

BIOLOGICAL CONTROL OF FRUIT PIERCING MOTH (*EUDOCIMA FULLONIA* [CLERCK]) (LEPIDOPTERA: NOCTUIDAE) IN THE PACIFIC: EXPLORATION, SPECIFICITY, AND EVALUATION OF PARASITOIDS

Don SANDS¹ and Wilco LIEBREGTS²

¹ CSIRO Entomology, 120 Meiers Road
Indooroopilly Queensland 4068 Australia
don.sands@csiro.au

² Eco-Consult Pacific Co. Ltd, PO Box 5406
Raiwaqa, Suva, Fiji
ecoconsult@is.com.fj

ABSTRACT

Adult fruit piercing moths (Noctuidae) are common pests of ripening fruit over much of tropical and subtropical Southeast Asia, Australia, and the western Pacific islands. *Eudocima fullonia* (Clerck), a target for classical biological control, occurs in that region including Papua New Guinea where it is not a pest and where it is thought to be controlled by natural enemies. Surveys conducted in Papua New Guinea revealed that two abundant egg parasitoids, *Telenomus lucullus* (Nixon) and *Ooencyrtus* sp. (*Papilionis*, species-group, Encyrtidae) were contributing up to 95% mortality of moth eggs. The host specificity of both parasitoids was studied in the laboratory by exposing them to eggs of related Noctuidae. *T. lucullus* was found to be specific to *Eudocima* spp. in the laboratory but *Ooencyrtus* sp. oviposited and developed on several non-target noctuid species in the presence of the moth host's food plants. *T. lucullus* and *Ooencyrtus* sp. were assessed as adequately host specific for release in Samoa, Tonga, Fiji and the Cook islands. However, the parasitoids were not assessed with the non-target *E. iridescens* (T.P. Lucas), a rare species from northern Australia unavailable for testing. The two egg parasitoids were released on Samoa, Tonga, Fiji, and the Cook Islands but were not released in Australia due to the inability to demonstrate adequate host specificity. *T. lucullus* and *Ooencyrtus* sp. both became established in Tonga and Fiji but only *T. lucullus* became established in Samoa and the Cook islands. After establishment of parasitoids increased levels of egg parasitism and declines in the abundance of target eggs occurred in Samoa and Tonga, and decreases in the abundance of the moths and its damage to fruit were observed in Fiji and Cook Islands. The methods for conducting surveys, host specificity testing and field evaluations are described.

267

INTRODUCTION

Fruit piercing moths (*Eudocima* spp. [= *Othreis* spp.], Noctuidae: Catocalinae) are serious pests of ripe and ripening fruit in many subtropical and tropical countries including parts of

Africa, Southeast Asia and western Pacific countries (Waterhouse and Norris 1987). The most widespread pest species, *Eudocima fullonia* (Clerck) occurs in Australia and western Pacific countries (Waterhouse 1997) including New Caledonia (Cochereau 1977). Although cosmopolitan in the Pacific, Waterhouse and Norris (1987) suggested that the Indo-Malaysian region is the most likely area of origin of *E. fullonia*.

Both sexes of adult fruit piercing moths puncture fruit with their long, stout proboscis which is adapted to penetrate the rind of firm, intact fruit allowing moths to feed on fruit juice and pulp. Secondary invasions by micro-organisms spread into damaged tissues causing rot and premature fruit-fall (Sands *et al.* 1993). There are two different biotypes of *E. fullonia*. In Papua New Guinea (PNG) and on most Pacific islands, larvae of *E. fullonia* feed on several *Erythrina* spp. (Fabaceae) as well as vines of the family Menispermaceae, whereas in Australia, Southeast Asia, and Africa, the larvae feed only on Menispermaceae (Sands and Chan 1996; Sands & Schotz 1991).

