The Bioscan 8(1): 01-10, 2013
AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES
www.thebioscan.in

FORTUITOUS BIOLOGICAL CONTROL OF INSECT PESTS AND WEEDS : A CRITICAL REVIEW

BABASAHEB B. FAND*, SACHIN S. SUROSHE[1] AND R. D. GAUTAM[2]
National Institute of Abiotic Stress Management (Indian Council of Agricultural Research) Malegaon
Baramati - 413 115, Maharashtra, INDIA
[1]National Research Center on Pomegranate (Indian Council of Agricultural Research)
Solapur - 413 255, Maharashtra, INDIA
[2]Biological Control Laboratory, Division of Entomology, Indian Agricultural Research Institute
(Indian Council of Agricultural Research), New Delhi – 110 012, INDIA
e-mail: babasahebfand@gmail.com

KEYWORDS
Exotic natural enemies
Fortuitous biological control
Invasive species
Quarantine escape
Scale insects

Received on :
08.12.2012

Accepted on :
27.02.2013

***Corresponding author**

ABSTRACT
Almost two third of the exotic biological control agents recorded from various parts of the world are accidentally introduced, giving excellent control of the pests of economic importance with no or rare environmental side effects. Contrarily, accidentally introduced alien species because of their invasive nature may put the native species at the risk of extinction, thus affecting the biodiversity and ecosystem sustainability. The spread of non-native insect fauna in the context of global biodiversity loss is a matter of serious concern to entomologists as well as ecologists. This review summarizes the documented fortuitous introductions that contributed significantly to the natural biological control of economically important pests and certain non target effects wielded by the alien species.

INTRODUCTION

Background

Universal recognition of the role of predators and parasitoids in pest control through classical example of the cottony cushion scale management in California piloted the global initiatives towards the introduction of exotic natural enemies for controlling invasive pests; resulting in significant control of more than 150 species of harmful insects (De Bach, 1964; 1971; Sankaran, 1974; Singh, 1994; Van Lenteren *et al*., 2000; 2003) and several species of invasive weeds (Crawley, 1989; McFayden, 1998; Muniappan and Viraktamath, 1993; Nechols, 2003; Shreshtha *et al*., 2010). Since its inception in early 90s, biological control has enjoyed the status of being environmentally sound and effective means of combating invasive pest problems (Smith, 1919; De Bach, 1964). However, recently the environmental safety of biological control, earlier taken for granted has become a topic of hot debate all over the world, largely because of certain nontarget effects wielded by introduced natural enemies (Elliot *et al*., 1996).

Biological control and Environmental Concerns

Although, biocontrol importations in the past rarely have caused negative environmental consequences (Blossey, 1995; Van Lentern *et al*., 2006), potential risks associated with the introduction of alien species for pest control have not been dealt adequately (van Lenteren *et al*., 2003, 2006; Murphy, 2004), especially in case of accidental introduction and establishment of unintended pest or natural enemy to the new areas (De Bach, 1964; 1971; Nechols, 2003). With its nontarget effects becoming more apparent, recently the environment friendly image of the classical biological control is challenged; consequently, is coming under the perview of increasingly intense scrutiny and regulatory oversight (Barnett *et al*., 1999; Messing, 1999, van Lenteren *et al*., 2006). Presently, biological control is treated as 'not free of risk' mostly because of inadvertently associated risks such as accidental introductions of unwanted species or of the species that attacks nontargets of ecological significance (Mc Fayden, 1998; Messing *et al*., 1999; Barnett *et al*., 1999; van Lenteren *et al*., 2003; 2006).

Classical biological control and Fortuitous introductions

There are enough records to prove that importations of natural enemies that were not highly host specific, provided control of nontarget pests to certain extent, besides the control of target ones (De Bach, 1971; Sailer, 1978; Lasalle and Pena, 1997; Ramani *et al*., 2002; Nechols, 2003; Van Lenteren *et al*., 2003, 2006; Gao and Li, 2006; Hoy *et al*., 2007, See the

Table 1 for details).This phenomenon of recruitment of accidentally introduced exotic natural enemy on exotic or native pest and/ or *vice*-a-*versa* has been described earlier as 'fortuitous biological control' (De Bach, 1971). Thus, it can be said that fortuitous biological control is the unintentional reduction and maintenance of pest population by a natural enemy wherein either the enemy or the pest is non-indigenous (DeBach, 1971; Nechols, 2003). It encompasses a part of naturally occurring biological control, however invariably associated with intentional and planned program of classical biological control (Ooi, 1987; Nechols, 2003).

Globalization and liberalization of world agricultural trade coupled with the rapid transport and communication means nowadays, have substantially and plausibly increased the chances of accidental introductions of insect-pests, pathogens, weeds and other unwanted organisms to the new areas where they were not known to occur previously, along with the consignments (Ooi, 1987; Mc Neely, 2001; Ramani, 2004a). To quote few of the examples are, serpentine leaf minor *Liriomyza trifolii* (Burgess) introduced from Florida to California along with cut chrysanthemum flowers (Parella *et al*., 1981), Coffee berry borer *Hypothenemus hampei* Ferrari entered into India along with coffee seeds from Sri Lanka (Kumar *et al*., 1990), *Parthenium hysterophorous* L. introduced from Mexico as seed contaminant in food grains imported to India (Krishnamurthy *et al*., 1977). Similarly, several studies across the globe revealed that, most of the cases of accidental introductions of unintended species of natural enemies were found invariably associated with the purposeful importations of exotic natural enemies for classical biological control (DeBach, 1971; Ooi, 1987; van Lenteren *et al*., 2003; 2006).

Apparently, the fortuitous biological control seems to be beneficial as accidentally introduced natural enemies in past did quiet excellent job of controlling pests of economic importance. However, the native species may be placed at the risk of extinction by accidentally introduced organisms through competitive displacement and reduced abundance (Elliot *et al*., 1996; Obrycki *et al*., 1998), leading to biological invasions. The rapid and serious effects of species invasions and biodiversity loss instigated global discussions on the growing concerns of environmental risks through exotic introductions for the biological control. As such, the earlier known ecofriendly version of the biological control has been put under the custody of strict regulatory framework.

In this review, we tried to enlighten the issues and ideas of relevance to the topic; the possible means for the fortuitous biological control to occur along with the important case histories occurred in various groups of insect pests and weeds. The possible environmental impacts of fortuitous introductions of exotic species are also discussed.

