Insect Biodiversity and Conservation of Natural Enemies in Integrated Pest Management

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Our ignorance of how many organisms we share our planet with is remarkable considering that astronomers have listed, mapped and uniquely named or numbered a comparable diversity of stars and other galactic objects. We still do not have an estimate to the near hundred of the number of living organisms on the earth. Amongst the organisms that inhabit the terrestrial environment insects as a group far surpass the others in numbers. It is estimated that there are well over 1 million different known species of insects in the world, though we do not know the number exactly. Three times as many insects have been described as those in the rest of the animal kingdom. About one million species of insects have been described and still perhaps as many as 30 million are yet to be discovered. The largest group among them are the beetles with around 5,00,000 species and in fact one in every four animals on this planet is a beetle.

Insects are the most successful life form on earth and have been on the earth for about 350 million years, compared to less than 2 million years for human beings, the last resident to occupy the planet. Being on this planet for the longest they have indeed adapted and learnt to live in every nook and corner, every crack and crevice, much better than us. Unfortunately as the last entrant it has been a 'Arab and the camel story' and we have been displacing large areas of the earth of its original inhabitants and causing the greatest damage to their and our homes. The insects are remarkably successful, as they have evolved in many directions to become adapted to life in almost every habitat and have also developed many unusual, picturesque and amazing features. Some of their life features are indeed mind boggling, intriguing or just fanciful.

Accurate taxonomy is essential for IPM

Accurate taxonomy is the basis of biological information retrieval and without that detailed biological information may be ascribed to the wrong species. Correct identification of the target pest and its natural enemies is important and is essential before initiating an IPM programme. Wrong identification may prove costly in terms of time, energy and money spent on research. Good taxonomy can help in saving billions.

One of the good examples which brings out the significance of good taxonomy is the case of the biological control of the California red scale, *Aonidiella aurantii* in citrus where both the pest and natural enemies were in need of taxonomic work to clear confusion over identification and resulted in an almost fifty year lag to bring about successful control of the pest. Taxonomic confusion on identification of scales and its parasitoids hampered biological control. The scales were a complex of species native to the tropics & subtropics of the Old World (Africa through S.E. Asia and the Orient). Body colour was used for identification and it proved unreliable in scale taxonomy. Some early parasitoid shipments were actually from the yellow scales, *A. citri,* which proved useless on the red scale, *A. aurantii*. Stable taxonomic characters were discerned in early 1900s by Dr. Howard Mckenzie and this allowed the workers to identify the target pest. Later the parasitoids that were collected from the scales also were not identified properly as there was taxonomic confusion on several species of *Aphytis*. All *Aphytis* parasites found were thought to be *A. chrysomphali* until reliable taxonomic characters were found in 1940s by Rosen and DeBach. *A. chrysomphali* did not provide satisfactory control of the red scale and in addition many shipments of parasitoids were never made as it was all thought to be *A. chrysomphali*. As a result of the work by Rosen and De Bach workers could recognize additional species of *Aphytis*. Efficient parasitoids were found in the Oriental Region with *A. lingnanensis* being found in China during 1948 and *A. melinus* in India during 1957, and both proved very successful in controlling the scale. This also paved the way to study the biology of these species and helped in identifying the superiority of these two species over the already available *A. chrysomphali.*

A serious mealy bug was seen affecting coffee in Kenya in 1930s and it caused serious crop loss. It was first misidentified as *Planococcus citri* and later as *P. lilacinus,* which were both incorrect. A year was spent in searching for natural enemies for the pest in four different continents and it proved futile in controlling the pest. The pest was correctly identified by LePelley in 1957 and described as a new species, *P. kenyae*. The species occurred in nearby Uganda and Tanzania and was under natural biological control in these two countries. Parasitoids were imported from there and it produced complete biological control of the pest in Kenya. The most promising among them was *Anagyrus kivuensis*.

Search for natural enemies of beet leafhopper *Eutettix tenellus*, was made in South America, a centre of distribution of *Eutettix* without success. Only its correct placement in *Circulifer* enabled discovery of the parasitoids, which were introduced to USA from the Mediterranean region to bring about control.