In eastern Australia the moths migrate annually in warmer months from the tropics, to temporarily colonise the temperate regions (Sands *et al.* 1991) and their abundance varies from year to year (Mosse-Robinson 1968) with climatic variation. In New Caledonia, outbreaks mainly follow prolonged periods of drought (Cochereau 1977). In western Pacific countries, including New Caledonia, indigenous natural enemies do not prevent the build up of moth numbers that invade orchards and cause serious damage (Cochereau 1977). However, *E. fullonia* is not abundant or a pest in Papua New Guinea, where its abundance is thought to be reduced by parasitoids (Sands and Broe 1991).

In early attempts to control *E. fullonia*, a larval parasitoid *Winthemia caledoniae* Mesnil (Diptera: Tachinidae) from New Caledonia, (Cochereau 1977) was relocated within the region but it failed to become established (Kumar and Lal 1983; Waterhouse and Norris 1987). Very few other parasitoids of larvae of *Eudocima* spp. are known. However, *Euplectrus maternus* Bhatnagar from India and *E. melanocephalus* Girault from northeastern Australia have been considered to be potential biological control agents (Jones and Sands 1999).

Two egg parasitoids from PNG, *Telenomus lucullus* Nixon (Hymenoptera: Scelionidae) (= *Telenomus* sp., LPL 530 in Sands *et al.* 1993) and an *Ooencyrtus* sp. (Hymenoptera: Encyrtidae) (*papilionis* Ashmead, species-group), were recently introduced into the western Pacific (Sands and Liebrechts 1992; Sands *et al.* 1993) in attempts at biological control of *E. fullonia*. The exploration, evaluation, and the release of these egg parasitoids, the introduction into Tonga of another egg parasitoid, *O. crassulus* from Samoa, and the reasons for not releasing egg parasitoids from Papua New Guinea in Australia, are discussed. Preliminary evaluation of *E. melanocephalus* from Australia, as a possible agent for the Pacific islands is also discussed.

MATERIALS AND METHODS

Exploration for parasitoids in Papua New Guinea. Surveys for parasitoids of *E. fullonia* were conducted in Papua New Guinea (PNG) in 1987 and 1988, at the edge of coastal rainforests and on roadside vegetation near Madang, northern PNG, near Vudal, New Britain, at Tep Tep in the Finisterre Ranges (alt. 2000 m), and at the edge of mesophyll vine thickets near Port

Moresby, southern PNG. In a search for any alternative hosts of *Ooencyrtus* sp. or *Telenomus lucullus*, eggs of Noctuidae (other than *E. fullonia*) were collected opportunistically near Madang, PNG and incubated in the laboratory until egg parasitoids emerged.

The host plants of *E. fullonia* were examined and any immature stages located were returned to the laboratory for rearing. Immature stages of the moth from individual eggs and egg masses deposited on leaves of the food plant, *E. variegata* var. *orientalis* L., and occasionally from vines (Menispermaceae) were collected from localities close to sea level, whereas at a high altitude (2,000 m) locality, Tep Tep, Morobe Province, stages of *E. fullonia* were collected from the menisperm vine, *Stephania japonica*.

Leaf portions of *E. variegata* or menisperm vines with single eggs and egg masses were excised and incubated in ventilated plastic containers for up to 28 days until parasitoids or larvae eclosed. Parasitoids that emerged were maintained by feeding with honey droplets smeared on wax paper. Moth larvae were provided with fresh leaves of appropriate food plants until they appeared to be parasitised, or if they pupated, until moths or parasitoids eclosed, or unparasitised pupae died. Percent parasitism of each host stage was calculated for each field locality and food plant based on the numbers of immature stages that developed fully, died or produced parasitoids. Parasitised larvae of *O. fullonia* were occasionally recovered from food plants in rainforest in PNG but none were successfully reared or positively identified. These parasitoids were thought to be a *Euplectrus* sp. (Eulophidae) (Sands unpublished).

