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Alien Invasive Insect and Mite Pests and Weeds in India and Their Management

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Abstract—In the past ten years at least six species of insect and mite pests have invaded India affecting agricultural production. Some of the recent invasive pests in India are psyllid, *Heteropsylla cubana* Crawford on *Leucaena leucocephala* (Lam.) De Witt; American serpentine leaf miner, *Liriomyza trifolii* (Burgess) on a number of vegetables and ornamental plants; coffee berry borer, *Hypothenemus hampei* (Ferrari) on coffee; spiraling whitefly, *Aleurodicus dispersus* Russell on a number of agricultural, horticultural crops and forest trees; Silver leaf whitefly, *Bemisia argentifolii* Bellows and Perring on tomato; and coconut mite, *Aceria guerreronis* Keifer on coconut. Outbreaks of coconut mite and silver leaf whitefly had devastating effects on the economy of the farming communities in south India. Some of the alien weeds that have invaded India are *Chromolaena odorata* (L.) King and Robinson; *Ageratina adenophora* (Sprengel); *Parthenium hysterophorus* Linnaeus; lantana, *Lantana camera* Linnaeus; mile-a-minute weed, *Mikania micrantha* Kunth; giant sensitive plant, *Mimosa invisa* Martius ex Colla; sensitive plant, *Mimosa pudica* Linnaeus; water hyacinth, *Eichhornia crassipes* (Martius); and salvinia, *Salvinia molesta* Mitchell. Classical biological control appears to be an important approach in the management of these invasive organisms in their new habitats. International cooperation for their effective management is of paramount importance as exchange of information on biology of invasive pests that are spreading their range and exchange of natural enemies, etc. can be effectively achieved by such cooperation.

Introduction

Large-scale movement of plant material such as vegetables, fruits, ornamentals, planting material, seeds, etc. between nations entails the danger of accidental introduction of insect pests, nematodes, plant pathogens and weeds. The problems due to accidental introduction of pests are manifold. The pest finds the new habitat ideal and conducive for its breeding and establishment without any restriction by natural regulating factors like natural enemies that keep the invasive species in check in its native range. Dominance of the invasive species in the new habitat would cause immense damage to the native fauna and flora thus

upsetting the natural balance of the invaded habitat. An ideal way of managing such invasive species, whether insects, mites or weeds, would be to intentionally introduce and establish effective natural enemies from the native home range of the invasive species. This method is often referred to as classical biological control in recognition of its relatively early first use in 1880s. In fact the spectacular success of cottony cushion scale *Icerya purchasi* Mask. (Homoptera: Margarodidae) control in California by exotic predator, *Rodolia cardinalis* Mulsant (Coleoptera: Coccinellidae) and *Cryptochaetum iceryae* (Willston) (Diptera: Cryptochetidae) greatly influenced both the entomologists and administrators to promote classical bio-control during the turn of the 20th century for invasive pests. In this paper, only the status of recently (in the last 15 years) introduced insect and mite pests in India is considered briefly. The information on weeds wherein management efforts have been made using introduced natural enemies has been dealt with.

Invasive Insect Pests and Their Management

In the last 15 years at least five insect species of economic importance have invaded India. It is interesting to note that majority of them are of Neotropical origin. Brief information on their status, distribution, and management are presented.

Leucaena psyllid, *Heteropsylla cubana* Crawford (Homoptera: Psyllidae)