Sibling species and the problems in identification

Several times pests to be managed may consist of species complexes bringing about the following difficulties

- Each species may differ in its susceptibility to an insecticide
- Each species may differ in its susceptibility to natural enemies
- Control of one species may lead to outbreak of the other in the complex
- Wrong identification of the key pest species may lead to introduction of an ineffective natural enemy

Some of the examples of such species are

Helicoverpa which consists of at least two sympatric species: *armigera* and *assulta*

Mango leafhoppers which consist of a complex of species of *Idioscopus* (3 spp.) and *Amritodus* (3 species)

Mango fruit fly of *B. dorsalis* complex - nearly 70 species

Red cotton bug in India that consists of at least 4 sympatric species: *Dysdercus koenigii, D. similis and D. olivaceus. D. cingulatus* is found only in northeast India

***Bactrocera dorsalis* species complex**

The family Tephritidae includes many species of economic importance. Fruit flies (Tephritidae) include some of the world's most serious agricultural pests. Of the more than 4,400 species known worldwide nearly 200 are considered pests. Of these about 70 species of fruit flies are considered important agricultural pests throughout the world and many others are minor or potential pests. Fruits are the most important crops attacked, including citrus, mango, apples, and many others, and some seed crops such as sunflower and safflower are also affected. Dacine fruit flies are one of the key pest groups in the world with the larval stages feeding on a wide range of fruits and vegetables. Several species complexes (sibling species complexes) are present in this family of which the *Bactrocera dorsalis* (Hendel) species complex is of great importance. Because there are so many species, many of which are extremely similar, the identification of species in the complex is complicated and difficult.

It has been known since early this century that Oriental fruit fly was more than just a single species. A number of species have been described in the complex and the complex has been extensively revised, redefined and expanded by Drew (1989) and Drew and Hancock (1994). *Bactrocera dorsalis* (Hendel) species complex now includes some 76 species that are found in the Oriental (60 species) and Australasian Regions (16 species) and two from India tentatively placed within the complex. Five of these species have become adventive outside of these regions and recently *B. invadens* from Sri Lanka has invaded several parts of Africa and has also been reported recently from India.

Molecular studies using DNA markers and PCR-RFLP analysis have been useful to a limited extent to distinguish species within the complex and for phylogenetic analysis. There has been no molecular test to date that is designed to identify each of the nine Asian pest species, with *B. caryeae* and *B. pyrifoliae* not included in any studies. Nine species of the complex, viz., *amarambalensis, caryeae, dorsalis, melastomatos, neoarecae, paraverbascifoliae, verbascifoliae* and *vishnu* are known from India though *amarambalensis* and *neoarecae* have not been officially placed in this complex.

For most of this century this fruit fly species complex has been thought responsible for causing enormous loss to horticultural crops throughout Asia/ South East Asia. The oriental fruit fly has been recorded from more than 150 kinds of fruit and vegetables, including citrus, guava, mango, papaya, avocado, banana, loquat, tomato, surinam cherry, rose-apple, passion fruit, persimmon, pineapple, peach, pear, apricot, fig, and coffee. The risk posed by potential invaders is great and it is necessary to know the indigenous range and distribution limits of each species of the complex. Great difficulty has been encountered in identifying *B. dorsalis* and its related species. There is no comprehensive single key for all species of the complex and the discrimination of species based exclusively on morphological criteria is difficult, even for professional identifiers. Accurate identification of species in the complex is essential in order to address errors in literature regarding host records and geographic distributions and for addressing quarantine restrictions imposed on fruit exports.

Species complexes such as the *dorsalis* complex have to be carefully resolved if the host relationships, pest status and other data for each true species are to be clearly understood. Several genetic diagnostic tools have been used to distinguish species in the complex but each of them have proved wanting. Resolving a species complex problem will necessitate the acquisition of a long series of reared specimens, often from carefully chosen areas such as possible areas of sympatric between member species of the complex. Careful morphological studies, including larval morphology and adult morphometrics, enzyme electrophoresis, DNA studies, phylogenetic work, host plant records, pest status, invasion biology, etc. are needed to tackle the problem.

The economic importance of the fruit flies gains greater significance because many of the fruit pest tephritids attack commercially produced fruit, quarantine restrictions have to be imposed to limit further spread and quarantine regulations imposed by an importing country can either deny a producing country a potential export market, or force the producer to carry out expensive disinfestation treatment.