TESTING THE HOST SPECIFICITY OF PARASITOIDS

269

Cultures of egg parasitoids *T. lucullus* and *Ooencyrtus* sp. (*papilionis* species-group) were established in the laboratory in Madang, PNG to provide material suitable for consignment to Australia. Parasitoids were reared in PNG through one generation using moth eggs obtained from a caged culture of *E. fullonia*. Parasitised eggs of *E. fullonia* were then separated from leaf substrates for subsequent packaging and consignment to Australia. All host specificity tests were conducted in a quarantine facility in Brisbane, Australia, where cultures of both PNG egg parasitoids were established using eggs of *E. fullonia* (Australian biotype) as hosts. Parasitoids were reared and tested in large (14 x 3 cm) ventilated plastic tubes containing a card smeared with honey as food.

Representatives of non-target, indigenous Australian Noctuidae were exposed to parasitoids for specificity tests. They were selected for testing on the basis of their taxonomic relatedness to the target genus, *Eudocima* (Noctuidae: Catocalinae), their known life histories, and the availability and practicability of obtaining fertile eggs or larvae. To obtain eggs of all species, gravid moths were held in cages and induced to oviposit on organza using the method described by Sands and Schotz (1991).

In a first group consisting of other *Eudocima* spp., eggs of *E. salamina* (Cramer), *E. materna* (Linn.), *E. aurantia* (Moore), *E. iridescens* (T.P. Lucas) and *E. cocalis* (Cramer) were nominated for exposure to *T. lucullus* and *Ooencyrtus* sp. In a second group, eggs of less closely-related Catocalinae, species of *Ophiusa* spp., *Dasypodia* spp., *Achaea* sp., *Phyllodes imperialis*, *Donuca* sp., *Erebus terminitincta* (Gaede) and an *Anomis* sp. were tested. Immature stages of two species *Helicoverpa armigera* (Hübner)(Heliothinae) and *Spodoptera litura*

(Fab.) (Acronictinae), representing other subfamilies as their life histories well known. Cultures of these were obtained from the University of Queensland, Brisbane.

The host specificities of *Ooencyrtus* sp. and *T. lucullus* originally from PNG, were evaluated for their suitability for introduction into western Pacific islands and mainland Australia. The host specificity of the Australian *E. melanocephalus* was determined as preliminary for its proposed introduction into Fiji and Samoa, countries where the temperature and humidity were predicted to be most favourable (Jones and Sands 1999).

Egg parasitoids from PNG were tested for their host specificity by exposing to eggs of selected non-target species attached to gauze: (i) without plant material and (ii) with leaf portions of plant hosts of *E. fullonia* (*S. japonica* and *E. variegata*) to test for any different (trophic) responses to the eggs (Table 1).

INDIGENOUS NATURAL ENEMIES IN AUSTRALIA AND THE PACIFIC

Prior to introducing an exotic agent, the indigenous natural enemies were surveyed in each proposed receiving country, to: (i) ensure that the agent species was not already present, (ii) identify indigenous natural enemies and distinguish them from the proposed agent, and (iii) quantify impacts by each indigenous species on the target host. Information from the literature (e.g., Sands *et al.* 1993; Waterhouse and Norris 1987) and a co-ordinated program focussed on indigenous and introduced parasitoids (Table 2) of *E. fullonia* in the western Pacific.

The most abundant indigenous parasitoids of eggs that needed to be distinguished from species proposed for introduction from PNG included: *O. crassulus* Prinsloo and Annecke (Hymenoptera: Encyrtidae) and *Trichogramma* spp. in Samoa; *O. cochereaui* Prinsloo and Annecke, *Trichogramma chilonis* Ishii (Hymenoptera: Trichogrammatidae) and *Telenomus* sp. (Hymenoptera: Scelionidae) in New Caledonia (Cochereau 1977; Maddison 1982).

The impact on eggs by an important predator of eggs, *Germalus samoanus* China (Hymenoptera: Lygaeidae), was quantified during the assessment of egg parasitism in Samoa.

