sustainability. The project received wide acclaim during the FAO-ITU led e-Agriculture Forum at Bangkok in 2016. It is the recipient of "WSIS 2018 Champion" award instituted by UN-ITU forum. It is one of the finalists in the Manthan South Asia awards for 2016. The project is also figuring in ITU-T study group case studies on e-agriculture.

Key words: eSAP, information communication technology, crop health management, pest surveillance

Crop health management is a complex subject. It majorly encompasses problems caused by and solutions for various pestiferous species of insects, viruses, fungi, bacteria, nematodes and weeds, and nutritional deficiencies that decrease crop production and impact farmers' welfare. There are numerous pests that affect each crop, and not all impact in equal propensities at any given space and time. They vary with soil type, short- and long-term weather patterns, physiography, cropping history, cropping pattern, cropping practices and such external influences. They are also impacted by other competing pests, predation, emigration from and immigration into the agro-ecosystem. Further, the host plant itself responds to pests differently in different space/time situations and affects the dynamics of pests. All these add significantly to the complexity of pest dynamics.

On the other hand, pest management options are equally complex. There are many microbial, botanical, chemical, cultural, mechanical and biological methods. There are many techniques and tools for administering these methods to manage pest populations. Some of them are ecologically sensitive, while some are part of the humble natural world; some are economical, while some are expensive; some methods suit intensively managed agriculture, while some others suit extensive farming systems, and a mismatch could have dire consequences on the society, like large-scale ecosystem poisoning.

Further, it is often observed that farmer preferences play a significant role in the selection of management strategies. Some look for organic methods, some for inorganic, some prefer cultural and biological, while some others are open to any effective management action. All such variations should be taken into consideration while suggesting remedial actions. Moreover, there is a constant influx of new pest management tools and molecules into the market. These too need to be used appropriately so that farmers and the Nation accrue the maximum benefit. Therefore, pest management is an extremely challenging and complicated section of agriculture.



Current Scenario of Pest Management in India

It is common to find farmers in India visiting pesticide-selling retail shops, with or without samples of diseased plants, and purchasing the ‘remedies’ sold by the retailer. More often than not farmer ends up buying excessive pesticides and unnecessary crop health enhancers, and without certainty that the concoction would resolve the problem. This is a very dangerous scenario. Just imagine the condition of the society if the medical world too had done the same — dumped a variety of medicines in the patient’s body without diagnosing and quantifying his disease! In the agricultural world, farmers’ capital expenses increase without any assurance of crop improvement (which has other serious ramifications — increased and ill-assured capital expense can result in undesirable social consequences). There is a significant increase in environmental pollution and raise in health

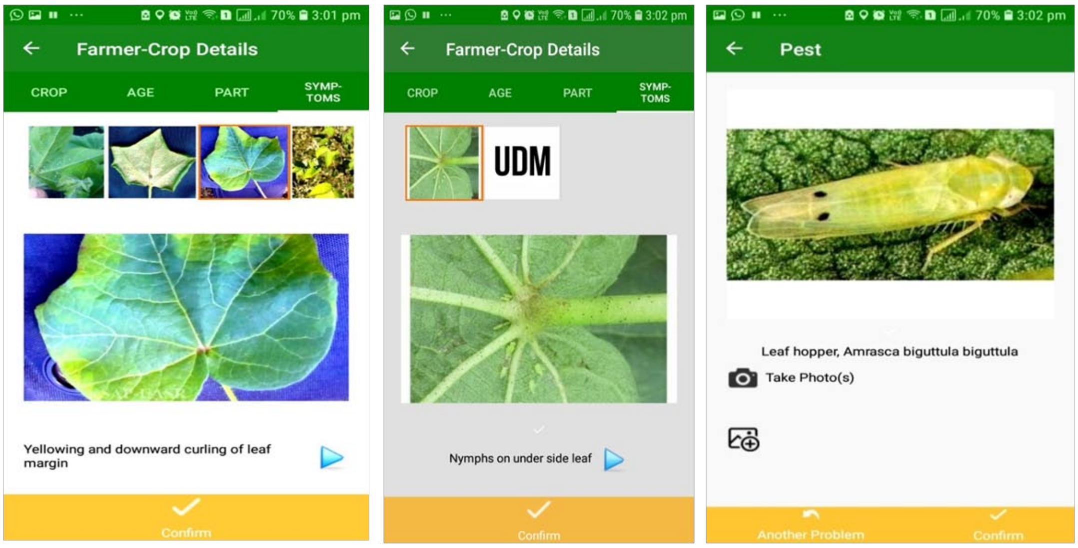
Farming society in India does not have access to timely and accurate crop health diagnosis and management.

issues concerning farmers and consumers. All this is because the farming society in India does not have access to timely and accurate crop health diagnosis and management.

Electronic Solutions against Agricultural Pests (eSAP) — a prudent choice

eSAP is a path-breaking ICT system dedicated to crop health management. Insect pests, microbial diseases, nutritional deficiencies, and weed problems are covered in the current version of eSAP. Further, it enables the enumeration of different species of natural enemies, which have gained importance during recent times. The potential of eSAP is such that any new agricultural technology can be communicated in an extremely effective manner, in real-time to the field; and, field situations across space and time are instantaneously made known to the managers/policy makers/researchers. For instance, if a new pest management strategy has to be disseminated to many field workers spread across a vast geography, a press of a button in some remote location would ensure instantaneous delivery to all of them. The platform can disseminate information built in various forms like videos, animations, images, text, and audio. Further, spatial coordinates of the field are instantaneously reflected on a GIS map along with extent of severity of the problem. Additionally, such data are presented in automatically updated graphs and tables that enable real-time monitoring of field situations. Inbuilt intelligence aids the process of decision-making so, that biases are minimized and decisions are based on authentic, verifiable field data. Concurrently, this system will ensure the seamless integration of different players in the agricultural ecosystem – field users, subject experts, managers, policy makers, and so on. This application has been built and successfully tested and put to practice for the first time in India by the University of Agricultural Sciences (UAS), Raichur, Karnataka.

The features can be briefly summarised as follows: eSAP is an application built on a platform that opens a gateway for two-way dissemination of information in real-time. Central to the platform is a handheld device that i) provides field users with all the relevant information in their hands; ii) information can be accessed offline; iii) information is intelligently metamorphosed into a form that can be easily understood and put to use by illiterate users transcending language barriers; iv) it has substantial in-built intelligence for on-field decision support; v) it has protocols for intelligent surveys and data collection; vi) specific information on any/all devices can be updated remotely that makes real-time dissemination possible; vii) there is real-time expert connect to handle emergencies and unknown field situations; and, viii) all forms of data, including multimedia, can be disseminated in both directions in real-time. The platform enables policy makers, researchers, and users at the other end of the spectrum to obtain field information in real-time. Field



data that streams-in is viewed over GIS platform. There are automatically updated graphs and tables along with decision-support intelligence. It is multidirectional, flexible and scalable.

The platform has these essential components – (i) handheld field device: it contains the application and content; has ability for multimedia data capture; can send and receive data in 2G/3G/4G/Wi-Fi modes; can be operated in the farms irrespective of the availability of network; (ii) web-based application: it would enable retrieval and presentation of data generated from field devices; forms the entry point for agricultural content to be disseminated to the field devices; provide GIS/other graphical reports from the data generated; enable device management; (iii) expert application: this is available exclusively to experts who are designated to resolve the few undiagnosed problems that might arise from the field. The experts shall be able to exchange opinions among themselves through the application and post their responses back to the field device; and (iv) cloud instance: it will enable data storage and retrieval; data analyses; be the single point of contact for the devices; facilitate data/content exchanges between the devices and web (local hosting is also possible with eSAP).

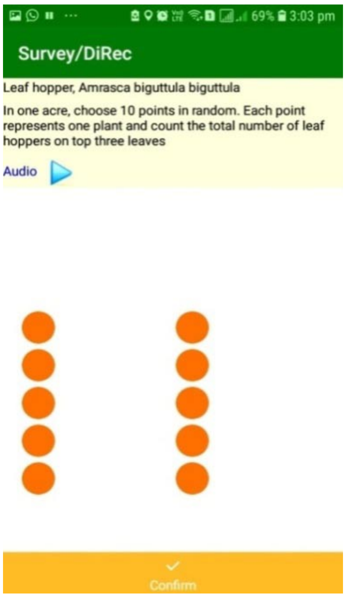
Features that assist field workers

Pest identification

This is one of the most highlighted features of eSAP. The architecture for pest identification follows a unique image-based branching model. High-quality images that characterize pests and their symptoms are adopted to intuitively guide users in identifying the pest. Audio assistance in local language is provided at every step; the user need not be literate. The user merely needs to touch a relevant image at each of the steps to identify the problem-causing organism. The content aims at covering all known pests, so that users are able to identify all pest-related problems in the field itself; dependency on external help is minimal. As the content can be accessed offline, it can be used anywhere, anytime.

Pest surveillance

Pest identification alone is not sufficient to take up remedial measures; it is essential to determine the extent of the pest problem prevalent in each farm. For this purpose, there are intuitively built pest-specific survey forms to quantify the damage caused by various pests. Data are automatically analysed based on the survey and the pre-determined economic threshold values for each pest. Results and respective suggestions are instantaneously visible on the field device. Depending on this, the user can decide on adopting management strategies or might simply watch for a further buildup of the pest. The survey can be conducted offline too and results can be obtained straight away.



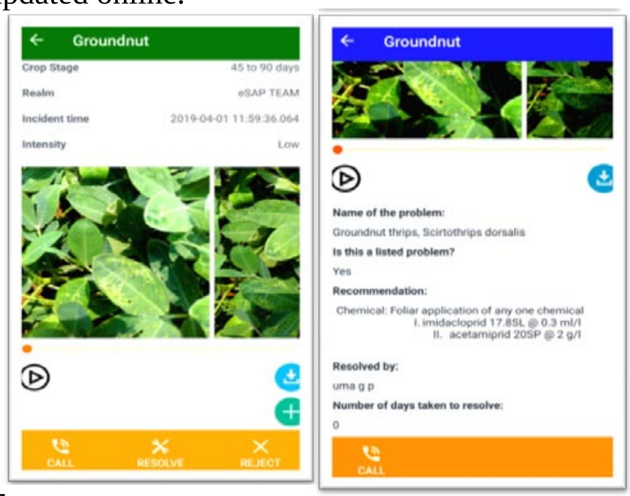
As surveillance entails multiple image capture by the field device, a set of close-ups and field images along with data on the crop, crop age, pest damage and geo-coordinates of the field are transmitted to the cloud for further use by researchers/policy makers. Data transfer occurs instantly on the availability of telecommunication signals.

Pest management

A schedule of recommended management strategies is made available against each pest after determining the extent of the damage. The strategy takes into account the crop, crop age and crop part affected. The user may adopt strategies depending on the automated suggestion made based on the survey conducted. Management strategies are also available offline. Any new strategy, or pest management technology, can be remotely made available on the availability of telecommunication signals.

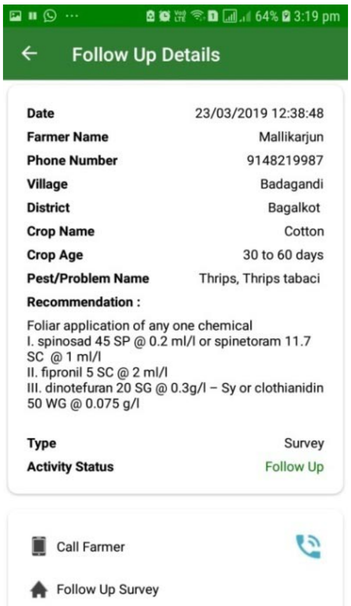
Pest information

To supplement the knowledge of users, details of pest are made available on the field device, which is available offline and updated online.



Expert connect

Under extraordinary cases, when the available content in the field device is insufficient or the user faces difficulty in using it correctly, expert connect is made available on the device. Here, the application not only enables capture of multiple images of the crop, but also makes it possible for the user to record his opinion as he speaks. These images and audio files along with other relevant details like geo-coordinates, crop and farmer details are transferred to the cloud in real-time. Designated experts receive an alert regarding the same, and can access information using eSAP web application. The application also allows inter-expert exchange of information before posting their suggestions to the field device. Normally, this process takes less than ten minutes when telecommunication networks are available to all the users.



Feedbacks

As with respect to adoption of technologies and assessment of technologies by field users, provision is made to capture feedbacks in the form of multimedia content, like audio and images, and intuitive grading.

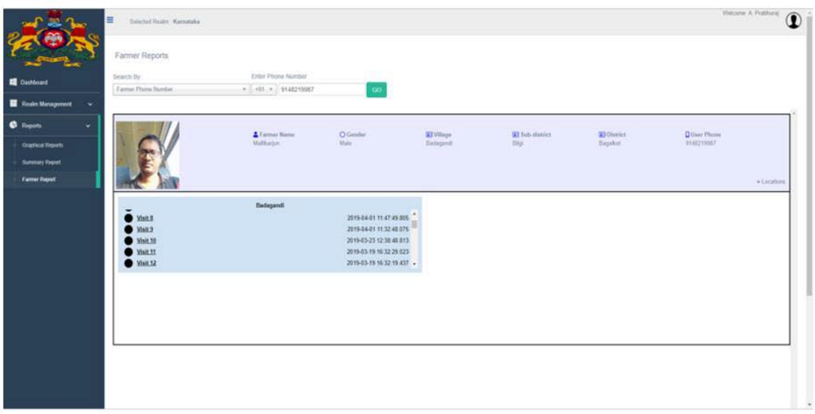
Features that assist policy makers/researchers

Farmer database

An important feature of eSAP is the ability to capture farmer-specific data in the field and build database of the activities of each farmer. All relevant details of farmer, including images, are captured on the field device and a database is created in the cloud, which is accessed through the web application. Every farmer is identified by a unique number with which a log of all his activities across time is created and made available for further use. Also, opportunities to capture any information on farm activity are made available.

Data analyses and reporting

Data captured from various field devices are fed into several databases in the cloud, which are then made available for viewing over the GIS across any defined time and any chosen set of parameters. Users can access automated graphs over eSAP's web application. Points over GIS maps and continuously updated graphs/tables allow real-time monitoring of pest situations across any defined space.



Decision support system

Micro-level decision support system is provided on the field device for taking decisions on pest management strategies to be adopted. eSAP also makes provision for macro-level decision support in the web application. Based on the data generated across space and time, and built-in analyses, alerts for various scenarios can be customised by each web-user, which would warn in several ways – on mobile phones, emails, etc. for taking immediate actions on a larger scale.

Content management

eSAP allows for real-time dissemination of pest management technologies and other information to all/designated field devices. Information on new pests or new information on existing pests, new/modified pest identification routes, additional/new symptoms, new survey plans, and new management strategies can be remotely updated on the field devices over existing telecommunication networks.

Device management

The device part of the platform exploits emerging technologies with capabilities to generate/provide data in a format that an illiterate user can generate/use easy-to-understand multimedia content. Today, telecommunication networks reach a wide spectrum of geographies. However, in the absence of such networks, the device utilises offline storage and delivers content on network availability.