Leucaena leucocephala (Lam.) de Witt (Fabaceae), a native of Central America was introduced into India during 19th century, but its real cultivation started only in 1972 (Krishnamurthy & Munegowda 1982) as a fodder crop. A psyllid, *Heteropsylla cubana* Crawford posed a serious threat to the cultivation of *Leucaena* all over the tropics except the African continent, where it has not entered yet. The *Leucaena* psyllid was described from Cuba by Crawford in 1914 and it started its journey in 1983 when outbreaks occurred in Florida and it was also intercepted in Hawai‘i in 1984 (Napompeth 1990). Within a short span of two years it reached Sri Lanka in 1986 crossing the Pacific Ocean and was noticed in Chengalpattu district of Tamil Nadu, India during 1988 (Gopalan et al. 1988) and Bangalore during May 1988 (DARE 1989). It sucks the sap from young shoots, leaves and inflorescences which results in complete defoliation of plants of susceptible *Leucaena* species and varieties. In severe cases, the plants could not recover (Napompeth 1990). In Karnataka, *Leucaena* is being cultivated in an area of 10,000 ha and its planned extension by the Karnataka Plantation Corporation by 4000 ha was abandoned for the fear of loosing the plantation due to the psyllid attack (Veeresh 1990). The developmental period of the psyllid is short, the five nymphal instars taking just 10.4 days (Pratap Singh 1988) and the fecundity is fairly high, 394 eggs (Nakahara et al. 1987). A number of native general predators such as *Cheilomenes sexmaculatus* (Fabricius) (Coleoptera: Coccinellidae) and *Pantala flavescens* (Odonata: Libellulidae) fed on the outbreak populations of the psyllid but they did not exercise the required control (Rajagopal et al. 1990).

In 1988, the ladybeetle, *Curinus coeruleus* Mulsant (Coleoptera: Coccinellidae) from Mexico was introduced from Thailand for the biological suppression of *H. cubana*. The predator has since successfully established in Karnataka, Maharashtra, Andhra Pradesh and Tamil Nadu (Jalali & Singh 1989). It is now providing control of the psyllid at par with monocrotophos, a chemical that was recommended for the control of the psyllid before the introduction of the predator (Singh 1995).

Serpentine leaf miner, *Liriomyza trifolii (*Burgess) (Diptera: Agromyzidae)

The scare was caused by a tiny but beautiful species of agromyzid fly, *Liriomyza trifolii* (Burgess) that entered India accidentally probably, during 1990-91 (Viraktamath et al. 1993). The first report of its occurrence in India appeared in the proceedings of the annual castor research workers' group meeting held at Hyderabad (Directorate of Oilseeds Research 1991). During the following year, the pest was reported from Andhra Pradesh and Karnataka on several host plants including castor (Lakshminarayana et al. 1992) and has now spread to most of the states in India. It is a polyphagous species affecting more than 78 annual plant species being especially serious on greens, cucurbits, tomato, castor and ornamental plants (Srinivasan et al.1995)

The native country of this pest is USA (Florida) (Spencer 1973). It was introduced probably along with cut chrysanthemum flowers during early 1970s to California, USA (Parrella et al. 1981). The fly was accidentally introduced into Kenya around the same period. Later, it reached the Canary Islands, Malta, southern France and commercial greenhouses in central and northern Europe (D'Aguilar & Martinez 1979). It is now very widely spread in most countries including Pakistan and India.

The adult female makes punctures in the leaf tissue with its ovipositor for both feeding and oviposition. The ratio of oviposition punctures to feeding punctures varies from 1:6 to 1:14. The male also uses the feeding punctures made by females for feeding. Temperature has profound effect on feeding, fecundity and longevity of adults. Maximum feeding by adults occurs during 2nd and 4th days after emergence. The fecundity may vary with host and locality. In India, the fecundity varied from 24.4 ± 12 on okra to 136 ± 2.5 on tomato (Jagannatha 1994). The larvae that hatch out from the eggs mine the leaf feeding on the mesophyll region leaving a serpentine structure and thus the common name. The severely affected leaves may drop. *Liriomyza* leaf miner may vector disease, kill seedlings, cause reduction in crop yields, accelerate leaf drop thus exposing fruits like tomato for sunburn and reduce aesthetic value of ornamental plants (Parrella 1987). The full-grown larvae come out of the mine drop down and pupate in soil. The development from egg to pupa may be completed within 14.4 to 19.7 days depending on the temperature. The adults have decided preference for cucurbits followed by tomato, beans, okra, and peas. The fly is known to successfully breed on 78 species across 16 plant families. There are usually two major population peaks in India, one during July-September and another during March-April. The

population of the fly is generally low during winter. The fly population was negatively correlated with relative humidity, wind velocity and rainfall whereas it was positively correlated with temperature and sunshine hours (Jagannatha 1994). Though a number of insecticides have been recommended for the management of the leaf miner, their continued use may result in development of resistance and thus failure of control (Parrella 1987).