Specimens of parasitoids reared from *E. fullonia* were retained in the Australian National Insect Collection, Canberra and others were submitted to the Natural History Museum, London for identification.

LARVAL PARASITIDS

On the Pacific islands very low levels of parasitism were recorded from larvae during the reported study. In Australia, egg and larval parasitoids (Huber 1999) were reared from immature stages of *Eudocima* spp.. *Euplectrus melanocephalus* Girault and an unidentified *Euplectrus* sp. were identified as larval parasitoids from northeastern Queensland, but they were only abundant during the warm, humid months each year (Huber 1999). Parasitised larvae of *Eudocima* spp., mostly instars 1 and 2, were collected from menisperm vines near Cairns, northern Queensland. Using methods described by Jones and Sands (1999) they were maintained with leaves of the food plant until they pupated, died, or parasitoids developed. The suitability of *E. melanocephalus* as a biological control agent was evaluated in a secure facility in Brisbane. The effects of temperatures on immature development times were

Table 1. Host specificity tests: parasitoids of *E. fullonia* exposed to eggs of Noctuidae.

Parasitoid	Host ^a /Non-target Host ^b	Stage of Host	Pars. Oviposition	Pars. development
<i>E. melanocephalus</i>	<i>E. fullonia</i>	2nd, 3rd inst. larva	+	+
"	<i>E. materna</i>	2nd, 3rd inst. larva	+	+
"	<i>E. salamina</i>	2nd, 3rd inst. larva	+	+
"	<i>E. aurantia</i>	2nd, 3rd inst. larva	+	+
"	<i>Erebus terminitincta</i>	2nd, 3rd inst. larva	-	-
"	<i>Spodoptera litura</i>	2nd, 3rd inst. larva	-	-
<i>Ooencyrtus sp.</i>	<i>E. fullonia</i>	egg	+	+
"	<i>E. materna</i>	"	+	+
"	<i>E. salamina</i>	"	+	+
"	<i>E. aurantia</i>	"	+	+
"	<i>Erebus terminitincta</i>	"	+/- *	+/- *
"	<i>Dasypodia spp.</i>	"	+/- *	+/- *
"	<i>Phyllodes imperialis</i>	"	+/- *	+/- *
"	<i>Ophiusa sp.</i>	"	+/- *	+/- *
"	<i>Achaea sp.</i>	"	+/- *	+/- *
"	<i>Donuca sp.</i>	"	+/- *	+/- *
"	<i>Spodoptera litura</i>	"	+/- *	+/- *
"	<i>Helicoverpa armigera</i>	"	+/- *	+/- *
<i>Telenomus lucullus</i>	<i>E. fullonia</i>	"	+	+
"	<i>E. materna</i>	"	+	+
"	<i>E. salamina</i>	"	+	+
"	<i>E. aurantia</i>	"	+	+
"	<i>Erebus terminitincta</i>	"	-	-
"	<i>Dasypodia spp.</i>	"	-	-
"	<i>Phyllodes imperialis</i>	"	-	-
"	<i>Ophiusa sp.</i>	"	-	-
"	<i>Achaea sp.</i>	"	-	-
"	<i>Donuca sp.</i>	"	-	-
"	<i>Spodoptera litura</i>	"	-	-
"	<i>Helicoverpa armigera</i>	"	-	-

*oviposition and development only in presence of *Erythina variegata* and *Stephania japonica*.

Table 2. Introductions of parasitoids for biological control of the fruit piercing moth, *Eudocima fullonia*.