Importance of collections in IPM

Taxonomic collections have very great significance and prove of immense value. Collections and their proper maintenance are of great relevance and importance to device strategies for IPM and these are emphasized by the following points:

- Collections are the basic tools of taxonomic research and provide important starting points for any IPM programme.
- Specimens collected in a project should be properly mounted and preserved.
- The specimens should also be taken care of through proper curation, cataloguing, referencing, etc.
- Types which are authentically identified reference specimens are important and need to be preserved very carefully for they are the reference points for that species.
- Collection information is invaluable and labels should have locality (lat/long), date, host, host plant, ecological data, collector, etc.
- Voucher specimens give an idea about the exact species on which the project has been carried and need to be preserved for addressing any problems later with proper reference in the publication that has emerged from the work.

A mealy bug on mango in 1981 caused a loss of > £1.5 million in Ghana. It was first identified as *Rastrococcus spinosus* (another Asian species) and parasitoids collected from it did not parasitize the mealy bug suggesting misidentification of the pest. It was described in 1986 as a new species, *R. invadens*. This called for reassignment of museum material and all the slides were looked at again. The reassignment helped in revealing the native distribution of *R. invadens* as South and Southeast Asia based on the locality labels. This helped in searching for parasitoids in Malaysia and India and the search proved fruitful with the discovery of the encyrtid parasitoids, *Gyranusoidea tebygi* and *Anagyrus mangicola* in India which helped in successful biological control of the pest in several West African countries.

The fern weevil, *Syagrius fulvitarsis* which had become a major pest of Sadleria ferns in Hawaii in 1920 and proved very difficult to control. Literature search did not reveal the original home of the pest which resulted in failure to locate natural enemies of the pest. In 1921, Dr. Pemberton was studying the old private collections and found a single specimen of the fern weevil, *S. fulvitarsis* in Sydney, Australia with a label containing the date of collection as 1857 and the locality. This provided a clue to search for natural enemies and a larval parasitoid, *Ischiogonus syagrii* (Braconidae) was found that resulted in the successful control of the Sadleria fern weevil in Hawaii. A collection and the label on the specimen helped in a biological control project after nearly 65 years.

Extensive insect collections in BMNH, London showed that the sugarcane white grub in Mauritius was of Trinidad origin. A search was done in West Indies and resulted in revealing both the insect and two natural enemies in Barbados.

Importance of taxonomic literature in IPM

Taxonomic literature has great use in IPM programmes. It gives us various pieces of information such as locality, distribution, hosts, diagnostic features, natural enemies, ecology, behaviour, etc. and these will give leads to understanding the weak links of the pest and thus help in formulating strategies in managing the pest. Some of these aspects have been very well brought out in several examples given in earlier headings. The work on the prickly pears and its control in Australia using a pyralid, *Cactoblastis cactorum* is a good example of the help literature yields in identifying strategies for control.

Another example where the lack of literature due to inadequate work in the country of origin as the insect did not happen to be a serious pest is the case of the Rhodes grass scale, *Antonina graminis* which became a serious pest in Texas and caused a serious setback to the cattle industry. Its centre of origin was found to be South East Asia and India. Survey for natural enemies began in India in 1958-59 but the pest itself was not observed here. Intensive surveys enabled locating the pest in some wild grasses near Delhi and it was found that more than 90 per cent of scales were parasitised. The encyrtid parasitoid discovered was found to be new to science and was described as *Neodusmetia sangwani* by Subba Rao from IIE, London. The parasitoids were sent to Texas, bred in the lab and released in various places in southern Texas. The parasitoids successfully reduced the scale population by 46-79 per cent and gave yield increases of forage production by 30per cent. This example is considered a major success and of great benefit to the cattle industry in Texas. The parasitoids were later sent to Bermuda in 1968 and are reported to have well established there also.

Biological control

Biological control may be defined as the action of predators, parasitoids, pathogens, antagonists, or competitor populations to suppress a pest population, making it less abundant and less damaging than it would otherwise be. In other words, biological control is a population-leveling process in which one species' population lowers the numbers of another species by mechanisms such as predation, parasitism, pathogenicity or competition. Biological control has proven relatively successful and safe. It can be an economical and environmentally benign solution to severe pest problems. Large numbers of biological control agents are active in the field and are naturally performing biological control functions. Natural biological control is the most important component of pest management in crop fields. In order to create favorable situations for natural enemies, interventions are often necessary. There are three major interventions: conservation, augmentation and introduction.