How fortuitous: accidental or intentional?

According to the De Bach (1964; 1971) and Nichols (2003), fortuitous biological control can take place through either of the possible means such as quarantine escape, recruitment of indigenous natural enemy on exotic pets and/ or recruitment of the purposefully imported natural enemy on the nontarget indigenous pest. As stated earlier, most of the exotic natural enemies found in various parts of the world have been accidentally introduced (De Bach, 1971; Sailer, 1978; Charles, 1998). In general, large numbers of cases of fortuitous introductions were found mostly in the parasitoids than the predators and those associated with the Hemipteran pests than the other groups of insects because of sessile and cryptic nature of these pests and the parasitoids are likely to be carried as immatures in parasitized or overwintering hosts (Sailer, 1978: Nechols, 2003).

In this section, we discussed certain ecological, biological and especially anthropogenic mechanisms involved in fortuitous biological control, explained with relevant examples. We compiled through extensive literature review the important examples of fortuitous introductions that occurred inadvertently in various groups of insect-pests and weeds, invariably associated with either the purposeful importations of exotic bioagents or transboundary movements of agricultural produce.

Quarantine Escape or accidental entry along with host

With the galvanization of certain nontarget environmental effects, the classical biological control has now become a subject of legislative control (Messing *et al*., 1999; Barnett *et al*., 1999; van Lenteren *et al*., 2006). Currently, almost all the countries in the world have in place, a well established system of quarantine legislation for regulating import and analysis of risks associated with exotic biocontrol agent introductions (IPPC, 1997; Shine *et al*., 2000; DAC, 2006; FAO, 2006). Despite the strict enforcement of quarantine, the accidental introductions of exotic insect-pests and their natural enemies seems to be increasingly common due to intense and rapid commercial exchanges through world agricultural trade; making the species invasions a serious issue of global concern (Murphy, 2004; Ramani, 2004). Increased transboundary movement of agricultural produce with increased global trade and tourism has resulted in accidental introductions of invasive, alien species in many parts of the world; representing serious threat to native biodiversity (Ooi, 1987; McNeely, 2001; Murphy, 2004; Ramani, 2004b; Reddy *et al*., 2008).

Unlike predators, the parasitoids being carried as immatures in overwintering/ parasitized host stages are most likely to escape the quarantine and get accidentally entered into the new areas (Nechols, 2003). In such cases, the introduced pests may be restricted from establishment and spread in new areas by accompanying natural enemies, because both the pest and the natural enemy being non-native; there is likely chance that the sympatric relationship in their original habitat help introduced natural enemy occupy and utilize the pest niche, effectively (De Bach, 1964; 1971).

Surprisingly, majority of the exotic biological control agents recorded in different parts of the world have been found introduced accidentally, invariably associated with the intentional importations for classical biological control (Table 1) (De Bach, 1971; Sailer, 1978; Rosen and De Bach, 1979; Charles, 1998; Ramani *et al*., 2002; Nechols, 2003; Hoy *et al*., 2007) and they are now a key component of natural biological control in various crop ecosystems, worldwide. Hence, the worth of accidentally introduced and established natural enemies in pest management can never be disregarded as the fortuitous biological control has been observed not only as an accidental but also a fortunate phenomenon, since

Table 1: Worldwide recorded instances of accidental introductions of natural enemies along with the hosts

S. No.Insect pest/ weed Hemipteran pests	Host plant/ utility	Natural enemy	Country of Origin	Accidentallyintroduced to	Reference
1. Purple scale *Lepidosaphes beckii* Newman(Homoptera: Diaspididae)	Citrus	*Aphytis lepidosaphes* Compere (Hymenoptera: Aphelinidae)	Hong Kong and Taiwan	Hawai, Florida, Turkey, Israel, Puerto Rico, Gaudaloupe, Jamaica, Australia, New Caledonia, El Salvado, and Argentina	DeBach, 1971; Rosen and DeBach, 1979
2. Californian red scale *Aonidiella aurantii* (Maskell) (Homoptera: Diaspididae)	Citrus	*Aphytis chrysomphali* (Mercet) (Hymenoptera: Aphelinidae)	Mediterranean Basin	Japan, Hong Kong, Taiwan, Philippines, Hawaii Australia, S. Africa, Argentina, California, The Caribbean and many others	DeBach, 1971; Rosen and DeBach, 1979
		Aphytis lignanensis (Compere) (Hymenoptera: Aphelinidae)	Orient	Mexico and South Texas	DeBach, 1971; Rosen and DeBach, 1979
3. San Jose scale *Quadraspidiotus perniciosus* (Comstock) (Homoptera: Margarodidae)	Apple	*Aphytis mytilaspidis* (Le Baron) (Hymenoptera: Aphelinidae)	-	North America	DeBach, 1971; Rosen and DeBach, 1979
4. Oleander scale *Aspidiotus nerii* Bouche (Homoptera: Coccidae)	Oleander	*Aphytis chiliensis* Kieffer (Hymenoptera: Aphelinidae)	Mediterranean area	Europe, South Africa, North and South America, Australia and New Zealand.	DeBach, 1971; Rosen and DeBach, 1979
5. Red wax scale *Ceroplastesrubens* Maskell (Homoptera: Coccidae)	Citrus	*Anicetus beneficus* Ishii (Hymenoptera: Encyrtidae)	Central and Southern, China	Japan	Murakami, 1997; Takagi, 2003
6. Spiraling whitefly *Aleurodicus dispersus* Russell(Homoptera: Aleyrodidae)	Banana, guava, papaya, cucurbits, dahlia, gerbera, gladiolus, tomato	*Encarsia guadeloupae* Viggiani (Hymenoptera: Aphelinidae)	-	India	Ramani *et al*., 2002
		Encarsia sp. nr. Meritoria Gahan(Hymenoptera: Aphelinidae)	-	India	Ramani *et al*., 2002
7. *Trialeurodes vaporariorum*Westwood (Homoptera: Aleyrodidae)	Greenhouse crops	*Encarsia pergandiella* Howard(Hymenoptera: Aphelinidae)	Italy	Spain	Viggiani, 1994; Gabarra *et al*., 1999
8. Green stinkbug *Nezara viridula* (Linnaeus) (Heteroptera: Pentatomidae)	-	*Trichopoda pennipes* F. (Diptera: Tachinidae)	New World	Italy	Colazza *et al*., 1996; Salerno *et al*., 2002
9. Brown citrus aphid *Toxoptera citricida* Kirkaldy (Homoptera: Aphididae)	Citrus	*Lipolexis oregmae* Gahan (Hymenoptera: Aphidiidae)	-	Jamaican island	Hoy *et al*., 2007
10. Asian citrus psyllid *Diaphorina citri* Kuwayama (Homoptera: Psyllidae)	Citrus	*Tamarixia radiate* Waterston (Hymenoptera: Eulophidae)	-	Jamaican island	Hoy *et al*., 2007
11. Mealybug *Hypogeococcus pungens* Granara de Wilink (Homoptera: Pseudococcidae)	Joyweed, a bedding plant	*Aprostocetus* sp. (Hymenoptera: Eulophidae)	Pawaa	Hawai	Wong, 2006
12. Pink hibiscus mealybug *Maconellicoccus hirsutus* (Green) (Homoptera: Pseudococcidae)	Ornamental and fruit crops	*Anagyrus kamali* Moursi (Hymenoptera: Encyrtidae)	-	Mariana Islands	Reddy *et al*., 2009
		Allotropa sp. near mecrida (Walker) (Hymenoptera: Platygastridae)	-	Mariana Islands	Reddy *et al*., 2009
13. Solenopsis mealybug *Phenacoccus solenopsis* Tinsley(Homoptera: Pseudococcidae)	Cotton, Tomato Okra, Brinjal, Chilli, *Hibiscus rosa- sinensis* L.	*Aenasius bambawalei* Hayat(Hymenoptera: Encyrtidae)	-	India	Gautam *et al*., 2009; Pala and Saini, 2010