Visible impact of the case study

A study on "*perception analysis of eSAP by farmers in the districts of implementation of eSAP"* conducted by the Extension Department has revealed highly positive response from the farmers (70% of the sample farmers gave positive response) regarding the power of the technology in all aspects of crop protection. eSAP has helped farmers overcome a major difficulty - reliable identification of their crop pest problems. Further, eSAP has effectively driven the concept of quantification of the pest problem and has introduced the concept of pest-intensity based management system. Today, many farmers receiving printed prescriptions carry it to the retailers and demand the same to be given to them. It has a significant impact on the interactions between the pesticide retailers and farmers. Their confidence levels for tackling pest problems have increased. This is largely because of the fact that farmers are completely involved in the identification and quantification process by the extension functionary.

Three more fellow agricultural universities in Karnataka have adopted eSAP. Together, there are more than 1,00,000 farms in Karnataka who have benefitted from eSAP till date. All the horticulture officers of two districts (Ramanagara and Chikkaballapura) provide pest solutions to farmers using eSAP systems. More than 100 extension workers recruited under various projects have received employment opportunities. The opportunities for selling ineffective (and sometimes, spurious) substances has drastically come down. The quantity of pesticides applied has also been according to the prescription, which has reduced indiscriminate usage.

Scientists have discovered many new pest problems in their areas of operation through eSAP. Notable has been the whitetip disease of paddy and banana skipper. eSAP has a provision for flagging difficult to identify problems in the field, which has resulted in these discoveries. More important has been the fact that identification of the new problems and their management strategies can be disseminated to the field devices in just minutes, such that the field users can henceforth manage these problems by themselves. Certain area-wide decisions have been taken by managers on the basis of data made available in real-time through eSAP system. Notable example has been management of cotton leafhopper resistance in Raichur area. Real-time data showed that the pest population was not declining in the area despite adoption of management strategies. Soon, the expert team found that the population had developed resistance to the pesticide. Administrators, with the help of researchers, decided on changing the strategy. The new strategy was made available on the field devices in real-time, which resulted in successfully managing the pest population before it got escalated to serious levels. Such has been the impact of eSAP.

Deployment of eSAP

Deployment of eSAP technology started since January 2013 after pilot scale studies during 2012 under the aegis of University of the Agricultural sciences, Raichur and has spread to all the districts under other Agricultural Universities in Karnataka. eSAP has reached over 1,00,000 farmers covering 26 crops in all the 25 districts of Karnataka involving all the five (5) agricultural universities.

Today, the need is to draw a holistic picture of pest management for the entire state of Karnataka. Recognizing this, the Government of Karnataka has adopted state-wide implementation of eSAP programme with UAS, Raichur as the nodal centre in coordination with other State Agricultural Universities and ICAR institutions.

Acknowledgement: The author acknowledges the financial assistance provided by RKVY, Govt. of India, KSDA and KSHD, Govt. of Karnataka. eSAP technical team, UAS Raichur, UAS Bengaluru, UAS Dharwad, UAHS Shimoga, UHS Bagalkot, IIHR Bengaluru as knowledge partners and Tene Agricultural Solutions Pvt. Ltd., Bengaluru as IT partner are deeply acknowledged.

Professor Aralimarad Prabhuraj of the University of Agricultural Sciences, Raichur, Karnataka, India works on insect ecology with special reference to migration and reproductive biology. His other area of research is development of ICT tools to enhance the extension services in crop health management. He and his team has been involved in developing a novel ICT application called e-SAP (Electronic Solutions against Agricultural Pests) which empowers the extension personnel to diagnose and quantify the problems related to insects, diseases, weeds and nutritional disorders in crops and provide solutions on real time.
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The role of citizen science in studying Lepidoptera biology and conservation in India

Sanjay Sondhi and Krushnamegh Kunte

Abstract: Citizen science is transforming the landscape of big data on biodiversity, ecology and conservation. In India, new data on the distribution and biology of butterflies and moths are being generated through the Butterflies of India and Moths of India websites with contributions from a large network of amateur naturalists. These efforts have led to new species descriptions, species rediscoveries, and range extensions into India. These citizen science platforms are filling gaps in our knowledge of butterfly and moth distributions, flight periods, early stages, larval host plants and other natural history information, including that of many endemic, rare and endangered species.

Key words: biodiversity informatics, butterflies, moths, Lepidoptera

Recent reports of decline in insect populations have raised alarm worldwide (Hallmann et al., 2017; Leather, 2018; Sánchez-Bayo and Wyckhuys, 2019). The situation with Lepidoptera is not any different, with many studies reporting population declines of butterflies and moths (Fox, 2013; van Langevelde et al., 2018; Thogmartin et al., 2017). In Europe and North America, citizen science programmes have been used successfully to generate large data sets for monitoring populations (Carpaneto et al., 2017; Chandler et al., 2017; Dennis et al., 2017; Pocock et al., 2015, 2017). The United Kingdom Butterfly Monitoring Scheme (UKBMS) has been collecting butterfly data since 1976 (https://www.ukbms.org). The Big Butterfly Count has been conducting annual butterfly counts in the United Kingdom since 2010 (https://www.bigbutterflycount.org).

National Moth Week, which started in 2013, conducts annual moth monitoring in July across the world (Moskowitz and Haramaty, 2013). In the United States, caterpillar-monitoring programs are being used to monitor arthropod early stages (Hurlbert et al., 2018).

In India, there has been no long-term monitoring of insect populations or large-scale rigorous documentation of insect biodiversity. In fact, the problem remains of insufficient data on even flagship groups such as butterflies with respect to their diversity and distributions, flight periods, early stages and other basic ecological information. In order to fill this gap, in 2010, the Indian Foundation for Butterflies launched a species-based bioinformatics platform, Butterflies of India (https://www.ifoundbutterflies.org/).

Using the same bioinformatics backbone, numerous other citizen science initiatives were launched subsequently covering odonates (April 2014), moths (November 2014), cicadas (February 2015), reptiles (August 2017), amphibians (August 2017), birds (October 2017) and mammals (September 2018). Collectively, they form Biodiversity Atlas – India (https://www.bioatlasindia.org/), which is a species-based bioinformatics platform that is voluntarily supported by numerous organisations such as the National Centre for Biological Sciences, Indian Foundation for Butterflies, Diversity India, and Titli Trust, and by thousands of naturalists and citizen scientists worldwide who contribute data. The platform is designed for aggregating, displaying and analysing biodiversity data from tropical developing countries and other biodiversity hotspots such as India. It is a distributed platform of stand-alone, taxon-specific, natural history websites that give ownership and recognition to contributing naturalists. These websites are being used extensively for research as well as educational and outreach activities by professional and citizen scientists. This article tracks the progress of the Lepidoptera sections of this bioinformatics platform and offers an insight into some of their user-friendly features.

Since the launch of the bioinformatics platform in 2010, the number of species pages for butterflies and moths has increased significantly. At last count on 12 January 2020, the Butterflies of India website (Kunte et al., 2019) had 1,029 species while the Moths of India website (Sondhi et al., 2019) had 1,200 species. Fig.

Table 1. Growth in numbers for the Butterflies of India and Moths of India websites

Websites in numbers	Butterflies of India	Moths of India
Launch year	2010	2015
No. of species pages	1,029	1,200
No. of lifecycles	360	77
No. of curated images	70,000	7,000
No. of contributors	Over 1,000	Over 160
No. of expert reviewers	21	18
No. of website visits	1,065,226	37,139
No. of unique visitors	312,096	17,357

Fig. 1. A. Growth of species pages on the Butterflies of India (blue line) and Moths of India (red line) websites. B. Growth of peer-reviewed images on the Butterflies of India website.

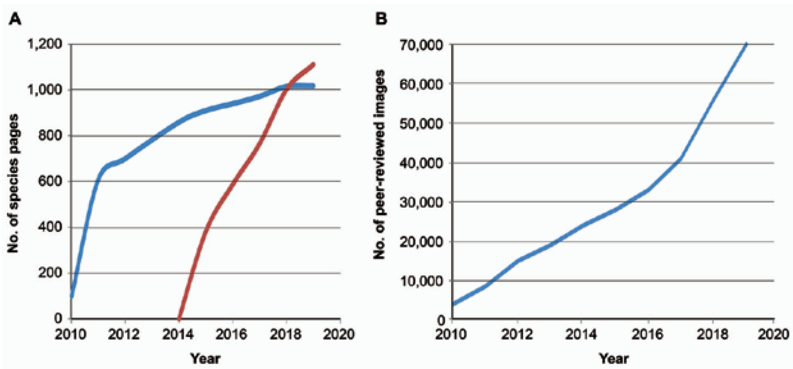
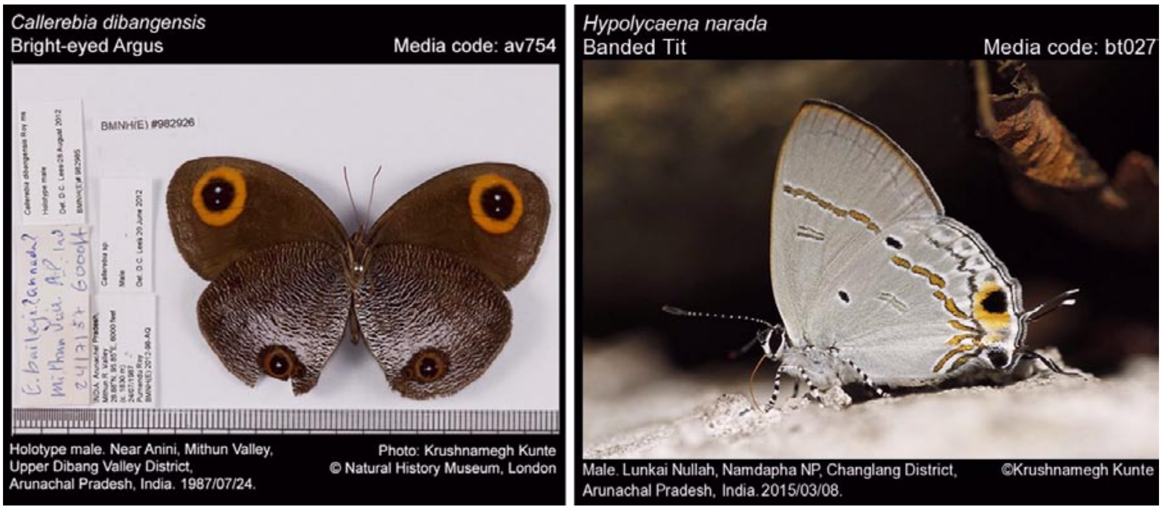


Fig. 2. *Callerebia dibangensis* and *Hypolycaena narada*, two recently described butterfly species, on the Butterflies of India website. Images: Krushnamegh Kunte from Butterflies of India, used with permission from the photographer, Natural History Museum, London, and NCBS.



1A shows the species page growth curve of the websites. The contributions from citizen scientists for both the websites have grown rapidly with over a 1,000 contributors for the butterfly website and 200 contributors for the moth website (Table 1). More than 70,000 butterfly images and 7,000 moth images, along with the associated information on precise locations, dates, species and subspecies, seasonal forms, sex, etc., form large datasets on the websites (Table 1, Fig. 1B).

Fig. 3. Representative species rediscoveries and first Indian records on the Butterflies of India website. Images: *Symbrenthia silana*: Krushnamegh Kunte, *Callinaga aborica*: Sanjay Sondhi, *Hestina nicevillei*: David Raju, *Bhutanitis ludlowi*: Sujatha Padmanabhan, *Byasa crassipes*: Arjan Basu Roy and Yoji Matsuda, *Erynnis pelias*: Balaji P. Balachandran; from Butterflies of India, used with permission from the photographers and NCBS.

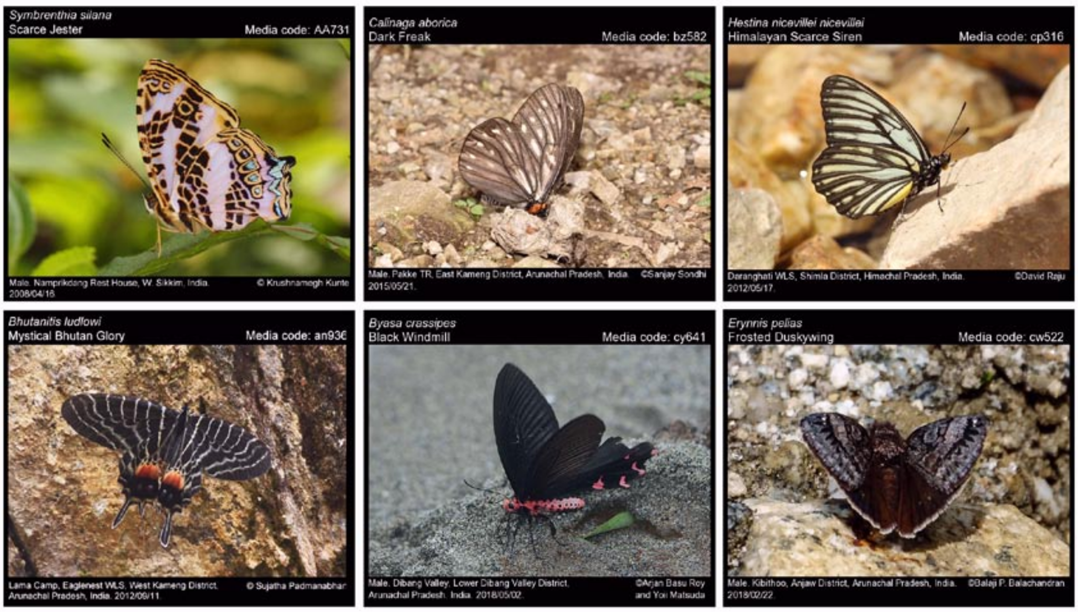
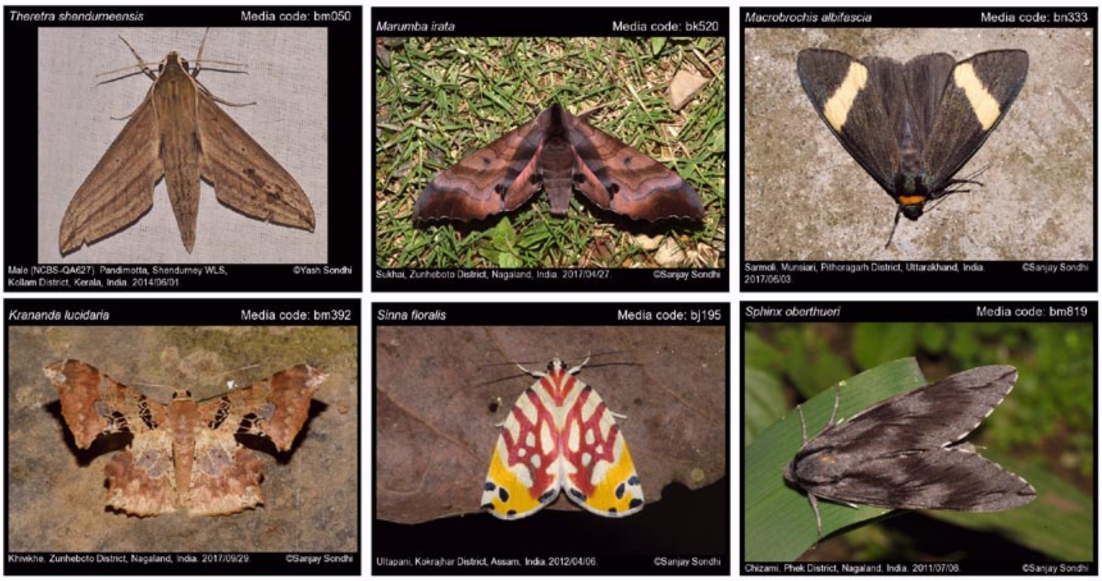
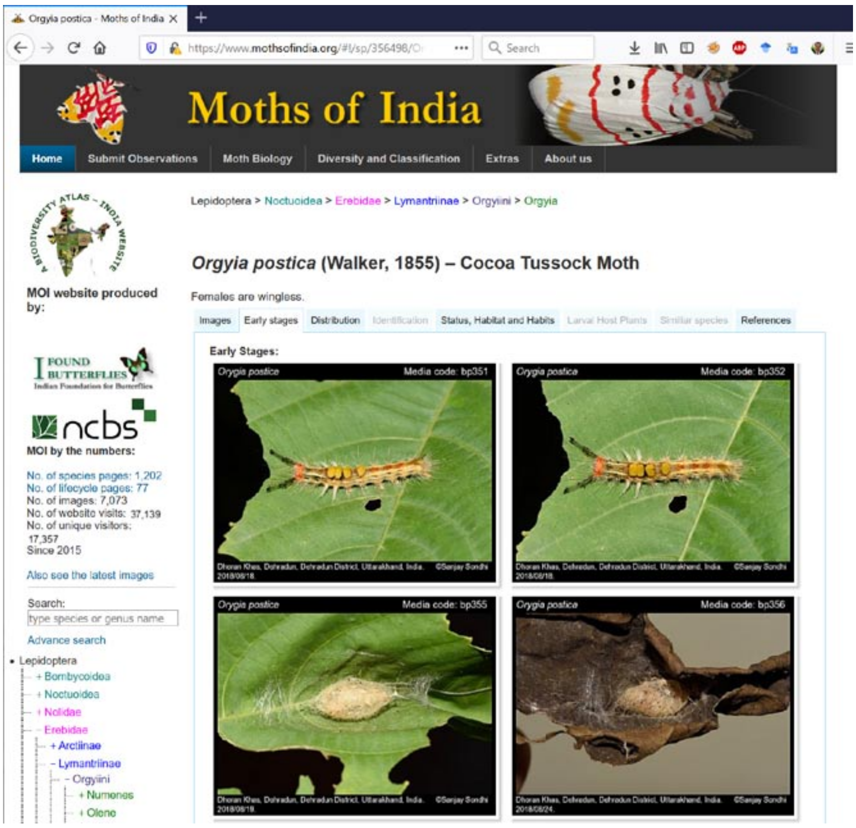