A number of parasitoids attack larval and pupal stages of *L. trifolii* in its native country. In countries where it has been accidentally introduced, the parasitoids which affect the indigenous species of agromyzids have been seen to parasitise this alien pest. Forty-five species of Chalcidoidea and Braconidae have been reported on larval and pupal stages of *L. trifolii* from different parts of the world. The parasitism in some areas may be as high as 51-98 % (Neuenschwander et al. 1987). Among the parasitoids *Diglyphus begini* (Ashmead) (Hymenoptera: Eulophidae), *D. intermedius* (Girault) (Hymenoptera: Eulophidae) and *Chrysonotomyia punctiventris* (Crawford) (Hymenoptera: Eulophidae) seem to be promising in exerting practical control of the pest under greenhouse conditions in different parts of Europe (Woets & Linden 1985). In India, parasitism by the indigenous parasitoids ranges from 0-39% in Bangalore on tomato and cucumber (Jagannatha 1994) to 49% in Gujarat on castor (Kapadia 1997) and *Hemiptarsenus varicornis* (Girault) (Hymenoptera: Pteromalidae) is the most predominant one. *D. begini* was introduced into India from California, USA and field released in the vegetable gardens around Bangalore during 1997 after laboratory tests. Reports indicate that it has not established in the field (Project Directorate of Biological Control 1997).

Coffee berry borer, *Hypothenemus hampei* (Ferrari) (Coleoptera: Scolytidae)

Coffee berry borer is believed to be a native of Northeast Africa (Wrigley 1988) but has spread to many coffee growing countries throughout the tropics.

This pest was not known in India till 1990 when it was reported from Gudalur in the Nilgiris (Kumar et al. 1990) probably introduced accidentally either through coffee brought by refugees from Sri Lanka or through illegally imported coffee seeds (Singh & Ballal 1991). It has now spread into many coffee growing areas of Tamil nadu (Gudalur and Kilkotagiri), Kerala (Wyanad) and Karnataka (Kodagu). The incidence varies from 2-95% (Anonymous 1993) and it attacks both *arabica* and *robusta* types of coffee. The adult beetle measures 1.0-1.9 mm, brownish-black. The population is usually female dominated. The fertilized female bores an entrance hole at the terminal pore or in the calyx ridge of the differential tissue that surrounds the pore and lays bean shaped eggs. She can lay from 30-70 eggs (2-3 eggs in a day in batches of 8-12 in chambers chewed out) during her life. She prefers ripe berries. The total development from egg to adult lasts for 25-35 days. Adults are long lived, a female can live for 282 days with an average of 156 days (Bergamin 1943). Females can survive up to 2 months in buried beans and mobile females can survive by feeding on immature berries (Clausen 1978).