Table 1: Cont.....

	Lepidopteran pests					
1.	Citrus leafminer *Phyllocnistis citrella* Stainton(Lepidoptera: Gracillaridae)	Citrus	*Ageniaspis citricola* Logvinovskaya(Hymenoptera:Encyrtidae)	Thailand and Taiwan	Jamaican island	Hoy *et al.*, 2007
2.	Leaf-mining Agromyzidae*Liriomyza huidobrensis* (Blanchard) (Diptera:Agromyzidae)	Vegetable Crops	*Neochrysocharis beasleyi* (Eulophidae: Hymenoptera)		Southeast Asia	Murphy and La Salle, 1999
		Neochrysocharis okazakii Kamijo (Eulophidae: Hymenoptera)			Southeast Asia	Murphy and La Salle, 1999 La Salle, 1999
		Neochrysocharis formo sa (Westwood)(Eulophidae: Hymenoptera)			Southeast Asia	Murphy and La Salle, 1999 La Salle, 1999;
	Weeds					
	Siam weed *Chromalaena odora*ta (L.) Pontederiaceae	Terrestrial invasive weed from Neotropics	*Pareucates pseu doinsulata* Rego Barros	Sabah, Malaysia	Palawan Island of Philippines	Aterrado, 1986
			Mite, *Acalitus odoratus* Kniefer (Acarina: Eriophyidae)	Trinidad, West Indies	Sabah, Malaysia, Asia	McFayden, 1993
2.	*Lantana camera*	Terrestrial	*Teleonemia scrupulosa*	Pohnpei islands	Chuuk	Denton *et al.* (1991)
	LinnaeusVerbenaceae	invasive weed		Stal (Hemiptera: Tingidae)		
1.			*Salbia haemorrhoidalis* Guenee Lepidoptera: Pyralidae) *Uroplata girardi* Pic, (Coleoptera: Chrysomelidae)			
			Lantanophaga pusillidactyla Walker (Lepidoptera: Pterophoridae)	-	India	Muniappan and Viaktamath, 1993;
				Pohnpeii slands	Chuuk	Denton *et al.* (1991)
			Epinotia lantana (Busck) Bhumannavar et al., 2004 (Lepidoptera: Tortricidae)	Pohnpei islands	Chuuk	Denton *et al.* (1991)
			Hypena laceratalis Walker (Lepidoptera: Noctuidae)	- -	Mauritius	Fowler *et al.*, 2000
			Hypena laceratalis Walker (Lepidoptera: Noctuidae)	-	Mauritius	Fowler *et al.*, 2000
			Orthezia insignis Browne (Homoptera: Orthezиidae)	-	Mauritius	Fowler *et al.*, 2000
			Lantana seed fly *Ophiomyia lantanae* (Froggatt) (Diptera: Agromyzidae)		India	Muniappan and Viraktamath, 1993
				Tropical America	Chuuk	Muniappan and Reddy, 2003
			Lantana leaf blotch minor, *Calycomyza lantanae* Frick (Diptera: Agromyzidae)	Tropical America	Chuuk	Muniappan and Reddy, 2003
3.	*Opuntia cactii*	Terrestrial weed	Cochineal insect *Cactoblastis cactorum*, Lepidoptera: Pyralidae	South America	Miami, Florida	Pemberton, 1995
	Carrot weed, *Parthenium*	Noxious terrestrial	*Zygogramma bicolorata*	Brevard Mexico	Nepal (introduced accide	Johnson and Stiling 1998; Shrestha *et al.*, 2010
	hysterophorous Linnaeous (Asteraceae)	weed	Pallister (Coleoptera: Chrysomelidae)		ntally along with host from India)	

Table 2: Fortuitous biological control of accidentally introduced pests by indigenous natural enemies

Insect pest/ Weed	Host plant/ utility	Accidentally introduced to	Controlled by native natural enemy/ s	Year	Reference
Spherical mealybug *Nipaecoccus viridis* (Newstead) (Homoptera: Pseudococcidae)	*Leucaena leucocephala* Lam.	Guam and Northern Marianas Islands	*Anagyrus indicus* Shafee, Alam and Agarwal (Hymenoptera: Encyrtidae)	1970-2000	Nechols, 2003
Liriomyza trifoli (Burgess) (Diptera: Agromyzidae)	Tomato, cucumber, castor	India	*Hemiptarsenus varicornis* (Girault)	1993-94	Kapadia, 1997
Citrus leafminer *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillaridae)	Citrus	Argentina	*Galeopsomyia fausta* LaSalle sp. n (Hymenoptera: Eulophidae).	1993-97	Lasalle and Pena, 1997
Water hyacinth *Eichhornia crassipes* (Mart.)	Invasive aquatic weed from Brazil	China	Blood worm or red worm, (midge) *Chironomus* sp. (Diptera: Chironomidae	-	Gao and Li, 2006

the beneficial species is carried by a pest to new area with no added cost or efforts (Nechols, 2003; Charles, 1998). e.g. Aphelinid parasitoids, *Encarsia guadeloupae* Viggiani and *Encarsia* sp. *nr. Meritoria* Gahan, accidentally introduced along with the host *Aleurodicus dispersus* Russell controlled the population of invading whitefly species in India (Ramani *et al.,* 2002).