Fig. 4. Representative species discoveries and first Indian records on the Moths of India website. All images: Sanjay and Yash Sondhi, from Moths of India, used with permission from the photographer and NCBS.



Peer review and curation of the images and other information contributed are two critical aspects of these websites, making them arguably the largest and most reliable sources of information on Indian butterflies and moths. Photo-documentation

Fig. 5. In addition to displaying images of adult butterflies and moths and all the variation that they represent, the websites also display images of early stages (eggs, caterpillars and pupae).



of early stages of 355 butterfly species and 77 moth species, along with information on larval host plants, is also presented. A dedicated team of 21 reviewers for the butterfly website and 18 reviewers for the moth website has worked on a voluntary basis to curate these resources. The number of website visits and the number of unique visitors continues to grow rapidly as the websites have become the go-to resources for casual nature lovers, serious naturalists, citizen scientists and professional researchers alike (Table 1). The websites have received dozens of citations in scientific research papers, along with mentions in popular articles and natural history books.

Two new butterfly species described from India in recent times, *Callerebia dibangensis* Roy, 2013 and *Hypolycaena narada* Kunte, 2015 are also displayed on the website (Fig. 2). Many species rediscoveries and new records for India such as *Symbrenthia silana*, *Erynnis pelias*, *Byasa crassipes*, *Bhutanitis ludlowi*, *Calinaga buddha*, *Calinaga aborica*, *Athyma punctata* and *Hestina nicevillei* are also featured on the butterfly website (Fig. 3). Similarly, a new moth species described from India, *Theretra shendurneensis* Sondhi, Kitching, Basu & Kunte, 2017 as well as several new records for India such as *Marumba irata*, *Macrobrochis albifascia*, *Krananda lucidaria*, *Sinna floralis* and *Sphinx oberthueri* are reported on the moth website (Fig. 4).

Such an impact is possible because of highly committed contributors and the Indian naturalist community on the whole. This community continues to grow because

Fig. 6. Contributors may also submit observations on larval host plants and nectar plants, which generate a useful understanding of plant-butterfly/moth relationships that are important for species conservation. Images: Paresh Churi, Medha Rao, Darraprasad Sawant and Abhinav D. Nair; from Butterflies of India, used with permission from the photographers and NCBS.

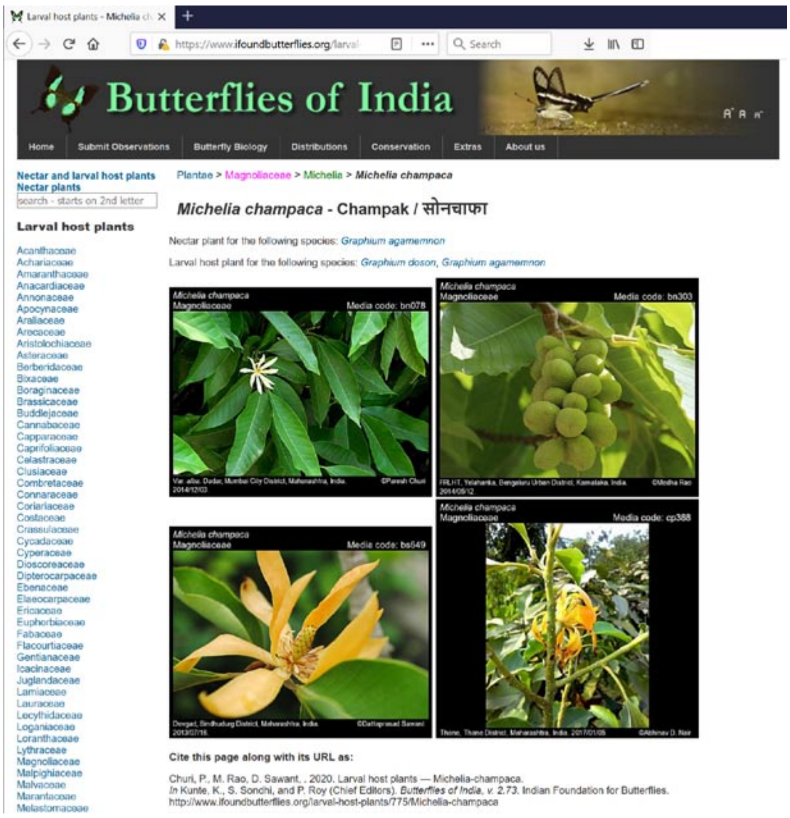
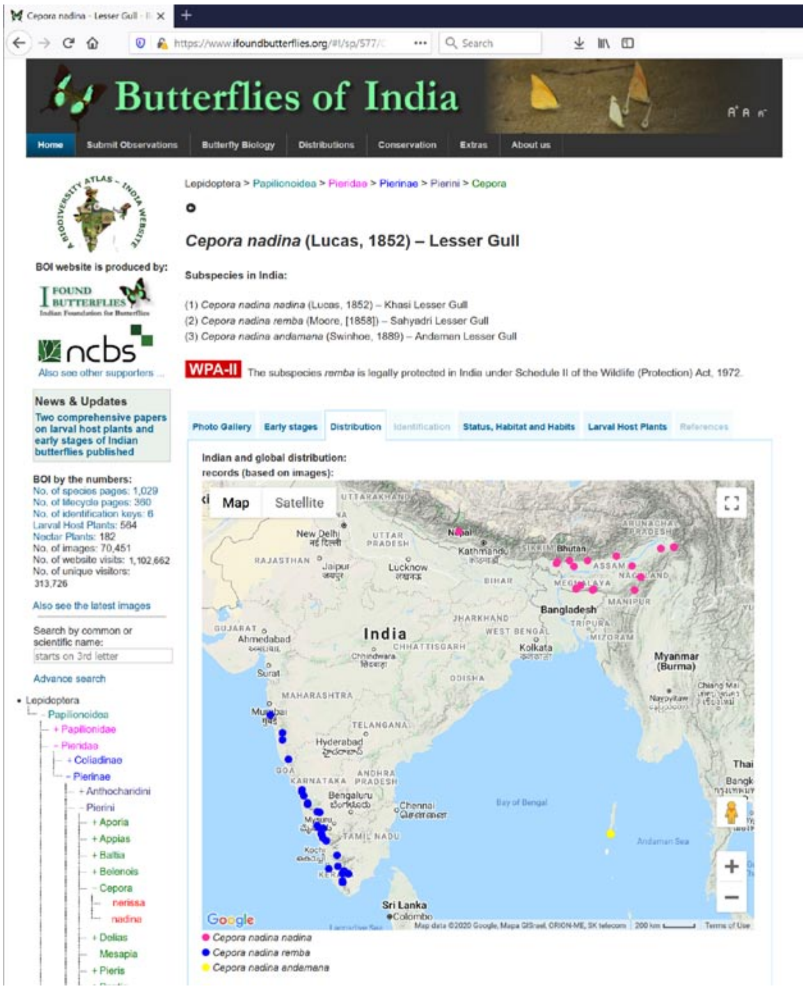
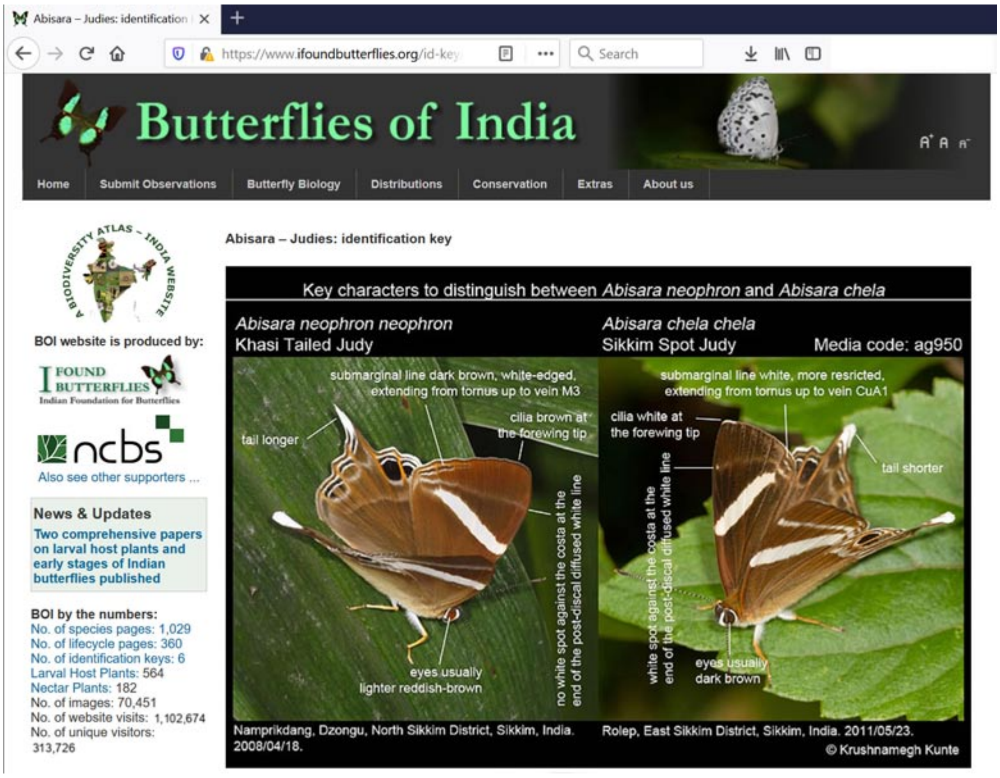


Fig. 7. All observations are centrally databased at a subspecies level. From these spot records, distributional ranges of species and subspecies are displayed on individual species pages. Such information, along with information on flight periods, is useful in the long term to study effects of climate change. The map is used with permission from NCBS.



of outreach and training achieved through Biodiversity Marathons and yearly meets. Biodiversity Marathons are data marathons that are held every few months in different parts of the country, typically hosted by local non-governmental organisations (NGOs) and other groups, and coordinated by NCBS. These events typically start with a nature trail, followed by an indoor session that explains various key features of these citizen science platforms, and encourage the participants to contribute their images and other data to these unique natural history data repositories. Annual Butterfly and Moth Meets are organised to help participants become better naturalists and citizen scientists through training in field methods and species identification. These meets are organised in partnership with NGOs such as Titli Trust, Diversity India and Nature Mates. The meets not only generate valuable biodiversity data, they also benefit local communities, who assist to organise these biodiversity meets. In the past decade, more than 20 such meets have been organised in diverse locations such as Arunachal Pradesh, Nagaland, Meghalaya, West Bengal, Uttarakhand, Karnataka and Kerala. Participation in global events such as National Moth Week helps generate additional data and awareness.