Conservation of natural enemies

Conservation of natural enemies is the cornerstone of an IPM approach, but methods for assessing the impact of natural enemies and encouraging their activity in cropping systems have been poorly studied by researchers, compared with the interventionists strategies of augmentation and classical biocontrol. Understanding the allelochemical diversity in host plants and their influence on natural enemy activity in different crop ecosystems is essential for conserving and enhancing the natural enemies. Tritrophic interaction studies help in increasing the efficiency of biocontrol programmes. Enhancing the field efficacy of natural enemies through kairomones and other semiochemicals is another strategy.

Training of farmers in IPM methods, particularly conservation and use of natural enemies is very important to make biocontrol work at farmers' level. Farmers Field School approach to IPM and conservation of natural enemies has worked wonders in the rice fields of South East Asian countries such as the Philippines, Indonesia, etc. and considerably reduced the pesticide applications. The Government of Philippines has adopted IPM in rice as a national policy and in Indonesia, use of several harmful pesticides in rice has been banned. Their experience can be emulated in other developing countries by proper education of the farmers.

Biodiversity and biological control

Biodiversity and biological control are so closely linked that several activities and principles in biological control closely follow the principles of biodiversity and its conservation like increasing species richness, restoring the lost natural balance between species and these give insights into conservation biology, importance of genetic diversity and prevention of its loss, ecosystem stability and community balance. Predators, parasitoids and pathogens are keystone species, i.e., species that have disproportionately large influence on the character or structure of an ecosystem. When keystone species are removed lost, or have their activities disrupted, there is a noticeable cascade effect on the system. They contribute to the maintenance of diversity by reducing the abundance of dominant competitors and thus preventing competitive exclusion. Thus natural enemies become important for the maintenance of diversity when they regulate the populations of species, which would otherwise out compete, and thus eliminate, other species. In agroecosystems, insects are key pests as well as key bio-agents. The aphelinids *Aphytis melinus* and *A. lingnanensis* are the best examples of keystone species which hold the California red scale, *Aonidiella aurantii* under complete or substantial control if not disturbed by frequent insecticidal sprays.

India with about 10 per cent of the world fauna of insects is one of the 12 megadiversity nations in the world in terms of insect diversity. Our insect biodiversity is unique as evidenced by the high level of endemism. At the generic level, endemism is as high as 75 per cent in Hymenoptera and 45 per cent in Coleoptera and at the species level, it is 68 per cent in Hymenoptera and 46 per cent in Hemiptera. Most of the endemic faunae have been recorded from the north east and Western Ghats.

India as a source of natural enemies of crop pests

Several insects have been introduced from India to other countries, some of which have not only permanently established but are providing recurring economic gains to the that country. The earliest recorded instance of biological control of a pest by employing a natural enemy from South East Asia was in 1762 when the mynah bird (*Acridotheres tristis*) was introduced from India into Mauritius to control the red locust, *Nomadacris septemfasciata* and it is reported to have successfully controlled this pest. More than 26 bioagents have been introduced from India into different countries of the world, with substantial economic gains and varying degrees of success.

Some of the outstanding successes recorded in the history of biological control have been achieved with natural enemies of Indian origin, e.g. "complete" biological control of Rhodes grass scale, *Antonina graminis* by *Neodusmetia sangwani* in the USA, Israel and other countries; mango mealybug, *Rastrococcus invadens* by *Gyranusoidea tebygi* and *Anagyrus mangicola* in Central and West Africa; cereal stemborers by *Apanteles flavipes* in Barbados and Africa; coconut scale, *Aspidiotus destructor* by *Chilocorus nigrita* in Seychelles.

Learning from traditional systems of agriculture

Many traditional agricultural systems in the tropics have in-built pest suppression mechanisms such as crop diversity. The farming methods of traditional farmers have benefited from systematic experimentation that has adapted them exceptionally well to local conditions. The wealth of practical knowledge in such systems should be preserved and useful methods should be fine tuned or augmented based on more systematic research. An understanding of what farmers are doing, why they are doing it that way and what is required in a technology to ensure farmers' acceptance should be thoroughly understood before formulating the research programmes to create pest management systems for small-scale farmers.