Of the several parasitoids that are recorded three were introduced into India. They are, *Prorops nasuta* Waterston (Hymenoptera: Bethylidae), *Cephalonomia stephanoderis* Betrem (Hymenoptera: Bethylidae) (both from Mexico) and *Phymastichus coffea* LaSalle (Hymenoptera: Eulophidae) (from Colombia) through the efforts of Project Directorate of Biological Control, Bangalore and the Coffee Board. Fertilized female of *P. nasuta* enters via the borehole of the adult *H. hampei* and kills the parent borer beetle and uses the cadaver to plug the entrance hole and stands guard over it. Several larvae and pupae may be injured with the ovipositor before any egg laying takes place; these larvae die because of injury. The female also feeds on several eggs, larvae and pupae before laying eggs on host pupae where the hatching larvae develop as ecto-parasites, often using more than one pupa. *C. stephanoderis* is a larval-pupal ecto-parasitoid and is similar to *P. nasuta* in feeding and parasitisation. *P. coffea* attacks female beetles as she begins to bore into the berry and lays two eggs. This prevents the borer from boring and two parasitoid larvae develop, one in the head and the other in the abdomen (Klein et al. 1988). Of these *C. stephanoderis* has established in a number of localities in India. However, unlike in South America where due to running blossoms there is a continuous supply of berries required for survival of both the berry borer and its parasites, in India, the blossom period is restricted for a short time probably becoming a limiting factor in the establishment of the parasitoids. Even then, during the harvest all the berries are removed which will take away the parasitoids with the infested berries thus necessitating inundative release of the parasitoids. In addition, the fungus, *Beauveria bassiana* (Balsamo) Vuillemin has also been used and is giving effective control of the berry borer in India. Plantation sanitation plays an important role in the management of this pest. The life cycle of the borer lends itself to this approach, as it is narrowly specific to coffee berries. It could also prove very useful in coffee growing areas like India, where the flowering is not continuous and the harvest is within a very short span of time. Clean harvest, removal of off-season berries, thorough gleaning collection, burning or burying the fallen berries at least 20 cm below the soil surface, drying the coffee to about 10% moisture content and training and pruning of bushes to avoid excessive shade constitute some of the practices recommended (McNutt 1975, Singh & Ramani 1995).

Spiraling whitefly, *Aleurodicus dispersus* Russell (Homoptera: Aleyrodidae)

This whitefly is a native of Caribbean region and Central America (Russell 1965). It is highly polyphagous affecting wide range of host plants - 481 plant species in 90 plant families (Srinivasa 2000). During 1970s it started spreading from the Central American countries. First reported in Hawai‘i outside its native range (Nakahara 1978), it started spreading westward in Pacific islands to Philippines (Waterhouse & Norris 1989). It reached Sri Lanka in 1990 (Chandrashekara 1990) and India in 1994 (David & Regu 1995, Palaniswami et al. 1995).

Female lays characteristic eggs with short sub-terminal stalk or pedicel which is inserted during ovipositon into the host plant, usually on the lower surface of a leaf in an irregular spiral and is covered with white waxy flocculent material, hence the name. Total developmental period lasts for 34-38 days. A female lays 14-26 eggs during her life- time (Wijesekera & Kudagamage 1990). Nymphs and adults suck sap from host plants and can cause premature leaf drop. Copious white, waxy flocculent material secreted by the nymphs is readily spread elsewhere by wind and creates a very unsightly nuisance. Furthermore, sticky honeydew is produced which serves as a substrate for dense growth of sooty mould interfering with photosynthesis. The adult population that builds up on avenue trees cause nuisance for people walking on roads under these trees during morning and evening hours.

A number of native species of general predators have been reported to feed on immature stages of the insect (Table 1). Srinivasa et al. (1999) reported the occurrence of *Encarsia ?haitiensis* Dozier (Hymenoptera: Aphelinidae) in Bangalore Karnataka and also showed that the per cent parasitism was influenced by the host plant. The per cent parasitism ranged from 0.00 to 38.88 on different host plants being highest on *Cassia siamea* Lamk. (Fabaceae). Ramani (2000) reported both *E. ?haitiensis* and *Encarsia guadeloupe* Viggiani (Hymenoptera:

Table 1. Native predators that are known to feed on immature stages of Spiraling whitefly, *Aleurodicus dispersus* Russell (Mani & Krishnamoorthy 1999, Ramani 2000)

Coleoptera: Coccinellidae
Axinoscymnus puttarudriahi Kapur
Cryptolaemus montrouzieri Mulsant
Cheilomenes sexmaculata (Fabricius)
Chilocorus nigrita (Fabricius)
Pseudoaspidimerus trinotatus (Thunberg)
Serangium parcesetosum Sicard
Scymnus nubilus Mulsant
Coleoptera: Nitidulidae
Cybocephalus sp.
Diptera: Drosophilidae
Acletoxenus indicus Malloch
Neuroptera: Chrysopidae
Apertochrysa sp.
Mallada astur (Banks)
Mallada boninesis (Okamoto)
Chrysoperla carnea (Stephen)
Neuroptera: Hemerobiidae
Notiobiella sp.