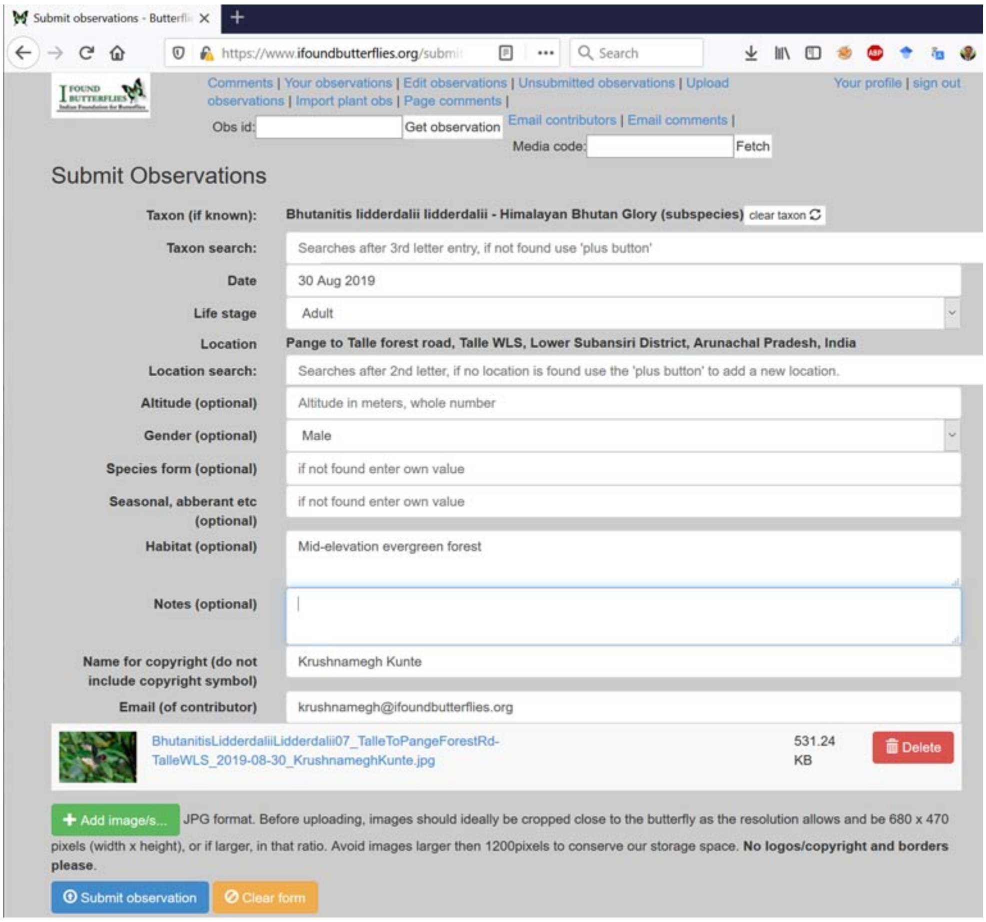
Fig. 8. An example of an illustrated identification key. Images: Krushnamegh Kunte; from Butterflies of India, used with permission from the photographer and NCBS.



The websites have numerous user-friendly features and functions that provide additional information to users. They also provide intuitive navigation and tools to identify species and explore the diversity of butterflies and moths. Some of these features include:

- Taxonomically updated binomial and trinomial scientific names, along with higher classification (tribes, subfamilies, families and superfamilies) for all the species covered.
- Reliable information and well-curated, peer-reviewed image libraries of butterflies and moths along with their early stages (eggs, caterpillars and pupae), larval host plants and nectar plants (Fig. 5-6).
- Complete information on the species name, exact location and date, along with the name of the photographer on each image displayed (Fig. 2-4).
- Distribution maps for species (Fig.7).
- Identification keys (Fig. 8).
- Information on flight periods by state.
- Information on similar species, references for identification, and bibliography (for moths).
- Advanced search that permits users to: (a) locate species by common name, scientific name, family, subfamily and genera, (b) browse species by life stages (adult, egg, caterpillar, pupa), and (c) search by photographer, month, state, district, etc. This can assist users to plan their field trips, prepare for species that they might encounter in a particular area in a specific season, and also prepare a

Fig. 9. Interface to submit observations by citizen scientists. Contributions from ordinary citizen scientists is driving the rapid growth of these websites and all the information that is generated on the butterflies and moths of India. Used with permission from NCBS.



personal field identification guide for their field trip.

- A user-friendly interface to submit images with relevant information, to be used by citizen scientists to submit their observations (Fig. 9).

Going forward, on the 10th anniversary of the Butterflies of India website in 2020, the Biodiversity Atlas – India platform will see a major upgrade to its content management system, launch of new features including mobile applications, and a long-term population monitoring programme for Indian butterflies. These are certainly exciting times to do natural history, citizen science and big-data science in India. We hope that these developments will build a substantial knowledge base on Indian biodiversity, and contribute towards its scientific exploration and conservation.

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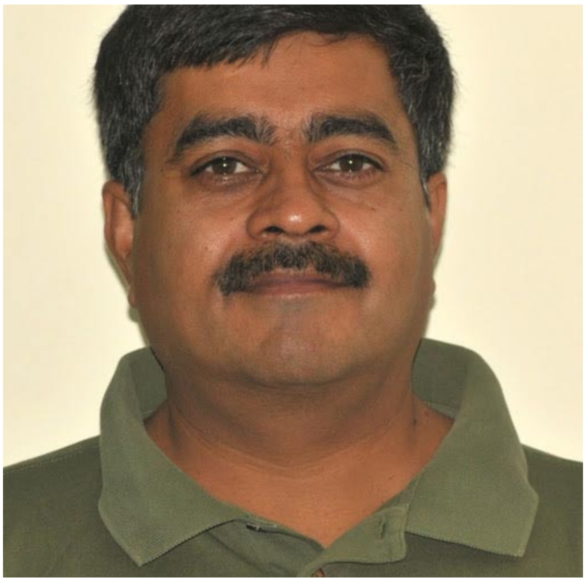

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REVIEW ARTICLE

Invasive insect pests in India: Current scenario and future perspective

Naveena, N.L., Shashank, P.R., Devaramane Raghavendra and Mallikarjuna Jeer

Abstract: Abundant biological diversity of India is more vulnerable to the invasion of new insects. The entry of invasive insects is increased across the globe due to the liberalization of trade and increased movement of human beings across the continents. There are 23 different invasive insect pests recorded in India. The exact monitory values of the losses caused by these are not properly known. Directorate of Plant Protection, Quarantine and Storage (DPPQ&S) is the National Plant Protection Organization (NPPO) for India and works to restrict the entry of any invasive species. Strict implementation of import regulations and international cooperation in trade and commerce, early detection and taxonomic identification at the entry points will make India secure from such invasive species.

Key words: invasive pests, quarantine, India, plant protection

A species that has established and spread or has the potential to do so outside of its natural distribution range, and which then threatens ecosystems, habitats and/or other species, potentially causing economic and/or environmental damage, or harm to human health is called Invasive species (Invasive species specialist group (ISSG) module, IUCN, 2012).

The majority of invasive species are alien (non-native species or non-indigenous species), but some native species may also become invasive. So, Invasive alien species (IAS) can be defined as "An alien species whose introduction and/or spread threaten biological diversity" (Convention on Biological Diversity, 2019). This is also referred to as Alien invasive species and IUCN defined it as, “an alien species which becomes established in natural or semi-natural ecosystems or habitat, is an agent of change, and threatens native biological diversity”.

These IAS are always a threat to local biodiversity. It may cause the extinction of native species, change in habitats, affecting human health and economic loss (Tu, 2009). Invasive alien species of Insects and microorganisms are a major threats to agriculture across the globe and in particular, underdeveloped and developing countries. They cause economic damage to crops, further, it leads to a change in cropping pattern in the area and affect agro-ecosystem and food security (Paini et al., 2016).

In general, the process of invasion includes Introduction, Establishment and

Spread. However, few species having Lag phase between establishment and spread. Where they occur in low densities and accumulate over a period (months/years) and rapidly explode as they reach the carrying capacity of the environment (Fig.1).

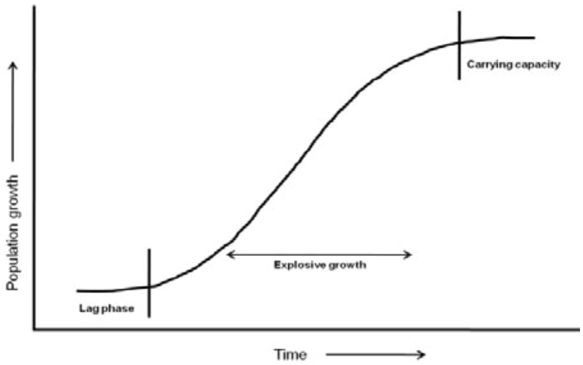

Fig.1. Stages of an Invasion (modified from the module by ISSG, 2012)

There are legal controls for the movement of these species across the world. International Plant Protection Convention (IPPC), 1951 of FAO, United Nations and its Regional Plant protection organizations (RPPOs). IPPC provides international framework for plant protection which includes, development of International Standards for Phytosanitary Measures (ISPMs) for safeguarding plant resources (guidelines for issuing Phytosanitary certificates (PSCs) for export purpose, PRA, Post entry quarantine guidelines, etc.), information exchange on pest status and regulated pest in each country and Sanitary and Phytosanitary (SPS) Agreement under WTO are mainly involved in protecting pest introductions and outbreaks across the globe.

India enacted and adopted various Acts and rules to avoid the entry of these IAS to the country and was amended based on the situation and time-to-time.

Invasive insect pests in India

Due to changes in climate, increase in international trade, modernization in agriculture - changes in cropping patterns/agro-ecosystem, loss of forest cover, expansion of host range and acclimatization to varied climatic conditions by insects. India's rich biodiversity is highly susceptible to invasive species.

India witnessed the first invasion of San Jose scale, *Quadaraspidiotus perniciosus* (Comstock) [Hemiptera: Diaspididae] in 1879 from china and recorded a total of twenty-three species as on today (2019) and affects agro-ecosystem of the country and causes a huge economic loss over the years. Table 1 depicts the invasive alien insect species and their biological control recorded in India.

The loss caused by these species is immense and in India, there is no proper study or documentation of the extent of loss caused by them, except few studies i.e., Papaya mealybug, where some reports mentioned loss in the area but not in exact monitory values. India losses 117 US Billion dollars in 2001 due to Invasive Alien Species (ISSG module, 2012). We need to monitor the invasive insects once they reported to their spread and acclimatization and also cost involved in controlling that invasive insect.

In India Invasive insects/Invasive Alien Insects, are being monitored by Directorate of Plant Protection, Quarantine and Storage (DPPQ&S), ICAR-NBPGR, ICAR-NBAIR and other crop-specific institutes of ICAR, Ministry of Agriculture and farmer's welfare, Government of India. DPPQ&S works by adopting various laws *viz*., The Destructive Insects and Pests Act, 1914 and amendments, The Plant Quarantine (Regulation of Import into India) Order 2003 – Amendments, and adopting international guidelines from International Plant Protection Convention (IPPC, 1951), WTO-SPS Agreement, and International Standards on Phytosanitary Measures (ISPMs) to avoid/stop any entry of invasive insects/pathogens/weeds to the country via international Trade and commerce. For the export of Agricultural commodities, Phytosanitary Certificates (PSC) is being issued in accordance with the IPPC convention.

In India there are 35 plant quarantine stations at various international airports, seaports and land frontiers (Table 2), 35 Central Integrated Pest Management Centers (CIPMCs) for promoting IPM approaches in the country and one Central Insecticide Laboratory (CIL) established under section 5 of Insecticide Act 1968, and it functions as per the rule 5 of Insecticide rules 1971. It also establishes Central Insecticides Board and Registration Committee (CIB&RC) Under Section 4 and 5 of the Insecticides Act, 1968. CIB&RC mainly works on pesticide registration after scrutinizing the formulae for manufacture, import, and export in the country and also advises the central and state governments for effective management of pesticide related issues in the country (Anonymous, 2019).

Management of IAS

Phytosanitary treatments are carried out by pest control firms accredited by DPPQS for killing insects in the containers with produces. Various Phytosanitary Treatments viz., Fumigation, Forced Hot Air Treatment, Vapour Heat Treatment, Hot Water Immersion Treatment, Irradiation, Dry Heat Treatment and other methods accepted by IPPC are more useful in managing quarantine pests in India.

In order to identify quarantine insect pests in the imported materials is examined at the entry points by various methods *viz*., Visual Examination, Microscopic Examination, X-ray, Fluoroscopy & Radiography. For examining nematodes washing and sieving test, Floatation test, and Baermann funnel apparatus are used in addition to visual and microscopic examination. For pathogens, Incubation test (Bacteria/fungi), Grow out test (Seed borne pathogens), Electron microscopic observation, and ELISA for viruses.

The present available methods/approaches for controlling invasive insects *viz*., Mechanical, chemical and biological approaches needs to be revised. Mechanical and chemical approaches are costly, laborious, and pro-environment, where as biological method is long-term and time consuming. So it is the time to re-think alternate management approaches.

1. Monitoring:

a. Preparation of Pest Risk Analyses (PRA) helpful to identify the quarantine pest in advance, so that mitigation measures can be prepared.

b. Prepare a complete document (mapping) of possible entry of invasive insects in to the country.

2. Prevention:

a. Identify the species known to be invasive at the quarantine entry points.

b. Early detection.

3. Management/Control:

a. The efforts should be region oriented

b. Taxonomic confirmation of the species, its origin.

c. Should have knowledge about insect morphology, bio-ecology and place of origin.

d. Find out availability of control agents in native place if any and also in the invaded location or importing from its native place.

Future Perspective

There is need of the hour to adopt modern technologies for detecting insect pests at various levels. There is a more scope for advanced research in use of Near-infrared spectroscopy (NIR) (Rapid method, no sample preparation), E-nose technology, Machine vision (Effective in detecting external insects), Electrical conductance (Hidden internal infestation can be identified), development of Sensor systems for early detection of insects and low cost DNA barcoding technology for easy and quick identification of insect pests. Further, there should be an international policy (other than PRA) to predict the possible invasion/incursion of the species to different countries and also to suggest mitigation measures every year will help to save the biodiversity, crop loss/food security and increase economy of the nation.

