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Biological Control Pacific Prospects — Supplement 2

Plate 1 **Top line:** 1. *Bactrocera tryoni* ovipositing in an apple. 2. *Fopius arisanus* probing a banana for tephritid eggs. 3. *Diachasmimorpha longicaudata* probing for tephritid larvae. **Middle line:** 4. *Icerya aegyptiaca* on a breadfruit leaf (D.P.A. Sands). 5. Adult *I. aegyptiaca* with wax filaments displaced by blowing lightly (G.S. Sandhu). 6. Larvae of *Rodolia* attacking *I. aegyptiaca* (D.P.A. Sands). **Bottom line:** 7. Coconut palm with bark channels of *Neotermes rainbowi* (M. Lenz). 8. Coconut palm stump following loss of top (M. Lenz). 9. Bark channels characteristic of *N. rainbowi* (M. Lenz).

Plate 2 **Top line:** 1. Thicket of *Clerodendrum chinense* in Western Samoa. 2. Roadside thicket of *C. chinense* in Fiji (D.P.A. Sands). **Middle line:** 3. Flower head of *C. chinense* (D.P.A. Sands). 4. *Phyllocharis undulata* and damage to *Clerodendrum* leaf (B. Napompeth). **Bottom line:** 5. Young prostrate plant of *Portulaca oleracea* (J.T. Swarbrick). 6. *P. oleracea* in flower (W.A. Whistler).

Biological Control Pacific Prospects — Supplement 2

D.F. Waterhouse

Australian Centre for International Agricultural Research
Canberra 1993

The Australian Centre for International Agricultural Research (ACIAR) was established in June 1982 by an Act of the Australian Parliament. Its mandate is to help identify agricultural problems in developing countries and to commission collaborative research between Australian and developing country researchers in fields where Australia has a special research competence.

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Foreword

Ever since its formation in 1982 ACIAR has been an enthusiastic supporter of classical biological control of insect and weed pests as one of the major means available to establish low-energy, sustainable agriculture in the oceanic Pacific. Amongst other initiatives, its support for, and publication of, 'Biological Control: Pacific Prospects' (1987) and its 'Supplement 1' (1989) by D.F. Waterhouse and K.R. Norris has generated a rapidly growing momentum for biological control in the south and west Pacific. The information provided in these books on the distribution and importance of the major pests of the region and on their promising natural enemies (if known), has had a significant multiplier effect. Amongst other outcomes, it has greatly facilitated the generation of financial support for some 20 current programs, already with several successes and other projects showing promise.

In order to foster safe and sound procedures for this increased activity, ACIAR and the South Pacific Commission have jointly sponsored the publication of 'Guidelines for Biological Control Projects in the Pacific' by D.F. Waterhouse (1991b) and these have now been adopted by the South Pacific Commission for a trial period of two years as a provisional code of practice.

As well as the current projects, there are at least a similar number awaiting attention and many additional species that have not yet been dealt with but which might well be suitable targets. However, relevant published and unpublished information in the latter group is not yet readily available to enable a sound assessment. ACIAR has, therefore, supported the preparation of this second supplement by Dr Waterhouse to start to fill this important gap.

Once again, ACIAR is very grateful to the many individuals in the Pacific who have enthusiastically and unanimously endorsed the project and often provided valuable unpublished observations; also to Dr Paul Ferrar, Coordinator of the Crop Sciences program for his unflagging support.

G.H.L. Rothschild
Director
Australian Centre for International
Agricultural Research, Canberra, 1993

1 Introduction

The five pest dossiers in this Supplement follow closely the format established in Biological Control: Pacific Prospects and its Supplement 1. Two of the dossiers, in draft form, (on *Icerya aegyptiaca* and *Clerodendrum chinense*) have already led to the initiation of projects in the Pacific and a third (on fruitflies) is basic to one that has recently been selected by the South Pacific Commission - German Agency for Technical Cooperation Biological Control Project based in Suva. The fourth dossier outlines encouraging prospects for the biological control of pigweed (*Portulaca oleracea*) which is of considerable importance not only in the Pacific but also in Southeast Asia. The fifth dossier (on *Neotermes rainbowi*) has been prepared so that, with the dossier on *Icerya aegyptiaca*, some attention is given to major problems, peculiar to low coral atolls. These problems often compete unsuccessfully for scarce resources with those of more populated high islands.

The distribution and importance in the Pacific of these pests is shown in Table 1.1 and that of the main pest fruit flies in Table 2.2, using the conventions adopted previously. The format of Chapter 2 dealing with a group of 18 fruit flies is somewhat modified to make it more appropriate to the interacting complexities involved.