Conversely, the quarantine escape of exotic natural enemies with potential for causing nontarget effects may pose serious threat to native biodiversity. Here, We would like to narrate an incidence that happened with the biological control of *Lantana camara* L. in India; wherein a Tingid bug *Telenemia scrupulosa* Stal imported from Australia in 1941 (Roonwal, 1952), despite its destruction in quarantine testing at Forest Research Institute, Dehra Dun after found feeding on flowers of teak *Tectona grandis* a forest species of economic value for its best quality wood, somehow escaped from quarantine and spread throughout the country. Fortunately, the insect has been kept under check by its hyperparasitoid *Erythmelus teleonemiae* a mymarid egg parasitoid; otherwise it might have wiped out teak plantations besides the control of *L. camara* (Singh, 1994; Ramani, 2004a).

Recruitment of indigenous natural enemy on exotic pest

Despite their adaptability to diverse crop habitats and amenability to mass production, the role of the indigenous natural enemies is still limited to augmentative and conservation biological control; while they may rarely be the effective bioagents for classical biological control largely because of niche differences (Charles, 1998; Gao and Li, 2006). This is another possibility for the fortuitous biological control to take place as a consequence of control by indigenous complex of natural enemies of accidentally introduced and established exotic pest (De Bach, 1971; Nechols, 2003). Of course, recruitment of the native natural enemy onto the invasive species is a spontaneous and slow process, which may limit its effectiveness. But once invasive species becomes a component of native ecosystem following its establishment and colonization, it gets controlled in fact by inhabited natural enemies (Charles, 1998; Gao and Li, 2006), as witnessed in case of suppression of spherical mealybug *Nipaecoccus viridis* (Newstead) invading Guam and the Northern Marianas by a resident complex of natural enemies *viz*., the coccinellid *Scymnus roepki* (Fluiter), two dipteran predators and the encyrtid *Anagyrus indicus* Shafee, Alam and Agarwal (Nechols, 2003). Additionally, the recruitment of indigenous natural enemies onto the exotic pest has very little or no environmental risk than importing exotic species of natural enemies. Hence, the studies focused on the role of indigenous biocontrol agents in pest population regulation and their conservation techniques needs to be emphasized (Charles, 1998; Gao and Li, 2006; Fand *et al.,* 2010[ab]).

There are quite few examples to mention of successful control of exotic pests by indigenous natural enemies (Table 2). The eulophid *Galeopsomyia fausta* LaSalle sp. n represents an example of an indigenous parasitoid recruited onto an invading pest species, the citrus leaf miner *Phyllocnistis citrella* Stainton in Neotropics (Florida, Mexico, Puerto Rico, etc.) showing levels of 28-68% pupal parasitism (Cano *et al*., 1996; Castano *et al.,* 1996; Cave 1996). *Hemiptarsenus varicornis* (Girault) along with other indigenous parasitoids has been reported to cause 39-49% parasitism in accidentally introduced agromyzid *Liriomyza trifoli* (Burgess) infesting tomato, cucumber and castor in various parts of India (Kapadia, 1997). Gao and Li (2006) reported the larva of midge *Chironomus* sp. as a potent native natural enemy of invasive aquatic weed, water hyacinth *Eichhornia crassipes* (Mart.) in Shanghai, China. Establishment of several indigenous coccinellids *viz*., *Hyperaspis maindroni* Sicard, *Brumoides suturalis* (Fabricius), *Scymnus coccivora* Ayyar, *Nephus regularis* Sicard, *Coccinella septumpunctata* Linnaeus and *Cheilomenus sexmaculata* (Fabricius) on newly flared up North American mealybug species *Phenacoccus solenopsis* Tinsley in India have been reported by many workers (Gautam *et al*., 2007; Jhala *et al.,* 2008; Fand *et al.,* 2010 a,b), but the pest was suppressed only after the fortuitous establishment of Encyrtid parasitoid *Aenasius bambawalei* Hayat (Gautam *et al.,* 2009; Pala and Saini, 2010; Fand *et al*., 2011).

Recruitment of purposefully imported natural enemy on nontarget pest

The exotic natural enemies for classical biological control are imported only after the rigorous testing for host specificity and non target safety (Murphy, 2004). However, in many instances of biological control introductions, the imported natural enemies were found to exercise control of unintentional or nontarget pests of economic importance (De Bach, 1971; Sailer, 1978; Lasalle and Pena, 1997; Ramani *et al*., 2002; Nechols, 2003; Van Lenteren *et al*., 2003, 2006; Gao and Li, 2006; Hoy *et al*., 2007). When a natural enemy imported to control a target pest attacks and controls non-target pest, this

Table 3: Fortuitous biological control of nontarget pests by purposefully imported natural enemies

Nontarget pest/ s	Host plant/ utility	Country of invasion	Controlled by natural enemy	Imported from	Target pest/ s	Year	Reference
Opuntia vulgaris Miller	Terrestrial invasive weed	India	*Dactylopius ceylonicus* (Green)	Brazil	*Opuntia cactii*	1795	Tryon, 1910; Ramakrishna Ayyar,1931
Citrus mealybug *Planococcus citri* (Risso), Pink hibiscus mealy bug *Maconellicoccus hirsutus* (Green)	CitrusGrape	India	*Cryptolaemus montrouzieri* Mulsant	Australia	Coffe green scale *Coccus viridis* (Green)	1898	Sankaran, 1974 Singh, 1994
Spodoptera litura (Fabricius)	Tobacco	India	*Telenomus remus* Nixon	Papua New Guinea	Castor semilooper, *Achaea janata* Linnaeus	1964	Sankaran, 1974
Red-banded whitefly *Tetraleurodes* sp. (Homoptera: Aleyrodidae)	Avocado	California	*Cales noacki* Howard (Hymenoptera: Aphelinidae)	Brazil	Mulberry whitefly *Tetraleurodes mori* (Quaintance), Acacia whitefly *Tetraleurodes acaceae* (Quaintance)	1982	Rose and Wooly, 1984