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Table 1. List of invasive alien insect pests in India

Sl. No	Common name	Scientific Name	Entry to India (Place)	From/Native	Biological control	References
1	San Jose scale	*Quadaraspidiotus perniciosus* (Comstock) (Hemiptera : Diaspididae)	1879 / (1921- Kashmir)	China	*Aphytis* (proclia group)- ectoparasitoid, *Encarsia perniciosi* Tower -endoparasitoid and *Coccinella infernalis* Mulsant -predator	Fotedar, 1941
2	Woolly apple aphid	*Eriosoma lanigerum* (Hausmann) (Hemiptera: Aphididae)	1889 Coonoor, Tamil Nadu/ 1909 Uttarpradesh	China / America	*Aphelinus mali* (Haldeman)	Thakur and Dogra, 1980
3	Potato tuber moth	*Phthorimaea opercullela* Zeller (Lepidoptera: Gelechiidae)	1906 (East Bengal- Now in Bangladesh)	Italy	*Copidosoma koehleri*, an egg - larval parasitoid; *Chelonus blackburnii* - exotic parasitoid	Lefroy, 1907
4	Cottony cushion scale	*Icerya purchasi* Maskell (Hemiptera: Margarodidae)	1920 Tamil Nadu	Australia	Predator-*Rodolia cardinalis*	Rao, 1951
5	Pine woolly aphid	*Pineus pini* (Macquart) (Hemiptera; Adelgidae)	1970/ Nilgiris, Tamil Nadu	Western & Central Europe	Anthocorid bugs- *Tetraphleps raoi*, *T. abdulghanii* Ghauri	McAvoy et al. 2007
6	Subabul psyllid	*Heteropsylla cubana* Crawford (Hemiptera: Psyllidae)	1988 Tamil Nadu & Bangalore	Central America	Lady beetle, *Curinus coeruleus* Mulsant from Mexico	Veeresh, 1990
7	Coffee berry borer	*Hypothenemus hampei* Ferrari (Coleoptera: Curculionidae)	1990 Gudalur, Tamilnadu	Northeast Africa	*Prorops nasuta* Waterston; *Cephalonomia stephanoderis* Betrem (Hymenoptera: Bethylidae) from Mexico and *Phymastichus coffea* Lasalle (Eulophidae) from Colombia	Kumar et al. 1990
8	Serpentine leaf miner	*Liriomyza trifolii* (Burgess) (Diptera: Agromyzidae)	1991 Hyderabad, Telangana	Florida (U.S.A.)	Chalcidoidea, Pteromalidae and Braconidae - *Diglyphus begina*, *D. intermedius*	Viraktamath et al. 1993
9	Spiralling white fly	*Aleurodicus disperses* Russell (Hemiptera: Aleyrodidae)	1993 Kerala	Central America	*Encarsia haitiensis* and *E. Guadeloupe* Viggiani (Hymenoptera: Aphelinidae) -Lakshadweep Islands; *Axinoscymnus puttarudiahi* Kapur (Coccinellidae) and *Cybocephalus* sp. (Coleoptera: Nitidulidae)	Palaniswami et al. 1995
10	Coconut Eriophid mite	*Aceria gurreronis* Keifer (Arachnida: Eriophyidae)	1997 Enakulam, Kerala	Mexico	Predatory mites-*Amblyseius largoensis Muma*, *Neoseiulus mumai*, *Neoseiulus baraki* and Fungi-*Hirsutella thompsonii*	Sathiamma et al. 1998
11	Eucalyptus gall wasp /Blue gum chalcid	*Leptocybe invasa* Fisher & La Salle (Hymenoptera: Eulophidae)	2001 Karnataka/ Tamil Nadu	Australia	*Megastigmus* sp. and *Aprostocetus gala* Walker	Jacob et al. 2007
12	Erythrina gall wasp	*Quadrastichus erythrinae* Kim (Hymenoptera: Eulophidae)	2006 Kerala	Tanzania, East Africa	Eulophids -*Quadrastichus ingens*, *Q. gallicola*, *Q. bardus*, *Aprostocetus nitens*	Faizal et al. 2006
13	Cotton mealy bug	*Phenococcus solenopsis*	2006 Gujarat	Central america	*Aenasius bambawalei* Hayat (Hymenoptera:	Tanwar et al. 2007

		Tinsley (Hemiptera: Pseudococcidae)			Encyrtidae).	
14	Papaya mealy bug	*Paracoccus marginatus* Williams and Granara de Willink (Hemiptera: Pseudococcidae)	2007 Coimbatore, Tamil Nadu	Mexico	*Cryptolaemus montrouzieri;* lepidopteran predator - *Spalgis epius* (Lycaenidae); *Anagyrus loecki* Noyes & Menazes, *Acerophagous papayae* Noyes & Schauff and *Pseudleptomastrix mexicana* Noyes and Schauff (Hymenoptera: Encyrtidae)	Tanwar et al. 2010
15	Jack Beardsley mealybug (Banana)	*Pseudococcus jackbeardsleyi* Gimpel and Miller. (Hemiptera: Pseudococcidae)	2012 Karnataka	America	*Cryptolaemus montrouzieri*, *Spalgis epius* and some species of gnats	Shylesh, 2013
16	Madeira mealybug (Hibiscus)	*Phenacoccus madeirensis* Green (Hemiptera: Pseudococcidae)	2012 Karnataka	Neotropical	---	Shylesha and Sunil Joshi, 2012
17	South American tomato pinworm/ Tomato leaf minor	*Tuta absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae)	2014 Pune, Maharashtra	South America	*Nesidiocoris tenuis* Reuter; *Neochrysocharis formosa* (Westwood); *Habrobacon* sp.; *Goniozus* sp. *Trichogramma achaeae*	Shashank et al. 2015
18	Coconut Spindle infesting leaf beetle	*Wallacea sp.* (Coleoptera: Chrysomelidae)	2014/2015 Andaman islands	Oriental region - Australia	----	Prathapan and Shameem, 2015
19	Rugose spiraling whitefly (coconut)	*Aleurodicus rugioperculatus* Martin (Hemiptera: Aleyrodidae)	2016 Tamil Nadu	Central America	*Encarsia noyesi, E. guadeloupae*	Srinivasan et al. 2016
20	Fall armyworm (Maize)	*Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae)	2018 Karnataka	America	Egg parasitoids-*Telenomus remus* Nixon (Hymenoptera: Platygastridae); *Trichogramma* sp.; Gregarious larval parasitoid- *Glyptapanteles creatonoti* (Viereck) (Braconidae); Solitary larval parasitoid-*Campoletis chlorideae* Uchida (Ichneumonidae).	Sharanabasappa and Kalleshwaraswamy, 2018
21	Nesting whitefly (Coconut)	*Paraleyrodes minei* Iaccarino (Hemiptera: Aleyrodidae)	2018 Kerala	Syria	--	Chandrika Mohan et al. 2019
22	Bondar's Nesting Whitefly (Coconut)	*Paraleyrodes bondari* Peracchi (Hemiptera : Aleyrodidae)	2018 Kerala	Central America	--	Josephrajkumar et al. 2019
23	Neotropical Whitefly (Coconut)	*Aleurotrachelus atratus* Hempel (Hemiptera: Aleyrodidae)	2019 Mandya/ Bangalore	Brazil	Parasitoid, *Encarsia* spp. (Hymenoptera: Aphelinidae) and predators *viz., Dichochrysa astour* (Neuroptera: Chrysopidae), *Cybochephalus* spp. (Coleoptera: Nitidulidae), *Chilocorus nigrita* and *Jauravia pallidula* (Coleoptera: Coccinellidae)	Selvaraj et al. 2019

Table 2. List of plant quarantine stations in India

Category I Stations	Category-II Stations	Category III Stations	Category IV Stations
Agartala	Panitanki	Kandla	New Delhi
Guwahati	Kalimpong	Visakhapatnam	Amritsar
Raxaul	Trivandrum	Tuticorin	Chennai
Sanauli	Tiruchirapalli	Cochin	Kolkata
Banbasa	Bhavnagar	Kakinada	Mumbai
Rupaidiha	Hyderabad	Nava Sheva	Bangalore
Jogbani	Attari-Wagah Border - LCS (working unit under RPQS, Amritsar)	Mangalore	
Attari-Wagah Border - Rly. Stn.	Air Cargo, Mumbai	Bongaon	
Amritsar Rly. Stn	Air Cargo, Kolkata		
ICD Tughlakabad (working unit under NPQS, Delhi)			
Air Cargo, Delhi Airport			
Calicut Airport			

In conversation with Dr. Chandish R. Ballal

Charismatic leader and Entomologist speaks to IE Associate Editor Dr. Bhagyasree about her journey from a small town girl to Director of the National Bureau.

Dr. Chandish R Ballal hails from a small town - Palakkad in Kerala, did her schooling in the English medium section of a Government School, Moyan Girls' High school, Palakkad. She was fond of reading English books and consistently won prizes for English proficiency, versification and elocution in school and college. She completed her B. Sc. in Zoology at Mercy College, Palakkad; Masters in Zoology with Entomology Specialisation at Government Victoria College, Palakkad and M.Phil Zoology at Calicut University, Kerala. She was a University merit scholarship holder throughout. She was and is a connoisseur of dance and music. During her childhood days her dream was to become a teacher, and later on to become a doctor, while destiny led her to turn into a successful, altruistic and generous woman scientist in Entomology and Director of ICAR- National Bureau of Agricultural Insect Resources (ICAR-NBAIR), who contributed significantly in the field of Insect ecology and Biological Control. The focus of her research was on understanding host and host plant interactions and development of mass production technologies for potential parasitoids and predators and evaluating their performance - with emphasis on beneficials like trichogrammatids, scelionids, braconids, ichneumonids, anthocorids and predatory mites. She is a prominent "Indian Entomologist" who has more than 220 research articles in her career baggage and a keystone for the Asia's largest live insect repository holding 130 insect cultures during her tenure as Head of the Division of Insect Ecology and presently as Director, ICAR-NBAIR and Project Coordinator, AICRP on Biocontrol.

During the early days of her career, she worked for an year as Senior Research Fellow at CIBC (Commonwealth Institute of Biological Control), Indian station, before joining Agricultural Research Service. In February, 1985, she stepped into the Indian Institute of Horticultural Research as a Scientist, later on moved to the Project Directorate of Biological Control (PDBC). Before taking charge as Director, she spent nearly three decades in the Division of Insect Ecology at NBAIR (then PDBC). She received the prestigious "Dr (Ms) Prem Dureja Endowment Award" 2017-18 instituted by National Academy of Agricultural Sciences, ICAR-Panjabrao Deshmukh Outstanding Woman Agricultural Scientist Award, 2015; Pradhan Memorial Award 2018 and Professor T. N. Ananthakrishnan Award, 2006.

Bhagyasree S. N. (BSN): Thank you for speaking to Indian Entomologist

magazine. How did you pursue career in Entomology??

Chandish R. Ballal (CRB): I am a small town girl from Palakkad, Kerala, where we did not have a whole lot of choices to pursue. Though I was very fond of English literature, wanted to pursue some course in science because those days the strange mindset amongst students was that taking up arts or literature was something not to be proud of. I was not great at physics and chemistry so chose Zoology (which I liked) as major and Botany and Chemistry (which I did not like… but was the only combination available) as minor subjects for my graduation. Later on I did M.Sc Zoology with specialization in Entomology, which again was the only option available other than M Sc Botany. However, I was lucky…I thoroughly enjoyed the entomology classes handled by excellent teachers (one of them Dr Prabhakaran Pillai was Dr Wigglesworth's student) at Govt. Victoria College, Palakkad. I had no idea regarding Agricultural Research Service till at Calicut University while pursuing my M Phil, I met Mariamma Chechi (Sister), (Dr Mariamma Daniel) who was then a Scientist at CPCRI Regional Station at Vittal, and was pursuing her PhD at Calicut University under late Dr T C Narendran. She inspired me to write the ARS exam, if not for her I would not have been here.

> ***"to the younger generation other than passing on the scientific knowledge, we have to pass on the tradition of science"***

BSN: Who is your role model or who you admire in your personal and professional life?

CRB: In my personal life, my mother is my role model, she was an epitome of patience, knowledge and strength. She encouraged me in my academic and co-curricular activities. When it comes to professional life I admire late Dr. Sathiamma Madam, retired Principal Scientist, ICAR-CPCRI, a hard working and dedicated scientist and a humble and down to earth human being, who has contributed immensely in the area of biological control of coconut pests.

BSN: How do you balance between work life and professional life?

CRB: I am fortunate to be receiving enormous and consistent support from my husband, mother in law and my daughters. Being systematic at home and office helps me in maintaining a balance between professional and personal lives. In a lighter vein I should add that I manage to cook myself at home as I plan for tomorrow's task at the Institute and tomorrow's menu at home, well in advance.

BSN: How do you react when things go out of hand or messy?

CRB: Generally, I do not react to unpleasant situations in an impulsive manner, and try to handle situations calmly. First and foremost, I try to understand the situation and if it is to do with a person who is accessible, I try to clarify the issues across the table. Most of the times, I have managed to ease the situation. However, when the person is not accessible either due to distance or due to mental set up of the concerned individual, I prefer to ignore for the well being of all concerned. When needed, I do discuss with my colleagues and take their opinions while trying to resolve some of the sensitive issues.

BSN: What is most memorable thing you would like to cherish as biological control specialist?

CRB: My mentor, the founder Director of PDBC, Late Dr S P Singh used to always discuss with us on the challenges involved in multiplying host insects and novel bioagents. Developing production protocols for biological control agents like predators and parasitoids and their hosts is truly a challenge and when you succeed in “taming” a difficult to multiply insect it really gives you a sense of great satisfaction. I have developed trays for mass production of lepidopteron host insects, developed technologies for continuous production of ichneumonid and scelionid parasitoids, anthocorid predators and predatory mites. I also feel extremely proud of the fact that NBAIR holds Asia’s largest live insect repository, with 130 insect cultures maintained year round.

BSN: What are the biggest hurdles you have faced as a biocontrol specialist?

CRB: Upscaling the production of macrobials and microbials; making the bioagents available to the farmers; ensuring large area coverage with bioagents and enabling registration of the potential local isolates of microbial biopesticides are the greatest hurdles faced by any biocontrol researcher not only in India, but even globally. Unless there is a mechanism enabling the generation of toxicology data for effective indigenous isolates at reasonable cost, registration of these isolates and making them available to farmers would remain a far cry.

BSN: How would you like to see biocontrol in the future?

CRB: I would like to see more companies producing microbial and macrobial biocontrol agents. Quality microbial biopesticides should be available on the shelves of local “Biopesticide outlets”, where farmers should be able to buy them as per need, the way they buy chemicals. It is encouraging to note that some chemical pesticide companies have opened units exclusively for producing bioagents. Wherever biocontrol options are available for the management of any pest, farmers should be aware of them and should be able to adopt the same. In several cases, it could even be a simple strategy of not resorting to chemical insecticides and thus conserving the natural bioagents to act and manage the pest.

BSN: What are the traits/attitude that can help women to achieve/perform prominent role in their organization?

CRB: Women should come out of the mindset that they are not being treated on par with men. If we are confident, we would be able to create an identity and a distinguished slot for ourselves in our sphere of work. It is for us women to remain strong and confident and to prove to the world that besides being great home makers, we can be dedicated researchers, capable administrators, great innovators, while we continue to be sensitive and wonderful human beings.

BSN: What are the leadership lessons you would like to pass on to younger generation?

CRB: Take your colleagues into confidence, work with them as a team, be conscious and concerned about their future and what they need in order to achieve their goal. Involve youngsters along with seniors in institutional activities. In one of the inspiring talks, Dr CNR Rao said "*to the Younger generation more than passing scientific knowledge, it is important to pass on the tradition of science*". Youngsters should not hesitate to collect and imbibe knowledge and wisdom from their seniors, which would truly help them in their careers. I believe that in order to maintain a clean and scientific work culture in an organisation, it is important for all the staff members to understand each other and have open discussions. Encourage guide and create opportunities for youngsters and this in turn would make them feel responsible not only for their allotted responsibilities, but also for the growth of the organisation.

BSN: How did you feel when you received "Panjabrao Deshmukh Outstanding Woman Agricultural Scientist Award", 2015 for your contribution in Biological control??

CRB: Humbled, honoured and overwhelmed. I felt "Probably I should have contributed more to deserve this…now will I be able to live up to the expectations?"

BSN: What is your advice to young females of entomology fraternity?

CRB: It is important to document and record your work, not only to retrieve as and when required, it will also help in self assessment. Work hard, be sincere, work as a team, be organized not only at work, but in your personal life too. Enjoy work and spend quality time with family. Always try to keep aside some "ME TIME" to do what you enjoy doing!!

Dr. S.N. Bhagyasree is working as Scientist at Division of Entomology, ICAR- IARI, New Delhi. She is an expert in biological control and one of the Associate Editors of IE.