In India, some NGO's have documented the indigenous technical knowledge of farmers, including various plant protection practices. Farmers' consistent deviation from recommended plant protection practices is often deliberate, based on economic criteria. Developing countries should pattern their research programmes to provide ecologically and socially acceptable solutions to small and medium farmers by taking into account all the relevant local factors.

Scope of biological control in NEH region

The economy of the northeastern states is mainly rural and agrarian. The region offers scope for cultivation of a wide variety of agricultural crops because of its diversities in topography, altitude and climatic conditions. The major crops grown are rice, sugarcane, potato, wheat, maize, ginger, cardamom, pulses, oilseeds, tea, flowers, fruits and vegetables. There are severe pest problems on several crops grown in this region. The northeastern region represents an important biodiversity hotspot, one of the 25 global biodiversity hotspots currently recognized. It is important to preserve this region and help conserve the biodiversity of the region. Pesticide consumption pattern in the region indicates that Assam consumes 0.4 to 0.6 kg/ha and Meghalaya 0.3 to 0.4 kg/ha. Data on the pesticide load in the environment indicate that substantial areas in Assam carry a pesticide load of 7-10 kg/sq. km while in Meghalaya, Nagaland and Manipur it is 1.3 kg/sq. km. However, it is encouraging to observe that there has been a reduction in pesticide consumption in the last decade in most of the states. The need of the hour is to search for potential natural enemies of the major pests of the region and we can be sure the search would yield promising results. It would be a folly and also counterproductive to resort to the use of chemical pesticides to check insect pests and diseases in the crops grown in this region, as they would indiscriminately kill the natural enemies along with the pests themselves. Indigenous natural enemies could effectively reduce pest numbers and conservation biological control could form the backbone of IPM for various pests. There is a need to set up mass production units for the production of some biocontrol agents and the opportunity is there for rural youth and women to come forward and set up such units to help the farmers of the region.

Biological control in rice

Rice is an important crop occupying about 40 lakh hectares in the northeastern states. Pesticide usage is minimal in the region on rice. Thus the natural enemy complex in the agro-ecosystems of all these states has not been adversely impacted. Conservation biological control, which is the recommended practice in rice, can easily be adopted in these states. In the case of some pests like the rice yellow stem borer and leaf folder inundation biological control may also have to be adopted.

Rice insect pests have had long, close associations with their natural enemies, allowing stable relationships to develop. Predator and parasitoid guilds recorded in rice ecosystems belong to ten orders and 57 families of predators and three orders comprising 40 families of parasitoids, indicating the great diversity and richness of the natural enemy community in rice. The interactions of such predators, parasitoids and insect pathogens are the cornerstone of modern integrated pest management programs in rice. The collective importance of natural enemies to pest population regulation is clearly demonstrated by observing outbreaks of insect pests after the removal of natural enemy communities by a broad-spectrum insecticide.

The rice plant can withstand and compensate for over forty per cent tiller loss during the early vegetative stage without significant reduction in yield. This gives natural enemies the requisite time to colonize and build up their populations so that they are there in numbers large enough to suppress the pests when they appear.

Conservation biological control in rice

Conservation is the modification of the environment or habitat in combination with judicious use of pesticides in order to conserve natural enemies and enhance biological control. Environment management to enhance biological control has proven valuable in many settings and appears to be very important for rice insect pest management. Conservation biological control contains two elements: judicious use of insecticides and modification of the environment.

Insecticides are more harmful to natural enemies than to pests. There is extensive evidence that the destruction of natural enemies by broad-spectrum insecticides leads to reduced biological control and the subsequent resurgence of some pests. Insecticide overuse is most damaging early in the season. Such circumstances create outbreaks of secondary pest such as brown plant hopper and impair biological control of some key primary pests such as stem borers. Insecticides are generally being misused in rice. Preventive use of insecticides in rice is common and widespread. Preventive use of insecticides is detrimental to biological control, pest management as a whole, the environment and human health. Judicious use of insecticides is essential for natural enemy conservation and for the enhancement of natural biological control.