Natural Enemy	Country of Origin	Country Released	Host Stage	Established	Reference
<i>Winthemia caledoniae</i> Mesnil	New Caledonia	Fiji (1983-84)	larva	-	Kumar and Lal 1983
<i>Winthemia caledoniae</i> Mesnil	New Caledonia	Tonga (1979)	larva	-	Waterhouse and Norris 1987
<i>Ooencyrtus cochereaui</i>	New Caledonia	American Samoa	egg	-	"
<i>Ooencyrtus cochereaui</i>	New Caledonia	Samoa	egg	-	"
<i>Ooencyrtus crassulus</i>	Samoa	Tonga (1992)	egg	+	Sands and Liebrechts 1992
<i>Ooencyrtus</i> sp. (<i>papilionis</i> group)	Papua New Guinea	Samoa (1989)	egg	-	Sands <i>et al.</i> 1993
<i>Ooencyrtus</i> sp. (<i>papilionis</i> group)	Papua New Guinea	Fiji (1992)	egg	+	Sands <i>et al.</i> 1993
<i>Ooencyrtus</i> sp. (<i>papilionis</i> group)	Papua New Guinea	Tonga (1992)	egg	+	Sands 1996
<i>Ooencyrtus</i> sp. (<i>papilionis</i> group)	Papua New Guinea	Cook Islands (1996)	egg	+	Sands and Liebrechts unpubl.
<i>Telenomus lucullus</i>	Papua New Guinea	Samoa (1989)	egg	+	Sands and Liebrechts 1992
<i>Telenomus lucullus</i>	Papua New Guinea	Fiji (1992)	egg	+	Sands <i>et al.</i> 1993
<i>Telenomus lucullus</i>	Papua New Guinea	Tonga (1993)	egg	+	Sands 1996
<i>Telenomus lucullus</i>	Papua New Guinea	Cook Islands (1996)	egg	+	Sands and Liebrechts unpubl.

determined to predict its adaptability to the tropical environments of the Pacific islands (Jones and Sands 1999). The suitability of the unidentified *Euplectrus* sp. was not evaluated.

MEASURING ABUNDANCE AND PARASITISM OF EGGS OF *E. FULLONIA*

To monitor the abundance of moth stages some variation in methodology was applied in each country, where the immature stages, mostly eggs of *E. fullonia* on the host plant *Erythrina* spp., were sampled monthly for more than 12 months, before and after release of PNG parasitoids in Samoa, Fiji, and Tonga.

Eggs and egg masses on leaves of the food plant (mostly *E. variegata* var. *orientalis* (L.) Merrill, but also *E. subumbrans* (Hask.) in Fiji and Samoa) were collected to calculate percent

parasitism by indigenous egg parasitoids (before release of PNG parasitoids). Only one pre-release survey for parasitoids was carried out in Rarotonga, Cook Islands.

Low trees of *Erythrina* spp. on properties, road boundaries or fence posts were selected for sampling sites when supporting the immature stages of *O. fullonia*. After each sampling event, trees were pruned to approximately 3 m to encourage lateral and terminal growth suitable for re-sampling. From each site each month, 100 terminal or lateral stems with leaves attached were cut from each of 20 *Erythrina* plants. Leaves were removed from terminals and all attached eggs and egg masses containing living stages (moth embryo or parasitoid) were recorded, returned to the laboratory and incubated in vials until moth larvae or parasitoids emerged. If a minimum of 30 eggs or masses was not recovered each month additional leaves were collected until 30 eggs or egg masses were retrieved. From the eggs recovered, egg abundance, egg mortality and identity of the egg parasitoids were recorded. Percent parasitism of single eggs and egg masses were calculated separately.

In the receiving countries for the egg parasitoids, *Ooencyrtus* sp. and *T. lucullus*, methods for post-release studies on eggs of *E. fullonia* were based on those to monitor pre-release parasitisation and egg abundance. The appearance of parasitised and post-parasitised stages allowed estimates to be made of parasitism in the field and were applied to the sampling methods. For example, eggs parasitised by *T. lucullus* were identifiable by markings on the chorion of eggs, and *Ooencyrtus* sp. and *Trichogramma* spp. were identified by the colour of the egg, eggshell and meconium. The abundance of eggs, levels of parasitisation by indigenous parasitoids and the release dates in each country for *Ooencyrtus* sp. and *T. lucullus* were recorded as follows:

Samoa. Single eggs as well as egg masses were abundant. An indigenous *Trichogramma* sp. ranged in abundance from 4-16% of host eggs parasitised and eggs parasitised by *O. crassulus* averaged 28-35% on the islands of Savai'i and Upolu. The PNG *Ooencyrtus* sp. and *T. lucullus* were released on both islands in 1988.