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Photo: Dr. S. N. Bhagyasree with Dr. Chandish Ballal during the interview.

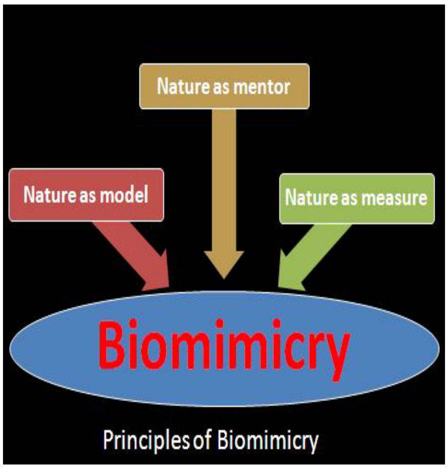
Insects as a muse for innovation of modern technologies

Raghavendra K.V., Omprakash Navik and Bhagyasree, S. N

From time immemorial, several technological advances are inspired by nature. Many a time's biologists find themselves attracted by the graceful perfection of nature. From molecules to organisms, engineers and scientists have frequently been fascinated by nature's skill and have followed natural designs in man-made innovations. The Science behind this is Biomimcry. The Discipline of science, which studies nature's best ideas and exploits those ideas, designs, and processes to solve human problems is known as Biomimicry.

The term "biomimetics" is originated from Greek words "*bios*" (life) and "*mimesis*" (to imitate). We could see Biomimetics in everyday life and often used without our knowledge. The fundamental idea of nature is that, during her past 3.80 billion years of experience and novel developments, she has come out with highly competent systems and processes that can provide solutions to many of the resource efficiency and management problems that we now tackle in our day-to-day life like from knives and axes inspired by the dental structures of extinct animals to the strongest revolutionary carbon nanomaterials. Bio-engineering has always being advanced along with human history. "Flying Machine" by Leonardo da Vinci's (1452–1519) was inspired by a bird is a basic example of biomimicry. The motorized airplane invented by Wright brothers (1867–1948) based on the flight pattern of eagles made to succeeded human flight for the first time in 1903.

A book 'Biomimicry' was published by J M Benyus in 1997, which highlights about biomimicry laying the path to the development of new-age technologies by learning from nature as the foundation for products, instead just using it for raw materials. According to J.M. Benyus, by treating nature as 'model, measure and mentor', many companies, governments, and universities are in a firm position to take benefit of the innovative opportunities provided by the emerging field of 'biomimicry'.



Principles of Biomimicry

Among the different components of nature, insects are one which motivates human beings in their innovation in one or the other ways. Insects are the brilliant creatures on the earth which are diverse, inventive and resilient which serves as a symbol of everything from beauty and rebirth to epidemic and iniquity. Insects pollinate or devour crops, contribute or cause chaos to technology, inspiring architecture or destroy it and advance human health or act as vectors for transmission of diseases in plants and animals.

Few examples of Insect biomimicry are as follows

1. Insect-inspired sensors for improving the tiny robot's flight

From Micro-roboticists technology, engineers have designed simple sensors based on insect simple eyes called ocelli to improve a miniature flying robot. A team of scientists has published a paper in *Science* journal describing their efforts to create a bee-sized robot, 'dubbed RoboBee'. This 'dubbed RoboBee' (about 100 mg weight) could fly by a preset route on two lightweight wings. In such tiny sized robots, power sources and navigation sensors must remain on-board and connected to the robot *via* thin wires. Neuro-ethological and Neuro-biological research findings on insects can be used to devise and create small robots controlling their navigation based on bio-inspired visual strategies and circuits. The Insect flight concept is also being used in aerospace engineering and mobile robotics.

2. Fog basking beetle to water harvester structure

Desert darkling beetle species (Tenebrionids) can absorb water content from morning fog in the desert to fulfill its water requirement. The body of these beetles is covered with minute bumps, while the shell itself is covered with a waxy substance that is highly hydrophobic. Desert beetle collects water on its back using the hydrophilic spots present on its hydrophobic surface. Designer Kitae Pak has fabricated an award-winning biomimetic device based on the beetle's strategy (Model insect – *Onymacris unguicularis*, Tenebrionidae, Coleoptera), which was made of stainless steel where the beetle-back-shaped dome collects drops of water from fog/air and runs them into a circular reservoir for further consumption. This could perhaps provide enough water per day for the survival of Namibian desert people.

3. Butterfly wings inspired screen display

Butterflies have brilliant colours on their wings and these colours are created through the prism-like, crystalline structure of the surface. Qualcomm, a wireless technology company imitated the butterfly wings in its Mirasol and IMod displays. The same structures that give a vibrancy to butterfly's wings were used to create an "always-on" effect without losing energy for backlighting. These displays are being used in cellular phones and other user interface devices.

4. Algorithms inspired by social insects

Social insect can solve a number of problems that none of the individual insects would be able to solve by itself. Some examples are, finding short paths when foraging for food, duty allocation when assigning work to workers and gathering when organizing brood chambers.

Direct communication: When a scout bee of a colony finds a food source, it communicates the direction and distance of the location of the food to the other bees by performing a characteristic dance. Bee dancing has inspired several important computing algorithms for the formation of the group and task allotment in scheduling theory and computational intelligence.

Insects swarms: Swarm Intelligence is a computational and behavioral symbol for solving scattered problems inspired by biological examples provided by swarming in social insects (ants, termites, bees / wasps), herd, flock and shoal phenomena in vertebrates such as bird flocks, fish and shoals. Therefore, Swarm Intelligence principles have been effectively applied to a sequence of applications including optimization algorithms, communications networks, and robotics.

5. Flea's Jumping Joints

Resilin, a cuticular protein that makes up the joints of many insects, including fleas. The effectiveness of resilin is significantly higher than synthetic rubber or natural rubber harvested from rubber trees. It helps fleas to store sufficient kinetic energy to jump up to 100 times their body length in a single leap. It is the most efficient elastic protein and its synthesized form can be used to improve everything from the responsiveness of human heart valves to the bounciness of sports shoes. This resilin influences CSIRO scientists to develop a rubber with 98% resiliency.

6. Social insects to learn teamwork in humans

As a result of co-evolution from past millions years, social insects (ants, bees, wasps, termites, *etc*.) have evolved as 'super-organisms' (A super-organism is an aggregate of individual organisms that behaves like a unified organism). These are exceptionally qualified to inform human design. Members of a super-organism have highly specialized social cooperative instincts, division of labour, and are unable to survive away from their super-organism for very long. They have evolved firmly integrated societies comprising millions of members in a colony and solve many problems inherent to social organization. Individual social insects exhibit comparatively simple behaviours, but together, colonies can perform complex tasks such as direction-finding, assigning labour and resources and constructing nests/mounds that provide physical and social services. Unlike most human operations, social insects complete such works without a supervisor and this is possible because of stigmergy, a form of indirect communication through alteration of the environment. 'Social Biomimicry' provided a forum for exchange between biologists, designers, engineers, computer scientists, architects, and business people.

7. Building with termites

The termite mound above ground level consists of porous but very hard material, with a series of channels for ventilation. Cool air is sucked upwards from subterranean channels, cooling the mushroom-shaped nest below the mound. During the night the air stream is reversed and regenerates the reservoir of cool air. Even termites construct deep channels to the groundwater to gain additional cooling in the mounds through evaporation. Termites even construct their asymmetrical flat-shaped mound with the long axis in east-west direction to avoid the direct heat in the summer. The simple reason behind this effort is to control humidity and temperature, to provide a stable environment for the termites, their offspring and the symbiotic fungi (fungal garden) in the nest. The termite mounds serve as a role model for an effective passive ventilation system for the control of the internal climate. Efforts have been made to translate this principle in architecture leads to the world's first all-natural cooling structure such as Eastgate Centre, in Harare, Zimbabwe, built-in 1996 by Mike Pearce. The roof and lower floor of this building are porous which leads to natural ventilation, similar to that of termite's nest. Hot air escapes through the roof, and the inflow of cold air from the bottom ventilates the building. Hence, the energy consumption rate of this building is 10percent and an internal temperature of 24°C is maintained even when the external temperature is higher than 38°C.

8. Moth eye surface, the role model for anti-reflection nanostructures

Microscopically tiny grating narrower than the wavelength of light coats the eye surfaces of moths. This structure influences the reflection and refraction of light and this delivers good night-vision and because with their eyes hardly reflecting anything, the available light and good camouflage are efficiently used. A phenomenon known as Areflexia is observed in moth's eyes, which reflect all wavelengths of light beyond the visible light spectrum to block them. The projections on moths' eyes, spaced at a distance of 200 nm, absorb most visible light rays, as they are shorter than most wavelengths of light. The refraction of the light rays entering the eyes will be increased, considerably decreasing reflection. This allows the moth to avoid its enemies and to find its host in the dark. This know-how is being used in national security agencies and also it is used in solar cell light-emitting diodes.

9. Insect navigation system

Many insect species complete their extraordinary navigation tasks. In their daily foraging trips, social insects like bees or ants cover distances of several kilometers and accurately and back to their nests. Besides methods like path integration (estimating distance and direction to the goal by constantly integrating distance and direction of movement) and systematic search (steering in pre-programmed patterns), they resort to visual homing strategies, also referred to as landmark navigation. Knowledge of the mechanisms used by insects for visual navigation can be used as a guideline for developing navigation methods for mobile robots. Since an insect brain contains only about one million neurons in total, evolution has found thrifty solutions for the problem of visual homing. These solutions are probably far away from the classical approaches to robot navigation which is usually based on complex processes of landmark recognition, computation of the position in maps of the environment, and planning of movements.

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Cartoon by Ashirwad Tripathy (ashirwadaspire351@gmail.com)

Bamboozling by cuckoo bumble bee

Mogili Ramaiah and Naresh M. Meshram

Raising kids is a great deal of work; it will take a lot of energy to provide food and defend helpless offspring. So, brood parasites trick someone else into doing it for them. This type of breeding strategy is well observed in birds, such as cuckoos or the brown-headed cowbird, but in insects the brood parasitism is very often. One of the best example from insects are the cuckoo bumble bees in the subgenus *Psithyrus* (now called "*Bumbus*"). Cuckoo bumble bee (parasitic bumble bee) queens employ sophisticated trick to enter into nests of their hosts, but they don't simply dump their eggs in another bumble bee nest, like a cuckoo bird. Because their host bumble bees (nest building bumble bee) are eusocial, where we can find the highest level of organization of sociality**.** Cuckoo bumble bees have to cheat the entire colony. These bees are also considered "social parasites" because they exploit the whole colony, tricking the host workers into rearing cuckoo brood.

Learning how cuckoo bumble bees cheat the eusocial system of nest building bumble bees can tell researchers a lot about how insect sociality as well as their host parasitic interaction evolves with each other.

Nest seizur: where one queen invades or occupies the nest of another, kills the original queen and adopts her brood - is common among bumble bees (intraspecific). This is called "facultative social parasitism". This type of strategy deployed by bumble bee queens only under certain ecological conditions. But cuckoo bumble bees are "obligate social brood parasites", where they cannot reproduce without their hosts. Because the worker caste is completely absent and they lack pollen baskets on their tibia of hind legs. So, cannot collect pollen from flowers to feed their own offspring and for them it's unable to produce wax from her abdominal segments to build their own nest.

Fig. 1. Forest cuckoo bumble bee (*Bombus sylvestris*), Photo credit: Bumble bee Conservation Trust

In the spring, female cuckoo bumble bees emerge from hibernation a few weeks later than their hosts. After their ovaries are fully developed, female cuckoo bumble bees start to search for host colonies, in which the first worker brood has already emerged. For this, cuckoo bumble bees must find a host colony of another bumble bee species, and it has to be just the right size. Too large, and there will be too many workers defending the nest and the cuckoo will be killed. Too small and there will be too few workers to raise the cuckoo's offspring. So, cuckoo bumble bees must be species-specific. They also have to be tough fighters to defend themselves from attacking workers as they infiltrate the nest and kill the host queen. Thus, cuckoo bumble bees are heavily armored with larger and stronger mandibles, a hardened abdomen, and a powerful sting with large venom sac. After discovering a suitable nest, they invade it and usually kill the queen and some of the host workers. However, often the cuckoo bumble bee is attacked and killed by host individuals. In cases of successful invasion, the parasite lays eggs that are reared by the host workers into new *Psithyrus* sexual. After the next generation of *Psithyrus* females and males has emerged, they leave the nest for the purpose of mating and the mated females subsequently hibernate.

Most of research work carried out during the past decade have shown that footprints of host bumble bees and chemical mimicry as well as allomone (chemical repellent- dodecyl acetate) produced by cuckoo bumble bees plays an important role in host nest recognition and invasion processes, in the takeover of host colonies, and in newly emerged parasites before they leave their host colony.

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VTOL UAVs for spraying insecticides

Chakravarthy, A.K., Nitin, K.S. and Kiran P. Kulkarni

India is an agriculture-dependent nation. From ages, India has been the driver of this sector. The data on agriculture and the crop defines the mood of the nation. As the economy of India is concerned, agriculture contributes nearly 5 to 6 percent of the GDP. Considering these factors, the modernizing the agriculture sector has become the need of the hour. In agriculture, information plays an important role in all types and stages of the crop. Lack of information leads to over or under production and crop loss. In the modern era of agriculture, this problem can be solved by adopting modern technologies like Imaging and the Internet of things (IoT) are going to play an important role.

In the agricultural activity, labour is adding a major cost factor. Aspects like lack of skilled labour and an increase in basic wages are pushing the engineering community to find an alternative solution. One such innovation is the use of UAVs (Unmanned Air Vehicles) in agriculture for various purposes. There are 2 major ways of deploying UAVs *viz.,* Imaging, and Crop-spraying (application of plant protection chemicals). The economic viability of these activities has been the centre of study for the government to take it further. Here we deal with crop spraying.

Crop spraying: There are many factors involved in crop spray activity in agriculture like

a. Type of crop
b. Type of pest and composition of spray
c. Crop canopy
d. Area
e. Season
f. Frequency
g. Effects of spray
h. Economics

A new technology called Aerial Electrostatic Spraying system using helicopters is now becoming popular. Helicopters can deliver pesticides in low altitude areas. Studies have shown that electrostatic spraying produces uniform and fine droplets with better distribution, deposition, low environmental contamination, and higher efficiency.

UAV based crop spraying activity is catching up fast. Various companies are deploying the VTOL (Vertical Takeoff and Landing) UAV for the purpose. The above-mentioned factors need to be studied before the successful deployment of VTOLs for crop spray.

When UAVs are deployed for spraying in agricultural tracts, the distribution and spread of active ingredients or particles on the crop canopy should be appropriate. The particles should not drift over or the particles should not impinge on crop canopy by imparting stress. The liquid should be able to penetrate the crop canopy and reach the target site on the plant.