also results in fortuitous biological control (Nechols, 2003). We quote here specifically the instances regarding purposefully imported natural enemies recruited on nontarget pests, which can be regarded as fortuitous as well as fortunate biological control since unplanned pests attacked by the introduced natural enemies were of economic concern (Table 3). The fortuitous control of one of the invasive and noxious weeds *Opuntia vulgaris* Miller in North and Central India by *Dactylopius ceylonicus* (Green), an insect bioagent native of Brazil introduced in 1795 mistakenly in place of *D. cocci* Costa, a true carmine dye producing scale feeding on *O. cacti* (Tryon, 1910; Ramakrishna Ayyar, 1931) is one of the best examples of purposefully imported natural enemies controlling nontarget but economically important pests. The Australian Ladybird beetle *Cryptolaemus montrouzieri* Mulsant was imported to India in 1898 against Coffe green scale *Coccus viridis* (Green). Though it has established under Indian conditions but failed to control the target pest and now is a common predator of variety of mealybug species including citrus mealybug *Planococcus citri* (Risso) and pink hibiscus mealybug *Maconellicoccus hirsutus* (Green) in South India (Rao *et al*., 1971; Sankaran, 1974; Singh, 1994). Similarly, in another case an egg parasitoid, *Telenomus remus* Nixon, basically imported from Papua New Guinea to India in 1964 against castor semilooper *Achoea janata* Linnaeus (Sankaran, 1974) has turned to be an important regulator of another non-target but one of the destructive pests *i.e.* tobacco leaf eating caterpillar *Spodoptera litura* (Fabricius). Suppression of red banded whitefly *Tetraleurodes* sp., an invasive species of avocado in California by *Cales noacki* Howard, an earlier introduced parasitoid for control of mulberry whitefly *Tetraleurodes mori* (Quaintance) and acacia whitefly *Tetraleurodes acaceae* (Quaintance), preventing the dispersal of the pest to uninfested areas has been reported (Rose and Wooly, 1984).

Do really fortuitous introductions are beneficial ecologically and economically?

Historically, invasive alien species of worldwide importance have been controlled successfully through classical biological control approach involving importation, mass rearing and release of several species of exotic natural enemies (Van Lenteren *et al*., 2000; 2003). By its very nature, classical biological control involves the introduction of biological control agents into the new areas outside their native range; it has every possibility of accidental introduction of other unintended organisms too. The literature says that most of the cases of accidental introductions of unintended species of natural enemies were invariably associated with the purposeful importations of exotic natural enemies for classical biological control (De Bach, 1971; Ooi, 1987; Nechols, 2003; Van Lenteren *et al*., 2003, 2006).

Regardless of when and how they entered into the new localities, the fortuitous introductions and establishments of exotic biological control agents resulted in incredible amount of natural biological control of pests of economic importance (Table 1) and are still going on in nature. Similarly, the recruitment of indigenous natural enemies onto invasive pests (Table 2) has very little or no environmental risk than introducing natural enemies from original area (Lasalle and

Table 4: Nontarget effects of fortuitously introduced biological control agents

Introduced natural enemy	Species affected	Ecological effect	Country/ Region	Reference
Coccinella septumpunctata (Coleoptera: Coccinellidae)	*Coccinella transverguttata, Adalia bipunctata* (Coleoptera: Coccinellidae)	Reduced abundance and competitive displacement	South Dakota	Elliot *et al*.,1996
	Coccinella maculate (Coleoptera: Coccinellidae)	Reduced abundance and competitive displacement	Iowa	Obracky *et al.,* 1998
Diplazon laetatorius (F.) (Hymenoptera:Ichneumonidae) *Anacharis zealandica* Ashmead (Hymenoptera: Figitidae)	Native predator species	Hyperparasitism, reduced abundance	New Zealand.	Charles, 1998

Pena, 1997; Gao and Li, 2006). Many times, natural enemies can easily be accessed for importation from accidentally introduced areas than from their native homes. Otherwise, it can be said that the fortuitous biological control is not only as an accidental but also a fortunate phenomenon since the pests carry along with them the beneficial species to the new areas (Nechols, 2003). Accompanying of natural enemies may prevent the establishment of exotic pets in new areas and thus invasive species is stopped from assuming status of an economic pest (De Bach, 1971).

Since the fortuitous biological control occurs accidentally without involving any human efforts, it helps saving a lot of time and money that needs to be spent for the purposeful importations of biological control agents as in case of classical approach. As the pest is kept below economically damaging levels naturally by reestablishment of balance between the invasive pest and fortuitous natural enemy, it may help reducing unwanted pesticide applications. Consequently it enhances the environmental quality through reduced pesticide pollution.

Environmental Concerns of Fortuitous Introductions

Fortuitous establishment of natural enemies of insect pests and weeds in new areas appear to be a very common phenomenon, invariably associated with the importations of exotic natural enemies to control invasive pests (De Bach, 1971; De Bach and Rosen, 1991; Nechols, 1995; 2003; SCOPE, 1996; Charles, 1998; van Lenteren *et al*., 2003; 2006) and/ or increased transboundary movements of agricultural produce through world trade (Ooi, 1987; Charles, 1998; McNeely, 2001; Murphy, 2004; Ramani, 2004). According to the literature survey, introductions of biological control agents during past twelve decades for the control of arthropod pests globally rarely have caused the negative environmental effects (Sailor, 1978; Charles, 1998) and in most of the cases of exotic introductions the benefits outweigh the risks.