In order to conserve indigenous natural enemies and enhance natural biological control, the following strategies for insecticide use are recommended:

1. Preventive or calendar-based use of insecticides should be stopped.
2. Early season spraying during the first 40 days after transplanting should be avoided.
3. Selective insecticides should be used only when pest population density reaches a damaging level.
4. When using insecticides, use appropriate formulations in the right dose. Apply at the optimum time of intervention following proper application methods. Broad-spectrum hazardous insecticides should be avoided. If available, use rice varieties that possess host plant resistance to major insect pests.
5. Modification of environment

The immediate crop environment can be intentionally modified to favor natural enemies. Habitat management should be aimed at providing environmental requisites to natural enemies such as: alternative hosts or prey; complementary foods – honeydew, pollen, nectar; over-wintering or off-season shelter; modified climate – windbreak. Some habitat management activities that have a positive influence on the abundance of the natural enemies of rice insect pests are described blow:

Vegetated rice bunds support many herbivore species (including a few pests) and many species of natural enemies. They can be a very important source of natural enemy colonization in rice fields just after planting. Rice bunds are important sources of biological control agents of arthropods. Bund vegetation provides alternative and supplementary food for predators and parasitoids. The importance of bund fauna on the early arrival of spiders for biological control of BPH has been demonstrated experimentally. Bunds also provide shelter for natural enemies at critical times during harvesting, land preparation and between seasons. Puddling (tillage in presence of water) can have drastic effects on natural enemy populations. Many natural enemies take shelter on the rice bunds at puddling and the presence of vegetation on the bunds greatly increases their survival. Generally, grasses and other vegetation in habitats adjacent to rice fields serve as habitats of natural enemies and also provide supplementary and complimentary food, over-wintering, or off-season habitats.

Some cultural practices seriously affect natural enemies. These include: burning of rice stubble and/or straw; trimming of non-rice vegetation from rice bunds prior to tillage (puddling); destruction of vegetation on the field during fallow periods; strictly synchronous rice planting over a large area. From plant nutrient and natural enemy conservation points of view, it is better to incorporate crop residues into the soil rather than burn them. If burning is essential then it should be done in heaps rather than burning residue spread all over the field.

In many countries insect predatory birds, toads and frogs are caught in rice fields for consumption. Conservation of insect predatory birds, frogs and toads by preventing capture from the rice environment can also enhance biological control of rice insect pests.

Thoughts to take home

There exists a strong link between IPM and biodiversity. It is fundamentally important to conserve a large reservoir of natural enemy diversity, regardless of what we know about the taxonomy or biology of that reservoir, because we cannot predict which species might become pests in the future. A variety of new pests enter new areas and some could be created through changing agriculture and forestry practices through the developing areas of the world. Maintaining the ability to control tomorrow's pests in a manner that is both economically and environmentally sound is one of the strongest arguments for preserving biodiversity. This will enable us to preserve the groups of importance to our future generations and give them the opportunity to take recourse to biological control to control pests in a manner that is both economically and environmentally sound. Without this option we will be denying the future generations of this opportunity and forcing them to use pest control measures which will surely accelerate the current decline in environmental quality. So we must conserve biodiversity so that we automatically conserve with it a pool of biological control agents.

The diversity of life on this planet is part of what makes it so great to live on, reduce the diversity and you reduce the pleasure of every life. Just imagine how boring it would be if there was only one kind of plant and one kind of insect, everywhere you went would look just the same. We must also realize that the perception of diversity and variety in the world around us is important for our mental and spiritual health. This fact is hard to prove scientifically, but it is true, quality of life is important. Rachel Carson in her fantastic book

"Silent Spring", describing the killing of several life forms due to use of pesticides, very aptly said that some wonderful subjects for English poetry has been lost.

We are a 'part of' the life' of this planet. Ultimately our life is intertwined with the health of the planet, which includes the full and ever increasing diversity of other life forms that share it with us. Extinctions do occur naturally, and are part of the cycle of and a major component of the evolution of life on this planet. However, mankind has recently accelerated the rate that other species are going extinct; so that now it vastly exceeds the rate at which new species evolve. This is not a good situation, and there is no excuse for us as an intelligent, conscious species failing to appreciate and take responsibility for the effect we have on the world around us. We must conserve our planet for our own benefit now, and for the benefit of future generations.

It is important for us to understand that if the work of destroying insects is to be accomplished satisfactorily, it will have to be the result of no chemical preparations, but of simple means, directed by the knowledge of the history and habits of the pests.

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