Tonga. Single eggs were abundant and egg masses uncommon. An indigenous *Trichogramma* sp. varied greatly in abundance from 6-85% of eggs parasitised on Tongatapu island and from 0-53% on the island Eua. An indigenous *Telenomus* sp. was uncommon with parasitism ranging from 0-5% on Tongatapu. The Samoan egg parasitoid *O. crassulus*: was released on Tongatapu between December 1992 and June 1993, and on Eua in November 1993. The PNG *Ooencyrtus* sp. was released in August 1992 on Tongatapu and *T. lucullus* on Tongatapu and on Eua in November 1993.

Fiji. Single eggs were abundant and egg masses uncommon. *Trichogramma* sp. parasitised 2-16% of eggs and a rare indigenous *Telenomus* sp. parasitised less than 2% of eggs. The PNG *Ooencyrtus* sp. was released in October 1990 on the island Viti Levu and *T. lucullus* on Vanua Levu and Viti Levu islands in October 1993.

Rorotonga, Cook Islands. Single eggs predominated over egg masses. *Trichogramma* sp. and an indigenous *Telenomus* sp. together parasitised less than 2% of eggs. The PNG *Ooencyrtus* sp. and *T. lucullus* were released in October 1996.

RESULTS

CLIMATIC SUITABILITY OF PARASITOIDS

The PNG egg parasitoids, *Ooencyrtus* sp. and *T. lucullus*, were confirmed to be well suited to tropical climates, and less suited to sub-tropical or temperate climates of the receiving countries. After they were released *Ooencyrtus* sp. and *T. lucullus* were recovered from the receiving islands, except from Samoa where only *T. lucullus* became established, and Cook Islands where only *Ooencyrtus* sp. became established. Although predicted to be suitable for release in most Pacific inland countries (Jones and Sands 1999), based on climatic and host range suitability, the Australian larval parasitoid *E. melanocephalus* was not released due to the lack of opportunity to culture it and monitor its establishment.

HOST SPECIFICITY TESTS WITH NON-TARGET NOCTUIDAE

In PNG, *Ooencyrtus* sp. or *T. lucullus* was reared only from field-collected eggs of *Eudocima* spp., and on no occasions were they recovered from eggs (35 spp. mostly unidentified) of non-target Noctuidae. Several parasitoids of the same genera emerged but their specific identities were not determined.

After the PNG parasitoids became established in Fiji, eggs of other Noctuidae and some unrelated moths with eggs of similar size to the target, *E. fullonia*, were sampled close to release sites in an attempt to find any evidence of attack on non-target species. In the Pacific, there was no evidence (monitoring discontinued in 1997) from samples of Noctuidae eggs, that *Ooencyrtus* sp. and *T. lucullus* had crossed over to attack eggs of any non-target moth species. On several occasions a similar *Telenomus* spp. were recovered from eggs including a hawk moth (probably *Agrius* sp.) but the parasitoid proved to be a species different to *T. lucullus* (W. Liebrechts unpubl.).

In Australia, *Eudocima* spp. available for testing in the laboratory were confirmed suitable hosts for the complete development of the PNG egg parasitoids *Ooencyrtus* sp., *T. lucullus* and the Australian *E. melanocephalus* (Jones and Sands 1999). Eggs of other related moths (Catocalinae) failed to support complete development of the parasitoids. However, when testing eggs of Noctuidae in the presence of leaves of the hosts (*Erythrina variegata*, *Stephania japonica*) of *E. fullonia*, *Ooencyrtus* sp. (but not *T. lucullus*), oviposited in the eggs of all non-target species and some, or complete parasitoid development occurred. When eggs of the same Noctuidae attached to gauze, without leaves were exposed to *Ooencyrtus* sp., no non-target species attracted oviposition by this parasitoid.