However, environmental risks from releases of exotics are of growing concern both for ecologists and entomologists. Accidental introductions of unintended species and introduction of species that attacks natural enemies of ecological or economic value are the major risks associated with the exotic introductions for biological control leading to the biological invasion (Messing, 1999; Gao and Li, 2006). Accidentally introduced organisms because of their invasive nature greatly outnumber natural enemies those are intentionally introduced (van Lenteren *et al*., 2006) which may lead to competitive displacement and reduced abundance of native species as documented in case of *Coccinella septumpunctata* (L.) competitively replacing *Coccinella transversoguttata* Fald and *Adalia bipunctata* (L.) in South Dakota (Elliot *et al*., 1996) and *Coccinella maculata* in Iowa (Obracky *et al*., 1998). Thus the native species are put at the risk of extinction by fortuitously introduced natural enemies. Nontargets becoming targets is another danger of species invasions as reported by Charles (1998) where two of the accidentally introduced Hymenopteran parasitoids, *Diplazon laetatorius* (F.) (Ichneumonidae) and *Anacharis zealandica* Ashmead (Figitidae) attacked native predators in New Zealand. Accidentally introducing unwanted organisms may contaminate the cultures of intended insects and microorganisms whereas some natural enemies are capable of carrying spores of unwanted plant pathogens which may lead to disease epidemics in the area of invasion. Hyperparasitoids accidentally entering along with the intended species may contaminate and kill the cultures of biological control agents, which upon release and establishment may reduce the effectiveness of the biological control agents (De Bach and Rosen, 1991; Nechols, 1995; 2003; Charles, 1998).

Even though, the causes of biological invasions are manifold and multifaceted (Dukes and Mooney, 1999), biological control and global climate change are recognised as primary drivers of species invasion. Convention on Biological Diversity (CBD) treats the invasive alien species as the greatest threat to loss of biodiversity in the world affecting ecosystems' functioning (Mooney and Hobbs, 2000).

What Next

Biological invasions and global species extinction are seems to be the greatest threats from biological control introductions. Despite numerous hurdles to the understanding and dealing with the problem of biological invasion, a well focused and coordinated legal and organizational approach is essential to meet this challenge. Most of the countries in the world have a well developed regulatory structure in place in order to prevent unwanted biological pollution. As the fortuitous biological control is going on unnoticed continuously in and around us, extensive pest surveillance in areas having probabilities of exotic introductions such as airports, sea ports, military camps, railway stations and their surrounding areas needs to be undertaken which may help adding to our knowledge of a poorly documented, yet another important component of naturally occurring biological control. Similarly, adverse effects or risk associated with the accidental entries if any, could be identified and due measures could be undertaken to mitigate the same. It is anticipated that because of globalization and

liberalization of an agricultural trade, chances of unintentional introductions have increased substantially and a number of unintended organisms have made their way across the overseas. This can be minimized through strict and proper enforcement of quarantine to avoid any side effect on environmental biodiversity. Managing insect invasions by watching neighboring countries, detecting new invaders by means of early warning systems and increasing public awareness about exotics are of paramount importance. Without rigorous quarantine procedures, the new invasions of exotic pests will continue to be high leading to a biological pollution.

ACKNOWLEDGEMENTS

Authors would like to thank the anonymous reviewer for critically reviewing the manuscript and giving useful suggestions.

REFERENCES

Aterrado, E. D. 1986. *Pareuchaetes pseudoinsulata* caterpillars on *Chromalaena odorata:* a new Philippine record. *Philippines J. Coconut Sci.* **11:** 59-60.

Barnett, B. I. P., Ferguson, C. M., Goldson, S. L., Phillips, C. M., Hannah, D. J. 1999. Predicting the risks from biological control agent introductions: A New Zealand Approach, in: Follett, P.A., Duan, J.J. (Eds.), Nontarget effects of biological control. *Kluwer Academic Publishers, Dordrecht, the Netherlands.* pp 316.

Bhumannavar, B. S. 2004. General procedures for introduction of biological control agents: current and proposed guidelines for weed biological control agents, in: Ramani, S., Bhumannavar, B. S., Rabindra R.J. (Eds.), Quarantine procedures and facilities for biological control agents. *Technical Document No. 54, Project Directorate of Biological Control, Bangalore.* pp 47-51.

Blossy, B. 1995. Host specificity screening of insect biological control agents as part of an environmental risk assessment, in: Hokkanen, H. M. T., Lynch, J. M. (Eds.), Biological control: benefits and risks. *Cambridge University Press, Cambridge, UK.* pp 84-89.

Charles, J. G. 1998. The settlement of fruit crop arthropod pests and their natural enemies in New Zealand: an historical guide to the future. *Biocontrol News Inf.* **19:** 47–58.

Colazza, S., Giangiuliani, G. and Bin, F. 1996. Fortuitous introduction and successful establishment of *Trichopoda pennipes* F., adult parasitoid of *Nezara viridula* (L.). *Biol. Control.* **6:** 409-411.

Crawley, M. J. 1989. The successes and failures of weed biocontrol using insects. *Biocontrol News Inf.* **10:** 213–23

DAC 2006. Guidelines for regulating export, import and release of biological control agents and other beneficial organisms. *Department of Agriculture and Cooperation (DAC) Ministry of Agriculture, Government of India, New Delhi, June* 2006. p. 19.

De Bach, P. (Ed.) 1964. Biological Control of Insect Pests and Weeds. New York. *Reinhold Publishing Corporation.*

De Bach, P. 1971. *Fortuitous biological control from ecesis of natural enemies*, in: Entomological Essays to Commemorate the Retirement of Prof. K. Yasumatsu, Tokyo, Hokuryukan Publishing Company. pp. 293-307.

Denton, G. R. W., Muniappan, R. and Marutani, M. 1991. Status and natural enemies of the weed, *Lantana camara*, in Micronesia. *Trop Pest Mgmt.* **37:** 338-34.

Dukes, J. S. and Mooney, H. A. 1999. Does global change increase the success of biological invaders? *Trends. Ecol. Evol.* **14:** 135-139.

Elliot, N., Kieckhefere, R. and Kauffman, W. 1996. Effects of an invading coccinellid on native coccinellids in an agricultural landscape. *Oecologia*. **105:** 537-544.

Fand, B. B., Gautam, R. D. and Suroshe, S. S., 2010a. Comparative biology of four coccinellid predators of solenopsis mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae). *J. Biol. Control.* **24:** 35-41.

Fand, B. B., Gautam, R. D. and Suroshe, S. S. 2010b. Effect of developmental stage and density of *Phenacoccus solenopsis* Tinsley (Homoptera: Pseudococcidae) on the predatory performance of four coccinellid predators. *J. Biol. Control.* **24:** 110-115.

Fand, B. B., Gautam, R. D. and Suroshe, S. S. 2011: Suitability of various stages of mealybug, *Phenacoccus solenopsis* (Homoptera: Pseudococcidae) for development and survival of the solitary endoparasitoid, *Aenasius bambawalei* (Hymenoptera: Encyrtidae), *Biocontrol Sci. Tech.* **21:** 51-55.