Aphelinidae) from Lakshadweep Islands (India). The latter species has since then been introduced into mainland India around Bangalore and has well established and is spreading (Ramani 2000). The two native predators, *Axinoscymnus puttarudiahi* Kapur (Coleoptera: Coccinellidae) and *Cybocephalus* sp. (Coleoptera: Nitidulidae) are able to discriminate between the parasitised and healthy larvae and pupae (Ramani personal communication). Both the species of parasitoids and the native predators are maintaining the pest under check now wherever they occur.

Silver leaf whitefly, *Bemisia argentifolii* Bellows and Perring (B Biotype of *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae)

In October 1999 the presence of the B biotype of the whitefly, *B. tabaci* in Kolar district, Karnataka state was noticed. This was associated with an outbreak of tomato leaf curl disease (ToLCVD) which resulted in failure of tomato crop (Banks et al. 2001, Muniyappa et al. 2001). Prior to this, populations from southern India were collected and analysed by the iso-enzyme technique. None of the populations studied were found to be B biotype and none induced silverised symptoms in squash. Work is under progress to study the nature and extent of damage caused and also the management of the pest.

Invasive mite pest and its management

The coconut mite, *Aceria guerreronis* Keifer (Acari: Eriophyidae) was first reported in 1960 from Mexico and is found in South America, The Caribbean and West Africa. In India, the mite was first observed causing serious damage to coconut in Kerala in 1998 (Sathiamma et al. 1998). Since then it has spread to other neighboring states namely Karnataka, Tamil Nadu, Andhra Pradesh, Goa and also to Lakshadweep Islands (Sreerama Kumar & Singh 2000). The mite inhabits the tender portions of the young nut covered by the perianth. The mite entry takes place after fertilization of the flowers when the nuts are of button size. The mite feeds on meristematic tissue beneath the perianth and a triangular whitish patch appears initially on the nut which subsequently turns brown. As the nut grows, the injury leads to warty and longitudinal fissures on the nut surface. Mite infestation is also associated with premature nut fall. Draining of the sap from the young buttons results in poor development of the nut, reduction in nut size, kernel content and poor quality husk. The losses caused by the mite have been assessed as high as 31.5% (Moore et al. 1989).

At present a number of chemicals such as triazophos, endosulfan, dicofol, carbosulfan, monocrotophos and neem-based insecticides have been suggested for control of the mite. However, the percent control achieved is often around 60-70%. The insecticidal treatment must be repeated with every production of a new inflorescence as they become susceptible to attack. A number of predators have also been reported feeding on the mite but the control effected by them appears to be negligible. Some of the predators are: *Bdella distincta* Baker and Balock

(Acari: Bdellidae), *Amblyseius largoensis* Muma (Acari: Phytoseiidae), *Neoseiulus mumai* Denmark (Acari: Phytoseiidae) and *N. paspalivorus* DeLeon (Acari: Phytoseiidae) (Howard et al. 1990, Moore 2000). However, they have not been very effective in the control of the pest. Efforts are being made to explore the possibilities of using the fungus *Hirsutella thompsoni* as it has been reported to give 25-88% control of the mite in Mexico (Becerril & Sanchez 1986, Sampedro & Rosas 1989) and the Project Directorate of Biological Control Bangalore has developed a product called 'Mycohit' which is being field tested (Sreeram Kumar & Singh 2000).