I. Type of pest and composition of the spray

Type of pest, whether it is highly mobile or sedentary with chewing or sucking mouthparts and feeding parts of the plants by the pests are crucially important. The composition of the spray mixture whether it is systemic or contact or dust or aerosol matters a lot. The formulation of the spray should be ultra-low volume spray such that it is meant for aerial spraying and not for a knapsack or gator spraying. Presently, a majority of the operators are increasing the dosage level to suit lesser flights for the same area, which harms the crop, soil, biodiversity, and environment.

II. Crop canopy

It plays a pivotal role in dispersing the spray particles. Horizontally -spread crop canopies imbibe major portion of the spray swathe. However, vertically shaped canopies require a different mode of delivery wherein the spray particles should disperse along with the height of the canopy. Since UAVs discharge, the spray particles overhead the crop canopy, the bottom portions of the crop remains free from the spray.

III. Area

Utilizing UAVs for spray applications will cover almost 5 times the area covered by manual spraying using power pack sprayers. But the cost per acre remains very high. Instead, it can be done utilizing more labour by creating jobs and value for money.

IV. Season

There are 2 major seasons of cropping in India *viz*., *Kharif* and Rabi. *Kharif* being a monsoon cropping constitutes 65% of major crops. During this season the wind speeds are very high with rain. When UAVs are deployed for spraying activity due to windy conditions it is observed that spray particles drift from the crop canopy. This is not desirable because of the loss of material and the effectiveness of the dosage/a.i. Since UAVs fly very low to the ground chances of gust and crash are

Fig. 1. Insecticide application using drone.

high.

V. **Frequency**

During Kharif season it is required to have multiple forays as the area under the crop will be high and rain washes away the sprayed chemicals. This becomes more expensive because of multiple deployments of UAVs.

VI. **Effects of spray on crop**

The impact of spray applications should not adversely affect crop architecture and structure. These UAVs are VTOLs that produce 12 to 14m/s downwash wing hitting the crop and lodging it. Further, this induces a high amount of stress on crops affecting the yield.

VII. **Economics**

The cost of a typical VTOL UAV with 10 liters to 15ltr liquid carrying capacity is about Rs12-14 lakhs (with minimum spares) in India. The total life of VTOL in most favoured conditions lasts for 1000 landings (if no accidents occur) i.e., Rs1200/- per landing of VTOL in addition to other overheads will add like, cost of labor, cost of transport, cost of operating overhead, cost of maintenance of UAV and profit of the company. This roughly comprises Rs. 2000/- flight. In each flight, UAVs are expected to cover only 1 acre (in *Kharif*). Therefore the cost of operating VTOLs for crop spray becomes unaffordable. It is also observed that the cost of UAVs and operating overheads have not reduced over the years.

Unlike imaging activity, the spraying activity is more labour intensive and time-consuming. So, by considering all these factors VTOL UAVs are economically not feasible in the present scenario of Indian Agriculture.

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Importance of honey bees in pollination of horticultural crops

Bhagyasree, S. N., Sachin S. Suroshe and Sweetee Kumari

Pollination means transfer of pollen from the male part of the flower, the *anthers*, to the receptive female part, the *stigma* for fertilisation and sexual reproduction. It is one of the most important feature in fruit production. Many types of commonly grown fruit require pollination in order to bear good marketable produces because fruit trees carry thousands of flowers, but unless there is adequate pollination, little or no fruit will be produced. For good, well shaped and higher fruit set, flower should get the right pollen to the right place at the right time. Pollination not only provides a good yield of fruits, berries or seeds, it may also give a better quality of produce which fits well in international markets and the efficient pollination of flowers may also serve to protect the crops against pests. For example, an apple will develop all the 10 seeds inside if it is pollinated by bees and fully fertilized apple with 10 seed will have good shape and appeals well for export. Similarly, strawberry needs about 21 visits of bees for complete development, a single strawberry can have 400-500 seeds sitting on the surface of one berry. The higher number of seeds developing fully, the bigger and more even shaped the berry will be.

Pollination happens in two ways *viz.*, abiotic and biotic. Abiotic pollination doesn't involve any living organisms, it happens by wind. Biotic pollination happens by the transfer of pollen by living organisms, it is the most common form of pollination and 3/4th all flowering plants are pollinated by living organisms like birds and insects. Among birds and insects, > 95 % of the flowers is pollinated by insects especially honey bees.

Insect pollination is a symbiotic process, providing benefits for both insect and plant. Insects provide pollination service and plants provide food to insects, primarily nectar and pollen during foraging. Nectar is a solution of sugars mixed with mineral nutrients and fragrances and is usually located at the flower's base and pollen is rich in protein and a potential food source for many pollinators.

Why honey bees often are the most important crop pollinators?

The effectiveness of honey bees is due to their high number, their social life and their ability to pollinate a broad variety of different flowers. A colony can consist of 20-80 thousand bees, and they will normally be visiting flowers over a distance of two kilometres when they are collecting pollen and nectar. If they are not getting food, they can fly even seven kilometres. A normal *Apis mellifera* honey bee colony will make up to four million flights a year, where about 100 flowers are visited in each flight. The honey bee's pollination effectiveness also arises from the fidelity to flowers of one species. Scout bees communicate to other bees in the colony which species to visit, and even give small tastes of nectar and scent from that flower.

What is the economic value of pollination?

The value of bee pollination in Western Europe is estimated to be 30-50 times the value of honey and wax harvests in this region. In Africa, bee pollination is sometimes estimated to be 100 times the value of the honey harvest, depending on the type of crop and in Western Europe pollination is estimated to be 30-50 times the value of honey and wax harvests in this region. The economic value of pollination worldwide may be as high as $ 90 billion and the monetary value of pollination for the Indian crops is given below in the table 1.

How many colonies are preferred for good yield?

A most important things lies in farmers mind is when and how many colonies are necessary to ensure good pollination of their crops? But this is a quite subjective question to answer because pollination studies are poor and their ecosystem services are not established and also the other heterogeneous factors like bloom periods, bloom density, bloom attractiveness, blossom structure, competing bloom and weather determine how well honey bees will forage and pollinate a given crop which is quite difficult to measure quantitatively. The number of hives also depends on the quality and working strength of individual colonies.

Timing for using pollinators?

It is important that hives can be moved quickly to a crop that is ready for pollination. Move hives into the crop after 5 to 10 % flowering has already begun. If you move them in advance you give bees a chance to forage on another non-target plant. As the bees shows high fidelity, once bees are trained/started visiting other flowers, they will not come back till the depletion of food and ignore the crop when it blooms. Growers can also spray chemical attractants contain synthetic queen pheromone or components of Nasonov pheromone, a chemical bees use to orient to nest sites, to increase the number of bees visiting their crops.

Conclusion: Globally bee are more and abundant compared to any other pollinators, it is estimated that one third of the food we eat each day depends on pollination by bees, most of the domestic and imported/exported commercial crops rely on pollination. Examples include almonds, avocados, blueberries, cucumber, citrus, soybeans, asparagus, broccoli, celery, Cherries, kiwi, peaches, squash, sunflowers and melons. So in order to get better bee ecosystem services, to increase food production and doubling the farmers income by pollination and commercial bee keeping for honey and other bee hive products, we need to make efforts to save them by providing friendly habitat and safe ecosystem along with creating awareness and campaign on their importance.

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Table 1. Monetary value of pollination for the Indian crops

Sl. No.	Crops	Economic value (INR/Crore)	Economic value (%)
1	Rapeseed and mustard	19355	--
2	Oilseeds	43993	34
3.	Fruits	17095	14
4.	Vegetables	19498	11
5.	Fibers (mainly cotton)	17290	23
6.	Condiments and spices	10109	25

Source: Chaudhary and Chand, 2017

Table 2. The average numbers of hives employed per acre for pollination in some important crops are listed below.

Sl. No,	Crops	Hives per ha	Crops	Hives per ha
	FRUIT CROPS		VEGETABLE CROPS	
1.	Apple	4	Bean (Lima)	3
2.	Almond	12	Cabbage	5
3.	Apricot	2	Brassica (canola, oilseed rape)	5
4.	Avocado	5	Carrot seed	8
5.	Blackberry	7	Cucumber	7
6.	Blueberry	8	Eggplant	3
7.	Citrus	2	Gourds	4
8.	Kiwifruit	8	Melon	7
9.	Mandarin	4	Onion seed	17
10	Mango	15	Pumpkin, squash, gourd	4
11	Watermelom	5		
12	Peach and nectarine	2		
13	Pear	4		
14	Strawberry	8		

* Number of colonies refers to colonies of *Apis mellifera* and number of recommended hives per ha depends on the attractiveness of the crop to bees, number of wild bees, number of competing weeds, strength and location of bee hives, weather and the grower's experience. Generally, anything that affects/hinder pollination efficiency invites more colonies per acre to compensate.

What came first, moth ears or bat sonar?

Adrish Dey

In the dead of the night occurs age-old aerial warfare between two parties- bats and moths. As this war occurs in hours of darkness, keen eyesight wouldn't prove to be a very convenient military asset. The bats, therefore, use echolocation which makes them exceptionally capable, predators. But insects are also not a rookie in this confrontation, they counter the bat's ultrasonic sonar with ears tuned to such high frequencies. In addition to this, they have evolved aerobatic evasive movements and anti-bat sounds. Such a sophisticated predator-prey interaction, significantly facilitated by an elegant paradigm of acoustic orientation, left the evolutionary biologists pondering when, why and how these moth-ears (tympanum Fig. 1) have evolved.

Until recently, predation by bats was hypothesized to be the driving force behind the evolution of hearing organs in moths, but the latest research confutes this proposition. The timing of when ears arose has remained untested because of a lack of a stable dated phylogenetic framework for the Lepidoptera. The studies conducted previously examining the macroevolutionary patterns of Lepidoptera did not have sufficient genetic data and carefully evaluated fossil sampling to confidently resolve the evolutionary history of the order.

In the recent study, first published in October 2019, a group of scientists sampled 186 extant species of moths and butterflies and constructed a dataset of 2,098 protein-coding genes. Then they conducted a phylogenetic analysis. The results were then calibrated using fossil data to obtain a dated tree which enabled the researchers to reconstruct the evolutionary history and determine the timing of ecological adaptations.

They found out that in four species-rich clades (Drepanoidea, Geometroidea, Notcuoidea, and Pyraloidea) ears evolved in the Late Cretaceous about 91.6 to 77.6 Ma; whereas, laryngeal echolocation in bats originated about 50 Ma. This suggests that

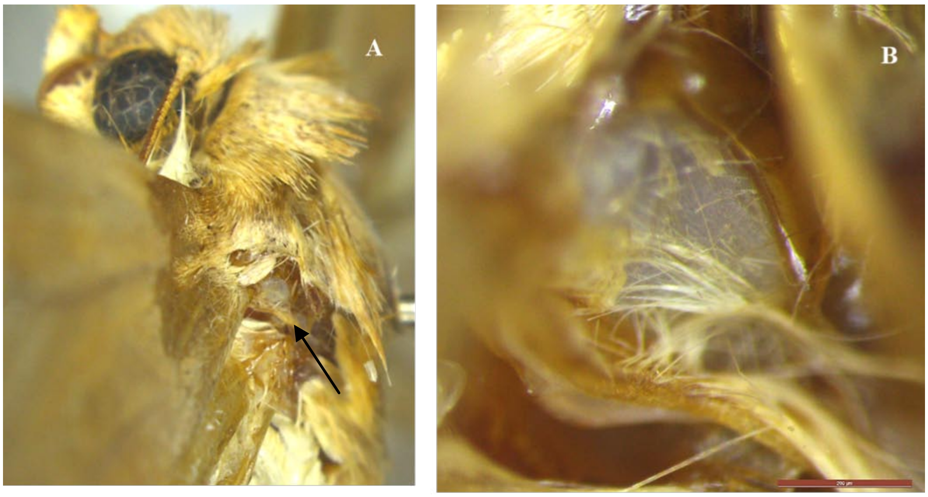

Fig. 1. Thoracic tympanum of noctuid moth. A: The arrow indicates tympanum of a Noctuid moth, B: The same tympanum at a higher magnification.

the evolution of moth hearing is not a consequence of selective pressure from bat predation. Then, what have these moths been listening to before the emergence of bats? The most probable explanation for the evolution of this trait is for detecting sounds of animal movement and general perception of the environment. In fact, the diurnal Lepidoptera and moths which were endemic to areas devoid of bats exhibited decreased responsiveness to high frequencies but were sensitive to low-frequency (caused by walking and wing beat of predatory birds). Thus, moth ears evolved primarily for auditory surveillance but were later co-opted for perceiving bat's position.

This study also disproves another hypothesis which states that butterflies became diurnal in order to escape bats. This trait of nocturnality in Lepidoptera existed in the Jurassic age, about 209.7 Ma, and the character can be traced back to at least the ancestor Heteroneura. The most notable event of switching to diurnality occurred in the ancestor of Papilionoidea about 98.3 Ma, which is again before bats evolved laryngeal echolocation (~50Ma). Therefore, some other factors, which may be the availability of nectar during the daytime, resulted in the evolution of this diurnal activity.

Now, returning to the original discussion on moth ears adapted to high frequencies; the most pertinent question that comes to the mind is haven't the bats developed counter adaptations? Turns out, that bats exhibit a multitude of phenomena from stealth echolocation (in which the calls are 10 to 100 times less in intensity when approaching an eared moth prey) to changing the timing parameters in call repetition rate (which prevents the insect to dodge the prey); thereby establishing the fact that an evolutionary arms race goes on between bats and moths ever since.

Such studies on evolutionary biology help us eavesdrop on the distant past, adding a new perspective to our perception of the prehistoric life and times.

Further reading:

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Effect of elevated temperature and CO_2 on natural enemies of insect pests

Yogesh Yele, Subhash Chander, Namita Poddar, Bhagyasree S. N. and Sachin S. Suroshe

Biological control is a key component of Integrated Pest Management (IPM) programmes in many agroecosystems. Tritrophic interactions between plants, herbivorous and natural enemies result from a long co-evolutionary process specific to a particular environment and stable climatic conditions. Global climatic change has affected every aspect of life processes on earth and is also expected to impact herbivore-natural enemy interactions in several ways. Elevated global temperature, increased CO_2 and O_3 concentrations, UV radiation and changes in rainfall patterns are major climate change parameters. Among these, elevated temperature and CO_2 are significantly affecting the plant, pest and natural enemy interactions. Climate change affects species distribution, life histories, community composition, and ecosystem function. The impact of climatic changes is likely even more important in higher trophic levels that depend on the capacity of the lower trophic levels to adapt to these changes. Parasitoids and predators are thus organisms for which severe impact is expected, as its represent the third and fourth trophic level. In such scenario, assessment of the potential impacts of climate change on biological control is critical and challenging due to complex interspecific interactions.

Effect of elevated temperature on natural enemies

Temperature is major abiotic factor which has direct effect on the survival, development and population dynamics of herbivore and its natural enemies. Each population of every insect species has different optimum thermal range for survival and development. In the context of global warming scenario induced by climate change, all species will be under strong selection pressures and natural enemies are no exception.