FAO, 2006. ISPM No. 3, Guidelines for the export, shipment, import and release of biological control agents and other beneficial organisms, in: *International Standards for Phytosanitary Measures* No. 1 to 24 (2005 edition). *Food and Agricultural Organization, Rome, Italy*. pp 23-32.

Fowler, S. V., Ganeshan, S., Mauremootoo, J. and Mungroo, Y. 2000. Biological Control of Weeds in Mauritius: Past Successes Revisited and Present Challenges, in: Spencer, N.R. (ed.), *Proceedings of the X International Symposium on Biological Control of Weeds.* Montana State University, Bozeman, Montana, USA, July 1999, pp 43-50.

Gabarra, R., Arno, J., Alomar, O. and Albajes, R. 1999. Naturally occurring populations of *Encarsia pergandiella* (Hymenoptera: Aphelinidae) in tomato greenhouses. IOBC/ WPRS *Bulletin*. **22:** 85-88.

Gao, L. and Li, B. 2006. A potential native natural enemy of invasive aquatic weed – water hyacinth. *Biol. Invasions* **8:** 689-1692.

Garonna, A. P. and Viggiani, G. 1989. *Notizie preliminari* sulla, *Comperiella lemniscata* Compere and Annecke (Hymenoptera: Encyrtidae), parassitoide di *Chrysomphalus dyctiospermi* (Morg.) in Italia. *Redia.* **72:** 523–527.

Gautam, R. D. 2008. Biological Pest Suppression. *Westville Publishers*, New Delhi. pp 308.

Gautam, R. D., Saxena, U., Gautam, S., Khan, M. A. and Gautam, C. P. N. 2007. Studies on solanum mealybug, *Phenacoccus solani* Ferris (Hemiptera: Pseudococcidae), its parasitoid and predator complex, reproductive potential and utilization as laboratory prey for rearing the ladybird and green lacewing predators. *J. Entomol. Res.* **31:** 1-6.

Gautam, R. D., Suroshe, S. S., Gautam, S., Saxena, U., Fand, B. B. and Gupta, T., 2009. Fortuitous biological control of exotic mealybug, *Phenacoccus solenopsis* - A boon for Indian Growers. *Annals Plant Prot. Sci.* **17:** 38-39.

Hoy, M. A., Jeyaprakash, A. and Harris, D. C. 2007. Fortuitous establishment of *Ageniaspis citricola* (Hymenoptera: Encyrtidae) in Jamaica on the citrus leafminer (Lepidoptera: Gracillariidae). *Florida Entomol.,* **90:** 270-27 3.

IPPC 1997. International Standards for Phytosanitory Measures. *https:/ /www.ippc.int/ IPP/En/default.jsp.*

Jhala, R. C., Bharpoda, T. M. and Patel, M. G. 2008. *Phenacoccus solenopsis* (Hemiptera: Pseudococcidae), the mealybug species recorded first time on cotton and its alternate host plants in Gujarat, India. *Uttar Pradesh J. Zoology***. 28:** 403-406.

Johnson, D. M. and Stilling, P. D. 1998. Distribution and dispersal of *Cactoblastis cactorum* (L: Pyralidae), an exotic *Opuntia* feding moth in Florida. *Env. Entomol.* **25:** 743-748.

Kapadia, M. N. 1997. Effect of host plants on *Liriomyza trifoli* (Burgess)

and development of its parasitoid, *Chrysonotomaiya* sp. *J. Appl. Zool. Res.* **8:** 68.

Kiritani, K. 2000. Insect invasions in the world. *Insectarium.* **37:** 224-235.

Krishnamurthy, K., Ramachandraprasad, T. V., Muniappan, T. V. and Venketa Rao, B. V. 1977. *Parthenium*, a new pernicious weed in India. *University of Agricultural Sciences Technical series.* **17:** 1-66.

Kumar, P. K. V., Prakasan, C. B. and Vijayalakshi, C. K. 1990. Coffee berry borer *Hypothenemus hampei* (Coleoptera: Scolytidae): first record from India. *J. Coffee Res.* **20:** 161-164.

LaSalle, J. and Pena, J. E. 1997. A new species of *Galeopsomyia* (Hymenoptera: Eulophidae: Tetrastichinae): a fortuitous parasitoid of the citrus leafminer, *Phyllocnistis citrella* (Lepidoptera: Gracillariidae. *Florida Entomol.* **80:** 461-470.

McFadyen, R. E. C. 1993. The accidental introduction of the *Chromalaena* mite *Acalitus odoratus* into Southeast Asia, in: Delfose, E.S., Scott, R.R. (Eds.), *Proceedings of the 8th international symposium on biological control of weeds,* Linccoln University, Canterbury, new Zealand. pp 649-652.

McFayden, R. E. 1998. Biological control of weeds. *Ann. Rev. Entomol.* **43:** 369-393.

McNeely, J. 2001. Invasive species: a costly catastrophe for native biodiversity. *Land use and water resources research*, 1, 1-10

Messing, R. H. 1999. What is the impact of real nontarget concerns on the practice of biological control?, in: Follett, P. A., Duan, J. J. (eds.), Nontarget effects of biological control, Kluwer Academic Publishers, *Dordrecht, The Netherlands*. pp 316.

Mooney, H. A. and Hobbs, R. J., (Eds.), 2000. Invasive Species in a Changing World. *Island Press, Washington, D.C.*

Muniappan, R. and Reddy, G. V. P. 2003. Fortuitous introduction of two natural enemies of *Lantana camara* to Chuuk. *Proceedings of Hawaiian Entomological Society.* **36:** 123-124.

Muniappan, R. and Viraktmath, C. A. 1993. Invasive alien weeds in Western Ghats. Curr. Sci., 64,555-557.

Murakami, Y. 1997. Natural Enemies of the Chestnut Gall Wasp - Approach to Biological Control. *Kyushu University Press, Fukuoka, Japan.*

Murphy, S. T. and La Salle, J. 1999. Balancing biological control strategies in the IPM of New World invasive *Liriomyza* leafminers in ûeld vegetable crops. *Biocontrol News Inf.* **20:** 91-104.