Invasive weeds and their management

Most of the invasive alien weeds in India are of Neotropical origin. Weeds such as *Lantana camera* L. (lantana) (Verbanaceae), *Chromolaena odorata* (L.) King & Robinson (Siam Weed) (Astraceae), and *Eichhornia crassipes* (Martius) (Water hyacinth) (Pontederiaceae) were introduced into India as ornamental plants. They escaped cultivation and became wild. The Government of India recognized the seriousness of alien weeds in the early 1900s. In 1916, Ramachandra Rao who was detailed to study the distribution and natural enemies of the exotic weed, *L. camara* throughout India and Burma gave a detailed account of *C. odorata, Opuntia dillenii* (Ker-Gawler) (Prickly pear) (Cactaceae), *Mimosa pudica* L. (Sensitive plant) (Mimosaceae), *E. crassipes, Lippia geminata* Kunth (Verbanaceae) and *Jatropha gossipifolia* L. (Euphorbiaceae) (Ramachandra Rao 1920). As in the case of insects, here also a number of host-specific natural enemies have been introduced in their management with varied success.

Prickly-pear, *Opuntia spp.* (Cactaceae)

The cochineal insect, *Dactylopius ceylonicus* (Green) (Homoptera: Dactylopiidae) was introduced to North India from Brazil in 1795 in the mistaken belief that it was *D. coccus* Costa (Homoptera: Dactylopiidae), which is cultured commercially for obtaining carmine dye. *D. ceylonicus* was multiplied on cultivated spineless pear cactus, *Opuntia ficus-indica* (L.) Miller (Cactaceae). In the field *D. ceylonicus* spread to its natural host plant, *O. vulgaris* Miller (Cactaceae) (origin: South America) which in the absence of its natural enemies had become a widespread weed in India. *D. ceylonicus* not only successfully established on *O. vulgaris* but also suppressed it in north and central India. From 1863-1868, it was introduced to southern India, where it brought about the first successful international use of an insect to control a weed (Ramakrishna Ayyar 1931, Beeson 1941, Tryon 1910). To suppress *O. stricta* in south India, *D. opuntiae* Lichtenstein (=*D. tomentosus*) (Homoptera: Dactylopiidae), a North American species, was intentionally introduced in 1926-27 from Sri Lanka. It readily accepted *O. stricta* (Haworth) Haworth (Cactaceae) and the closely related *O. elatior* Miller (Cactaceae) and gave spectacular suppression of these weeds (Kunhi Kannan 1928).

Lantana, *Lantana camara* (Verbenaceae)

Muniappan and Viraktamath (1986) reviewed the status of this weed in India. It was first introduced to Calcutta in 1809. It has adapted well to tropical and subtropical climatic conditions and to semiarid to humid regions of India. It was a very troublesome weed in Karnataka (Coorg), Kerala (Wyanad, West Coast, and Travancore, Cochin) and Tamil Nadu (Tirunelveli, Yercaud, parts of Coimbatore and up to 500 feet in the Nilgiris) (Tadulingam & Venkatanarayana 1932). However, invasion of Siam weed has replaced *L. camara* in the western parts of the Western Ghats (Muniappan & Viraktamath 1993). In 1921, a seed fly of lantana, *Ophiomyia lantanae* (Froggatt) (Diptera: Agromyzidae) was introduced from Hawai'i (origin: Mexico) and released in south India. Though established, it has not provided adequate control of the weed. *Epinotia lantana* (Busck) (Lepidoptera: Tortricidae) and *O. lantanae* affect over 95% of the lantana berries around Bangalore (Muniappan & Viraktamath 1986). The tingid bug, *Teleonemia scrupulosa* Stål (Hemiptera: Tingidae), a native of Mexico, was introduced from Australia in 1941 (Roonwal 1952). However, the culture was destroyed as the adults fed on teak flowers in the quarantine at Dehra Dun. But the insect escaped quarantine and has now spread throughout India. If a sufficient population of *T. scrupulosa* is available it does not allow lantana to overgrow (Singh 1995). However, an egg parasitoid, *Erythmelus teleonemiae* (Subba Rao) (Hymenoptera: Mymaridae) parasitises up to 85% of the tingid eggs thus affecting its efficacy. Two leaf miners of lantana, *Octotoma scabripennis* (Guerin) (Coleoptera: Chrysomelidae) and *Uroplata girardi* Pic. (Coleoptera: Chrysomelidae) were imported from Australia in 1971 by the Forest Research Institute, Dehra Dun and released in Haldawani and Bhopal between 1972 and 1975. They have since established. The introduced natural enemies that feed on leaves, flowers and berries have slowed down the spread of this weed. There is room for introduction of increased number of natural enemies to suppress this weed in India (Muniappan & Viraktamath 1993).