1. Effect on host searching ability

Parasitoids can sustain a broad thermal range, although exposure to temperature extremes even for short periods is likely to influence parasitoid survival and host searching ability. Studies from 1993 to 1996 correlating climate data with egg parasitism suggest that rate of egg parasitism by *Trichogramma* spp. on European corn borer was drastically reduced to zero owing to extremely dry and hot weather experienced in May 1993 in Slovakia (Cagan et al., 1998). Similar study on Tachinid flies in relation to increased temperature suggests reduced range of parasitism up to 51%. Host location falls off sharply at temperatures above 35 ^{0}C of the egg parasitoid, *Trichogramma carverae* Oatman and Pinto (Thomson et al., 2001). In case of predators, it could be different. For example, it has been predicted that coccinellids reduce aphids more strongly in hot summers than in moderate summers.

2. Effect on reproduction and sex ratio of natural enemies

Extreme temperature events also have the detrimental effects on biological parameters. Temperature influences the fecundity and sex ratio in ichneumonid larval parasitoid, *Campoletis chloridae.* However, up to 50% reduction in fecundity is commonly reported in *T. carverae*, *T. pretiosum* and *T. bactrae* Nagaraja at 30 ^{0}C. Endosymbiotic bacteria, *Wolbachia* and *Buchnera* which influence several aspects of parasitoid reproduction can be eliminated or drastically reduced by short exposure to extreme temperatures.

3. Effect on host tracking by natural enemies

It is predicted that a 1^{o}C rise in temperature would enable species to spread 200 km northwards or 140 m upwards in altitude. Herbivore pests having greater mobility are likely to track the expansions. For example, rise in temperature will allow the pink bollworm, *Pectinophora gossypiella* (Saunders) to expand its range to non-traditional cotton growing areas that are presently non habitable (Guiterrez et al., 2008). Mobile species such as diamondback moth, *Plutella xylostella* L. and European corn borer, *Ostrinia nubilalis* (Hubner) will track the new areas faster than less mobile species. The probability of hosts escaping their specialist parasitoids will be highest as they may struggle to track the spatial shift of their host. These changes in the distribution of crops and expansion of herbivores range may lead to escape of these pests from natural enemies which may ultimately affect the pest control.

4. Phenological asynchrony between natural enemy and herbivore host

Change of phenology (the timing of biological events) is the most immediate response to climate change and has been widely documented across a range of species. Temperature is the most critical factor to affect the herbivore phenology; which alters the synchrony between herbivores and their natural enemies. Mismatched phenological asynchrony between a parasitoid and its host has been reported in several of cases. Grabenweger et al., (2007) reported lower level of parasitism in the first generation of horse chestnut leafminer, *Cameraria ohridella* Deschka & Dimic, which is might be due to emergence of hibernating parasitoids of leaf miners at a time when hosts are not available.

5. Temporal asynchrony between natural enemy and herbivore host

Irrespective of the species, speed of development of herbivores will generally increase under global warming. Multivoltine species will be able to increase the number of generations per year owing to more rapid development in higher temperatures. Fluctuations in parasitoid abundance and field parasitisation levels might get directly affected by rising temperature. Two way effect of temporal asynchrony may lead to extinction of host and/or natural enemy. Increased synchrony exposes host to intense parasitoid pressure, potentially leading to local extinction of the host which will ultimately lead to parasitoid population crash or local extinction due to unavailability of host in next generations (Hance et al., 2007). Conversely, decreased synchrony will lead to unavailability of host to emerging parasitoids, again causing their decline (Godfray et al., 1994).

Effect of elevated CO_2 on natural enemies

Global atmospheric CO_2 concentration is currently 390 ppm and would reach to 500-900 ppm by the end of the 21st century. Increasing atmospheric CO_2 concentrations will have a great effect on tritrophic interactions, which could modify plant resource allocation. It would also affect plant defense by altering C:N ratio. For example, in cotton, *Gossypium herbaceum* L., increasing CO_2 concentrations cause a corresponding elevation in concentrations of the phenolic aldehyde, gossypol, which has an antibiotic effect on the cotton aphid, *Aphis gossypii* Glover (Gao et al., 2009). This improved the fitness of coccinellid predator, *Propylaea japonica* Thunberg. In contrast, Dyer et al. (2013) showed that increased CO_2 and temperature weakened the biological control of armyworm caterpillars by parasitoids because of decrease in the nutritional quality of the lucerne plants and prolonged larval duration of armyworm. As a result, the parasitoids were unable to complete development, causing local extinction of parasitoid populations and weakened biological control.

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Our Tryst with Science

Beneath a smiling face
Silently I weep
When I put my little boy to sleep
In the scented fragrance of pyretheroids

Beneath a smiling face
Silently I weep
What if I am to feed my little boy
With lethal genes of GM food?

Beneath a smiling face
Silently I weep
When I clothe my little boy
With lethal genes of GM cotton

Beneath a smiling face
Silently I weep
When I would fail to nurture my little boy
The priceless natural air, food or clothing

Beneath a smiling face
Silently I weep
Enshrouded in languishing science
Pushed away miles from nature

Beneath a smiling face
Silently I weep
Tear by tear falling down in vain
Like pearls thrown before swine

Beneath a smiling face
Silently I weep
Hoping for a silver lining
In our tryst with science

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FIRST INDIAN ENTOMOLOGIST PHOTO CONTEST

The Indian entomologist photo contest aims to encourage insect photography among photographers, professionals, amateur entomologist and the layman. The central theme of the first episode of the photo contest was ‘Insects and aspects related to insect life’.

With these objective entries were invited during December 2019. Each participant was to submit one good photograph which met a few prescribed standards along with the filled in application form in which the participant had to furnish his/her details, caption, description, specifications of the photograph and also a declaration on the ingenuity of the photograph. We received a total from 105 entries which were screened first for the prescribed standards and overall quality of the image. Final evaluation was done for 28 images by a committee of three independent members in the presence of the three editorial board members based on the following criteria quality (clarity, lighting, depth of field, composition), relevance of the subject matter (theme, rareness of subjects), creativity and originality. To ensure a blind review the details of the photographer was hidden and the evaluators were only presented with the photograph, caption, description and technical specifications.

- The first place was won by Shashidharswami Hiremath (Shashidhar.ph@gmail.com) who captured a wasp in action near a flower at Kadaramandalagi (Byadgi-Taluk, Haveri-Dist, Karnataka) (Magazine cover page).
- The second place was won by Alfred Daniel J (danieljalfred@gmail.com) for his photograph which portrayed a robber fly preying on a hopper with a caption – Robbing the hop(p)e(r). Image was captured at Ziro, Arunachal Pradesh.
- The third place was shared by Amith Kiran Menezes (amithsonu@gmail.com) who captured a well-lit jewel beetle at Bangalore University, Karnataka and Sailaja Vallabuni (sailajavallabuni@gmail.com) who captured a wasp and sunbird in action near a trickling water source at Forest College and Research Institute, Siddipet, Telangana.

All together we got an overwhelming response from the participants with many good quality entries.

BUG STUDIO ASSOCIATE EDITORS

First prize, Shashidharswamy Hiremath, ‘Yellow banded Ichneuimonid wasp visit flower’, Haveri, Karnataka, Nikon D 300S with Sigma 150 mm F-2.8 Macro, shutter speed 1/320, ISO 640, aperture f/13, focal length 150 mm.

Second prize, Alfred Daniel J, ‘Robbing the hop(p)e(r)’, Ziro, Arunachal Pradesh, Panasonic FZ 300 with Raynox DCR250, shutter speed 1/200, ISO 100, aperture f/4, Focal length 28. 7 mm.

Third prize (Shared), Sailaja Vallabuni, 'Water source is a ray of hope for all life', Mulugu, Telangana, Nikon D500 with Tamron 150-600mm, shutter speed 1/3333, ISO 1250, aperture f/7.1, focal length 500 mm.

Third prize (Shared), Amith Kiran Menezes, 'Metallic wood boring beetle', Bangalore University, Bengaluru, Canon 700D with Canon100 mm F-2.8 Macro, shutter speed 1/125, ISO 400, aperture f/13, focal length 100 mm.

MOHAN GANESH BALAGA

DEPARTMENT OF ENTOMOLOGY, ASSAM AGRICULTURAL UNIVERSITY, JORHAT, ASSAM

Mohan Ganesh is pursuing his PhD on Genetic diversity of fruit fly species from different regions of Assam using molecular tools. He also wants to prepare and illustrate key, distribution maps and *mtCo1* barcode of the collected and reared species. For which he has to collect samples from 5 districts each from northern, central and lower Assam regions. He collected six different fruit fly species from lower Assam, from those samples he was able to identify five fruit fly species with the help of taxonomic keys which were *Bactrocera cucurbitae, Bactrocera dorsalis, Bactrocera latifrons, Bactrocera tau, Bactrocera zonata*. The remaining unidentified specimen were sent to NBAIR Bangalore for identification. He will also be carrying out molecular work using universal primers barcode region (*mtCo1*) for the collected specimens and will continue the rest of his work in remaining regions of Assam.

In future, he would like to work on the effect of elevated CO2 and temperature levels on fruit fly biology and explore their morphological and molecular variations.

SOUMYA E

DEPARTMENT OF ENTOMOLOGY, UNIVERSITY OF AGRICULTURAL SCIENCES, RAICHUR, KARNATAKA, INDIA

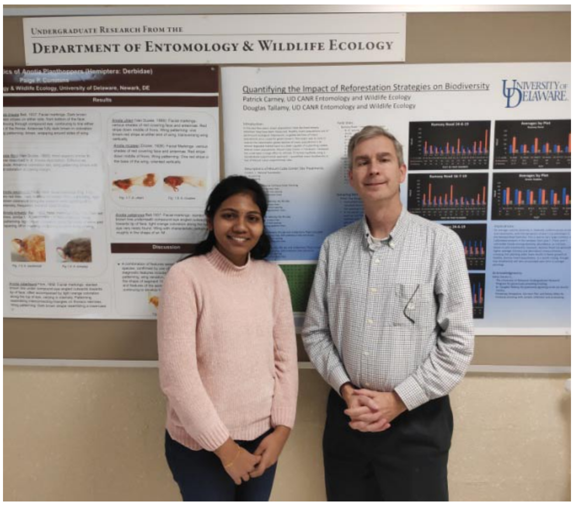
Sowmya is a Ph.D. student working on Isolation and molecular characterization of entomopathogenic fungi and their efficacy studies against the sugarcane root grub *Holotrichia serrata* Fab. (Coleoptera: Melolonthinae) in Northeastern Karnataka under the guidance of Dr. Arunkumar Hosamani and Dr. Ramanujam. B (ICAR-NBAIR, Bangalore). Goal of the investigation is to describe the root grub species associated with the major crops of Northeastern Karnataka. Also to facilitate the accurate identification and authentication, isolation, morphological and molecular

characterization of different strains of *Metarhizium anisopliae* and to conduct bio efficacy studies against *H. serrata* and thereby develop a liquid formulation for the management of sugarcane root grub.

Further, she is planning to continue her research on major subfamilies of Indian Scarabaeoidea and genome editing of root grub with Ovo gene using CRISPR-Cas 9 in order to disrupt the wing and gonad development in *H. serrata*, a major pest of sugarcane in India.

International training at Univerity of Delaware, USA

Hi everyone, I am Ramya N, Ph.D. Scholar at Division of Entomology, ICAR-IARI, New Delhi. Presently working on the Biosystematic studies of family Delphacidae (Hemiptera: Fulgoroidea) from India. I recently visited the University of Delaware, Newark, USA -19716 under student exchange program of Centers for Advanced



Agricultural Science and Technology- National Agricultural Higher Education Project, Indian Council of Agricultural Research, Ministry of Agriculture and Farmers Welfare, Government of India (CAAST-NAHEP). It was a great opportunity for me to work under the guidance of renowned planthopper taxonomist Dr. Charles Bartlett, Associate Professor, Department of Entomology and Wildlife Ecology, University of Delaware. He is hosting a website on Planthoppers of North America and Curator of University of Delaware Insect Research Collection. It was an amazing experience to work in his lab, where I learned both classical and molecular taxonomy techniques. We had healthy discussion on the Indian delphacid fauna. The current research in delphacids, from the very basic insect collections to improved techniques like mitogenome sequencing and its applications in getting better results for identification as well as for evolutionary studies.

Despite the well-known economic importance of delphacids, very few attempts have been made to explore and identify these in India. We have attempted to explore the delphacids from different localities of India and identity them. Fortunately this International training made it possible to understand and shown the way forward in delphacids

Ms. Arya P. S. and Mr. Mogili Ramaiah, Division of Entomology, ICAR-IARI, New Delhi compiled the information for this section.

ABOUT THE MAGAZINE

Indian Entomologist is a quarterly magazine that publishes articles and information of general, scientific and popular interest. The magazine publishes letters to the editor, columns, feature articles, research, reviews, student opinions and obituaries. The magazine accepts articles on all aspects of insects and terrestrial arthropods from India and worldwide. Short field notes and observations are also welcome. This magazine is intended to provide a broad view of topics that appeal to entomologists, other researchers interested in insect science, and insect enthusiasts of all stripes.

Notes for Contributors

Articles submitted should not have been published elsewhere and should not be currently under consideration by another journal/ magazine. Interested authors are advised to follow the author guidelines of Indian Journal of Entomology for reference citations and to follow as closely as possible the layout and style, capitalization and labelling of figures. All papers are subject to peer review and may be returned to the author for modification as a result of reviewers reports. Manuscripts are acknowledged on receipt and if acceptable proofs are sent without further communication. Minor editorial alterations may be made without consulting the author. Make sure to submit the photographs of high quality in .jpg format. For those who want to contribute commentary and feature articles please contact editors before submission.

About articles

IE is intended to publish following categories of articles

Commentary – We encourage opinions or critical analysis of current entomological happenings. Submissions should be no more than 5,000 words in length.

Reviews – two types of reviews will be published a. invited review (editorial team will contact eminent entomologists to contribute) and b. peer reviewed review (any author/s can submit a comprehensive reviews on modern entomological developments).

Feature articles – these must be of broad interest to biologists, amateur and professional entomologists. These articles should be no longer than approximately 5,000 words. Articles should contain high quality photographs.

Natural histories & short research articles- with focus on insect life cycle, occurrence etc. and have the same requirements as feature articles. Submissions should be up to 5,000 words in length.

Field notes - on unusual observations entomologists encounter during fieldwork (Invasive insects, outbreaks, behaviour etc.). Submissions should be no more than 2,000 words in length.

Bug studio- "Indian Entomologist Photo Contest" will be conducted for every volume of the magazine and best three winners will be announced in the magazine. Images should be submitted as high quality (300 dpi TIFF, jpeg files) files with a detailed photo caption. The announcement for photo contest will be made on our website www.indianentomologist.org

Student corner- students working on interesting topics of entomology to share their views and opinions about their research work. Can submit with personal photograph; it should not be more than 1,000 words in length.

We encourage entomologists to contact us if you have any interesting story to share about insects.

Contributions to be sent to the Managing Editor, in digital format (MS Word) as an e-mail attachment to indianentomologist@gmail.com