Murphy, S. T. 2004. Principles, protocols and facilities for the introduction of biological control agents: a global perspective, in: Ramani, S., Bhumannavar, B. S., Rabindra R. J. (Eds.), Quarantine procedures and facilities for biological control agents. Technical Document No. 54, Project Directorate of Biological Control, Bangalore. pp 1-4.

Nechols, J. R. 2003. Biological control of the spherical mealybug on Guam and in the Northern Marianas Islands: a classic example of fortuitous biological control. *1st International Symposium on Biological Control of Arthropods*. USDA-Forest Service FHTET-03-05. June, 2003, pp 324-329.

Obrycki, J. J., Giles, K. L. and Ormord, A. M. 1998. Interactions between an introduced and indigenous coccinellid species at different prey densities. *Oecologia.* **117:** 279-285.

Ooi, P. A. C. 1987. A fortuitous biological control of *Lantana* in Malaysia. *Int. J.Pest Mgmt.* **33:** 234 - 235.

Pala, R. and Saini, R. K. 2010. Biological control of solenopsis mealybug, *Phenacoccus solenopsis* Tinsley on cotton: a typical example of fortuitous biological control, *J. Biol. Control*. **24:** 104–109

Parella, M. P., Allen, W. W. and Morishita, P. 1981. Leaf miner species causes California mum growers new problems. *California Agric.***35:** 28-30.

Pemberton, R. W. 1995. *Cactoblastis cactorum* in the United States: an immigrant biological control agent or an introduction of the nursery industry. *American entomol.* **41:** 230-232.

Ramakrishna Ayyar, T. V. 1931. The Coccidae of the prickly pear in South India and their economic importance. *Agriculture and Livestock India*. **1:** 154-159.

Ramani, S., Poorani, J. and Bhumannavar, B. S. 2002. Spiralling whitefly, *Aleurodicus dispersus* in India. *Biocontrol News Inf.* **23:** pp 55-62.

Ramani, S. 2004a. Classical Biological Control attempts in india, in: Ramani, S., Bhumannavar, B.S., Rabindra R.J. (Eds.), Quarantine procedures and facilities for biological control agents. *Technical Document No. 54, Project Directorate of Biological Control, Bangalore.* pp 5-15.

Ramani, S. 2004b. General procedures for introduction of biological control agents with special reference to parasitoids and predators, in: Ramani, S., Bhumannavar, B.S., Rabindra R.J. (Eds.), Quarantine procedures and facilities for biological control agents. Technical Document No. 54, Project Directorate of Biological Control, Bangalore, pp 23-38.

Reddy, C. S., Bagyanarayana, G., Reddy, K. N. and Raju, V. S. 2008. Invasive alien flora of India. *National Biological Information Infrastructure, USGS, USA*

Reddy, G. V. P., Muniappan, R., Cruz, Z. T., Naz, F., Bamba, J. P. and Tenorio, J., 2009. Present Status of *Maconellicoccus hirsutus* (Hemiptera: Pseudococcidae) in the Mariana Islands and its control by two fortuitously introduced natural enemies. *J. Econ. Entomol.* **102:** 1431-1439.

Roonwal, M. L. 1952. The natural establishment and dispersal of an imported insect in India – the lantana bug, *Teleonemia scrupulosa* Stal (= *lantanae* Distant; Hemiptera: Tingidae), with a description of its egg, nymph and adult. *J. Zool. Soc. India*. **4:** 1-16.

Rose, M. and Woolley, J. B. 1984. Previously imported parasite may control invading whitefly. *Californian Agric.* **38:** 24-25.

Rosen, D. and De Bach, P. 1979. *Species of the Aphytis of the World* (Hymenoptera: Aphelinidae). *Jerusalem: Israel Universities Press, The Hague.*

Sailer, R. I. 1978. Our immigrant insect fauna. *Bull. Entomol. Soc. America.* **24:** 3-11.

Salerno, G., Colazza, S. and Bin, F. 2002. *Nezara viridula* parasitism by the Tachinid fly *Trichopoda pennipes* ten years after its accidental introduction into Italy from the New World. *Bio Control.* **47:** 617-624.

Sankaran, T. 1974. Natural enemies introduced in recent years for biological control of agricultural pests in India. *Indian J. Agric. Sci.* **44:** 425-433.

Shine, C., Williams, N. and Gundling, L. 2000. A guide to designing legal and institutional frameworks on alien invasive species. *Gland, Switzerland: IUCN*. pp 138.

Shrestha, B. B., Poudel, A., K. C. J., Karki, D., Gautam, R. D. and Jha, P. K. 2010. Fortuitous biological control of *Parthenium hysterophorous* by *Zygogramma bicolorata* in Nepal. *J. Nat. History Museum*. **25:** 333-338.

Singh, S. P. 1994. Fifteen years of AICRP on Biological Control, Technical Bulletin No. 8, Project Directorate of Biological Control, Bangalore, India.

Takagi, M. 2003. Biological control of citrus scale pests in Japan. *1st International Symposium on Biological Control of Arthropods*. USDA-Forest Service FHTET-03-05. June, 2003, pp 351-355.

Tryon, H. 1910. The wild cochineal insecrt with reference to its

injurious action on prickly pear (*Opuntia* spp.) in India and its availability for the subjugation of this plant in Queensland and elsewhere. *Queensland Agric. J.* **25:** 188-197.

van Lenteren, J. C., Babendreier, D., Bigler, F., Burgio, G., Hokkanen, H. M. T., Kuske, S., Loomans, A. J. M., Menzler-Hokkanen, I., Van Rijn, P. C. J., Thomas, M. B., Tommasini, M. G. and Zeng, Q. Q. 2003. Environmental risk assessment of exotic natural enemies used in inundative biological control. *BioControl.* **48:** 3-38.

van Lenteren, J. C., Bale, J., Bigler, F., Hokkanen, H. M. T., Loomans, A. J. M. 2006. Assessing the risks of releasing exotic biological control agents of arthropod pests. *Ann. Review of Entomol.* **51:** 609-634.

Viggiani, G. 1994. Recent cases of interspecific competition between parasitoids of the family Aphelinidae (Hymenoptera: Chalcidoidea). *Norwegian J. Agric Sci.* **16:** 353-359.

Wong, L. 2006. New pest detection and identification-Plant Industry Division. *In: Hawaii Department of Agriculture, Annual Report, Financial year,* 2006.