Siam weed, *Chromolaena odorata* (Asteraceae)

It was possibly introduced to Bengal as an ornamental plant in 1800s (Hooker 1881). After World War II, it was accidentally introduced into Kerala through the contaminated clothing of the soldiers returning from Bengal (Bennett & Rao 1968). It has a definite climatic adaptation and competes well with other vegetation in humid tropical zones up to a height of 1000 m in the Western Ghats of India (Muniappan & Viraktamath 1993). It has now spread in most of the areas of Peninsular India and forms dense thickets in the forests of Western Ghats that had been cleared and planted with cashew, *Eucalyptus*, teak and rubber. It invades rapidly into the disturbed areas. It is also spreading to drier areas in Bangalore (for example GKVK Campus of the University of Agricultural Sciences). Field adapted population of an arctiid moth, *Pareuchaetes pseudoinsulata* Rego Barros (Lepidoptera: Arctiidae) was introduced from Sri Lanka in 1984 for the suppression of Siam weed. The insect has established on *C. odorata* in a rubber planta-

tion at Trichur, Kerala and it has defoliated the weed over about 2 ha (Anonymous 1986). There are a few reports of its establishment in Karnataka also (Anonymous 1992).

Crofton weed, *Ageratina adenophora* (Sprengel) (Asteraceae)

It is a native of Mexico. It invaded rangelands, vacant lands, roadsides and forests in Himachal Pradesh, the foothills of the Himalayas, northeastern India and above a 1000 m elevation in the Western Ghats and Shevroy hills. A host specific gall-forming tephritid fly, *Procecidochares utilis* Stone (Diptera: Tephritidae) from Mexico was introduced to India in 1967 (Rao et al. 1971). The fly has spread to all parts of India wherein *A. adenophora* has invaded. However, as in the case of *T. scrupulosa*, the effectiveness of the fly has been reduced due to attack by local parasitoids in India.

Carrot weed, *Parthenium hysterophorus* L. (Asteraceae)

It is a native of Mexico and neighboring USA. It was first recorded in Pune in 1955 and has now spread throughout the country infesting about 5 million hectares of land (Krishnamurthy et al.1977). It has occupied fallow land along roadsides, railway tracks, pastures, cultivated lands and is a serious public health hazard. A number of native natural enemies have been recorded on this weed in India but they do not suppress its population but rather utilize it as an alternate host (Kumar et al. 1979). In 1983, a field collected population of *Zygogramma bicolorata* Pallister (Coleoptera: Chrysomelidae) was received from Mexico, tested for host specificity and released during June/August 1984 around Bangalore. Early sign of establishment was evident. The insect undergoes diapause from November to June (Jayanth & Geetha Bali 1993) in drier areas but continued to breed in small numbers along irrigation canals, tank beds where moisture and green parthenium plants are available. Till 1990 the beetle population was very low and then it started building up and by 1992 it spread to many areas in Karnataka, Maharashtra, Andhra Pradesh, Tamil Nadu and Kerala. The first generation of beetles completely defoliate Parthenium by July-August and the emerging beetles from the second and subsequent generations migrate to other areas in search of Parthenium and could be seen on several plants other than Parthenium. The beetles have been reported to feed on sunflower leaves in Karnataka (Sridhar 1991). Jayanth et al. (1993) reported variability in feeding response of the beetle to sunflower under laboratory and field conditions. Parthenin - a sesquiterpene lactone specific to *P. hysterophorus*, acted as a phagostimulant for *Z. bicolorata* adults. *Z. bicolorata* did lay eggs on sunflower, however, the first instar larvae failed to survive.