The inability to obtain immature stages of the rare *E. iridescens* for testing, a species closely-related to the target pest species, influenced the decision not to release the PNG egg parasitoids *Ooencyrtus* sp., *T. lucullus* in Australia.

RELEASE AND ESTABLISHMENT OF EGG PARASITOIDS

Samoa. *Ooencyrtus* sp. from PNG failed to become established in Samoa. *T. lucullus* released at the same time, became established and was first recovered in Samoa in October 1988. After the establishment of *T. lucullus* on Savai'i, total egg parasitism of *E. fullonia* increased from 62% to 79% for single eggs, and from 56% to 80% of egg masses.

Tonga. *O. crassulus* became established on Tongatapu and was recovered in October 1993 and December 1994. *Ooencyrtus* sp. was recovered on the same island from 1993 with egg parasitism reaching an average of 30% in 1996. *T. lucullus* was recovered on Tongatapu in 1994 where total egg parasitism increased from 19% to 27% in 1996. On Eua total egg parasitism increased from 22% in 1994 to 69% in 1996 after release of *T. lucullus*.

Fiji. *Ooencyrtus* sp. was recovered on the island Vanua Levu from September 1992 and *T. lucullus* was recovered from both islands in October and November 1993. Quantitative data on egg parasitism after parasitoids became established were not available.

Rorotonga, Cook Islands. The PNG *Ooencyrtus* sp. and *T. lucullus* were released in October 1996. Only *Ooencyrtus* sp. was recovered in April 1997. In the Cook Islands quantitative data were not collected and sampling was discontinued after establishment of the parasitoids was confirmed.

DISCUSSION

The procedure for testing exotic parasitoids with non-target species highlighted some of the difficulties in obtaining the appropriate stages of species for testing and the need to avoid testing non-target species in the presence of the certain plants to avoid 'false positive' results (Sands and Van Driesche 2000). In this example, the parasitoid *Ooencyrtus* sp. oviposited in eggs of a range of non-target hosts when portions of the food plants of *E. fullonia* were present but did not do so when the plant material was withheld. Identified also were the difficulties of making decisions about whether or not, to release an agent, when these anomalous results are obviously obtained and when the risks of releasing an agent could potentially affect a rare species closely related to the target, when it could not be obtained for testing.

Although field data show increases in total parasitism of eggs of *E. fullonia*, and decreases in the 'hatch' (moth larvae) of eggs in all countries wherever *Ooencyrtus* sp. and *T. lucullus* became established, the resulting declines in adult moth density were not easily demonstrated. However, levels of damage to fruit were reported to have decreased in all countries. For example, in Fiji in 1997 levels of damage to oranges and mangoes were noted by orchard managers and agricultural research staff, to have decreased when compared with earlier years. Damage to fruit was lower since monitoring began in the early 1990's, 5 years after the parasitoids had become established (S. Lal pers. comm.). In Samoa a decline in damage to firm fruit (e.g., citrus), but not soft fruit (e.g., carambola) was noted in 1997 (unpublished data). In Rarotonga, Cook Islands, a marked decrease in moth abundance occurred after egg parasitoids had become established (M. Poschko pers. com.). Clearly more attempts are needed to quantify levels of parasitism to eggs of *E. fullonia* and damage to fruit, to determine if the introduced egg parasitoids have had a permanent beneficial impact on horticultural production in those countries.

ACKNOWLEDGEMENTS

We thank Sada Lal, Maja, Pila Kami, Martina Schotz, Rose Broe and Veronica Brancatini for their contributions to this project. The project was supported by Australian Centre for International Agricultural Research.