Water hyacinth, *Eichhornia crassipes* (Pontederaceae)

It is an aquatic weed of Brazilian origin with a tremendous capacity of doubling its number in 10 days. In 1982, three exotic natural enemies, *Neochetina bruchi* Hustache (Coleoptera: Curculionidae), *N. eichhorniae* Warner

(Coleoptera: Curculionidae) and *Orthogalumna terebrantis* Wallwork (Acari: Galumnidae) were introduced for the biological suppression (Jayanth & Nagarakatti 1987a, 1987b). These have given spectacular control of the weed around Bangalore (Jayanth 1987a, Jayanth & Singh 1993). During 1982, Bangalore City Corporation had allocated Rs 350,000 (approximately US$ 78,000) for clearing water hyacinth from one of the tanks and after the establishment of the weevils this recurring expenditure has been saved (Singh 1995). *N. eichhorniae* also has established in parts of Kerala, Manipur, Assam, Uttar Pradesh, Rajasthan, Maharashtra (Anon. 1987). *O. terebrantis* has established in Kerala and Karnataka, and complements the two exotic weevils in Karnataka but in Kerala it has established in many areas and is particularly effective in water bodies covered by partial shade (Anon.1992).

Water fern, *Salvinia molesta* (Salvinaceae)

It is a native of southeastern Brazil. The first effort to control the weed was made with the grasshopper, *Paulinia acuminata* (De Geer) (Orthoptera: Pauliniidae) from South America (Brazil) but it failed to establish here. In 1982, *Cyrtobagous salviniae* Calder & Sands (Coleoptera: Curculionidae) was introduced from Australia (Jayanth 1987b). The release of weevils provided spectacular results in many parts of Kerala and in some areas 99% suppression was achieved in 12-16 months (Joy et al. 1985). Savings due to the weevils has been estimated to be Rs. 6.8 million (approximately US$ 2.90 million) every year that was spent for labour alone for clearing the weed manually (Anon. 1987).

Other invasive weeds

Mikania micrantha Kunth (Asteraceae) (mile a minute) is Neotropical in origin adapted for humid tropical climatic conditions. As a climbing vine, it climbs on local vegetation and smothers them. It is now prevalent in northeast India and Kerala. In Kerala it is replacing *C. odorata* in some places. There is a need for exploring its natural enemies in its native country and introduce them as the host specific, *Liothrips mikaniae* (Priesner) (Thysanoptera: Phlaeothripiadae)from Trinidad failed to control the weed in Solomon Islands and Malaysia (IIBC 1990). Evaluation of many strains of the microcyclic rust, *Puccinia spegazzinii* de Toni from Mexico, Brazil and Trinidad against *Mikania* collections from India has resulted in the identification of a few strains of the rust suitable for introduction into India.

Mimosa (invisa) diplotricha C. Wright ex Suavalle (Mimosaceae) and *Bidens pilosa* L. (Asteraceae) which are also of Neotropical origin, have spread widely in India (Muniappan & Viraktamath 1993). There are no suitable biocontrol agents that have been introduced for them. The bug *Scamurius* sp. (Hemiptera: Coreidae) and the psyllid, *Heteropsylla* sp. (Homoptera: Psyllidae) used in Australia and Western Samoa for the control of *M. invisa* could be introduced into India after host specificity tests (IIBC 1990).

Conclusions

With an increase in the movement of plant material, each country is at risk of being invaded by new organisms and some of them may become global pests and weeds. Quarantine alone will not prevent the entry of an invasive pest. The impact on the environment and agricultural production in the first few years of invasion of a pest species is tremendous. Such impacts can be minimized with international cooperation through exchange of information on invasive pests and their natural enemies. There is a need for interdisciplinary coordinated work among ecologists, agronomists, weed scientists, entomologists, plant pathologists and others in identifying already invaded organisms and in assessing their ecological problems, environmental concerns in different ecosystems, economic damage and methods of control. It is also important to know about the future-invading organisms to recommend appropriate programs to prevent their introduction and to take immediate and necessary steps to contain and eradicate them when introduced which can only be achieved with cooperative efforts of all the countries.

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