REFERENCES

- Cochereau, P. 1977. Biologie et écologie des populations en Nouvelle-Calédonie d'un papillon piqueur de fruits: *Othreis fullonia* Clerck (Lepidoptera, Noctuidae, Catocalinae). Travaux et Documents ORSTOM No. 71, 322 pp.
- Huber, P. 1999. "Population Dynamics and Ecology of *Eudocima* spp. (Lepidoptera: Noctuidae) in Northern Queensland". Ph.D. Thesis, James Cook University, Cairns.
- Jones, P., and Sands, D. P. A. 1999. *Euplectrus melanaocephalus* Girault (Hymenoptera: Eulophidae), an ectoparasitoid of larvae of fruit piercing moths (Lepidoptera Noctuidae: Catocalinae) from northern Queensland. *Australian Journal of Entomology* 37, 377-381.
- Kumar, K., and Lal, S.,N. 1983. Studies on the biology, seasonal abundance and host-parasite relationship of fruit-sucking moth *Othreis fullonia* (Clerck) in Fifi. *Fiji Agricultural Journal* 45, 71-77.
- Mosse-Robinson, I. 1968. Fruit-sucking moths (Lepidoptera: Noctuidae). *Australian Zoologist* 14, 290-293.
- Muniappan, R., Silva-Krott, I. U., and Lali, T. S. 1995. Distribution of larval host plants of the fruit piercing moth, *Othreis fullonia*. *Chemoecology* 5/6, 75-77.
- Sands, D. P. A., and Broe, R. J. 1991. Prospects for Biological Control of the Fruit Piercing Moth, *Othreis fullonia* (Clerck) (Lepidoptera: Noctuidae). In "Proceedings 1st A.D.A.P. Crop Protection Conference" (M. W. Johnson, D. E. Ulman, and A. Vargo, Eds.), pp 155-158. University of Hawaii, Honolulu, May 18-19, 1989.
- Sands, D. P. A., and Chan, R. C. 1996 Survivorship of Australian *Othreis fullonia* on *Erythrina variegata*: hypotheses for development of host-plant biotypes in the Pacific. *Entomologia Experimentalis et Applicata* 80, 145-148.
- Sands, D. P. A., and Schotz, M. 1991. Biology and Prospects for Control of Fruit Piercing Moths in the South Pacific. Proceedings of the First Asia-Pacific Conference of Entomology (APCE). The Entomology and Zoology Association of Thailand. Bangkok, Thailand, November 8-13, 1989, Chiang Mai, Thailand.
- Sands, D. P. A., Schotz, M., and Bourne, A. S. 1991. Effects of temperature on development and seasonality of *Eudocima salamina* (Cramer) (Lepidoptera: Noctuidae) in eastern Australia. *Bulletin of Entomological Research* 81, 291 -296.
- Sands, D. P. A., and Van Driesche, R. G. 2000. Evaluating Host Specificity of Agents for Biological Control of Arthropods: Rationale, Methodology and Interpretation. In "Proceedings of Session: Host Specificity Testing of Exotic Arthropod Biological Control Agents" (R. G. Van Driesche, T. A. Heard, A. S., McClay, and R. Reardon Eds.), pp. 69-83. X International Symposium on Biological Control of Weeds, July 4-14 1999 Bozeman, USA Forest Service Bulletin, Morgantown, West Virginia, U.S.A.
- Sands, D. P. A., Liebrechts, W. J. M. M., and Broe, R. J. 1993. Biological control of the fruit piercing moth, *Othreis fullonia* (Clerck) (Lepidoptera: Noctuidae) in the Pacific. *Micronesica* Suppl. 4, 25-31.
- Waterhouse, D. F. 1997. The Major Invertebrate Pests and Weeds of Agriculture and Plantation Forestry in the Southern and Western Pacific. ACIAR Monograph No. 44, ACIAR Canberra, Australia.
- Waterhouse, D. F., and Norris K. R. 1987. "Biological Control: Pacific Prospects." Inkata Press, Australia.