Table 1.1 Distribution and importance of four Pacific pests.

Country	*Icerya aegyptiaca*	*Neotermes rainbowi*	*Clerodendrum chinense*	*Portulaca oleracea*
Cook Is		*+++	P	+
Federated States of Micronesia	*+++			+
Fiji	?		*+++	++
French Polynesia	?		P	*+++
Guam	P			P
Hawaii			P	++
Kiribati	*+++			++
Marshall Is	P			++
New Caledonia				++
Niue			*+++	P
Northern Marianas	P			+
Palau	+			P
Papua New Guinea			P	P
American Samoa			*+++	+
Western Samoa			*+++	+
Solomon Is				++
Tokelau				P
Tonga				+
Tuvalu		*+++		*+++
Vanuatu	?			++
Wallis				P

Plant protection experts in the Pacific have, on three occasions (1985, 1990, 1992), generously provided information on their major arthropod pests and weeds and also ratings for importance, on the following scale:

*	one of the country's top 10 arthropod pests or top 10 weeds
+++	very widespread and very important
++	less widespread, but of great importance
+	important locally
P	present, but unimportant

No attempt has been made to summarise all the literature on each pest, especially in relation to chemical control, for which recommendations often rapidly become outdated; and, in any case, pesticide use is less relevant in the Pacific than to many other countries. On the other hand, published (and, where available, unpublished) information on natural enemies has been covered in some detail, including biological and ecological information relevant to successful biological control.

The predecessors of this publication have, apart from the inclusion of Guam, been heavily biased towards the south west Pacific. In this Supplement the coverage has been extended to all of Micronesia. The treatment remains focussed on the relevance of the information to traditional agriculturists in the Pacific, although the dossiers contain much information relevant to the same pests elsewhere.

It would not have been possible to assemble as much information without the unstinting assistance of many colleagues throughout the Pacific (and elsewhere) who have given generously of their time and knowledge and often provided unpublished observations.

Over 400 insect species are referred to in the chapters, and the author, order and family of each is provided in the index of scientific names of insects. There have been many changes in the names used in the literature quoted in the chapters. These changes have been incorporated as far as possible although, in some instances, there is no consensus among modern taxonomists on what the correct terminology should be. Most frequently, the terminology of the CAB Institute of Entomology has been adopted. Where confusion may occur, the superseded name, preceded by an equals sign is enclosed in brackets. This is not intended to imply that the bracketed name is necessarily a formal synonym, since the change may have been made for other reasons.

In the maps at the head of chapters 2 to 6 the lines do not imply that all islands or land masses encircled are necessarily infested, as the lines generally follow political boundaries. As additional information becomes available, or the situation changes, there will certainly be a need to adjust the extent of some of the areas included.

The precis at the front of each chapter is not intended to serve as a summary of the information it contains, but rather as a rapid aide-memoire to some of the key matters relating to prospects for biological control.

For ready reference the 55 dossiers that have already been published in Biological Control: Pacific Prospects and its Supplement 1 (on 36 insect pests, 1 mite, 1 mollusc and 17 weeds) are listed on pages 137-138.

It is essential when carrying out biological control introductions that appropriate precautions are taken to ensure that natural enemies to be introduced are adequately specific and that they are not accompanied by any unintended organisms, especially harmful species. Guidelines dealing with these and related matters and provisionally endorsed by the South Pacific Commission are available for the Pacific (Waterhouse 1991b).

I wish to acknowledge the facilities generously provided by the Division of Entomology, CSIRO and the valuable assistance of many of its staff, in particular of Dr D.P.A. Sands (Brisbane). Special thanks are also due to M. Carver, P. Cranston, E.D. Edwards, B. Fletcher, C. Hunt, M. Lenz, K.R. Norris (Canberra) and M. Julien (Brisbane) all of CSIRO, together with P. Ferrar (ACIAR), P. Gullan (ANU), M.A. Bateman (Sydney), R.A.I. Drew, R. McFadyen and J.T. Swarbrick (Brisbane), J. Beardsley, C.J. Davis, W.C. Mitchell and M.A. Whistler (Hawaii), A. Allwood (Suva) R.A. Wharton (Texas), A.C. Pont (UK) and I.M. White (CABI, London).

With unfailing good humour and dedication, Ms A. Ankers (Canberra) converted manuscripts, apparently effortlessly (!), into camera-ready copy.

Figure 2.1 Distribution of pest fruit flies in the Pacific

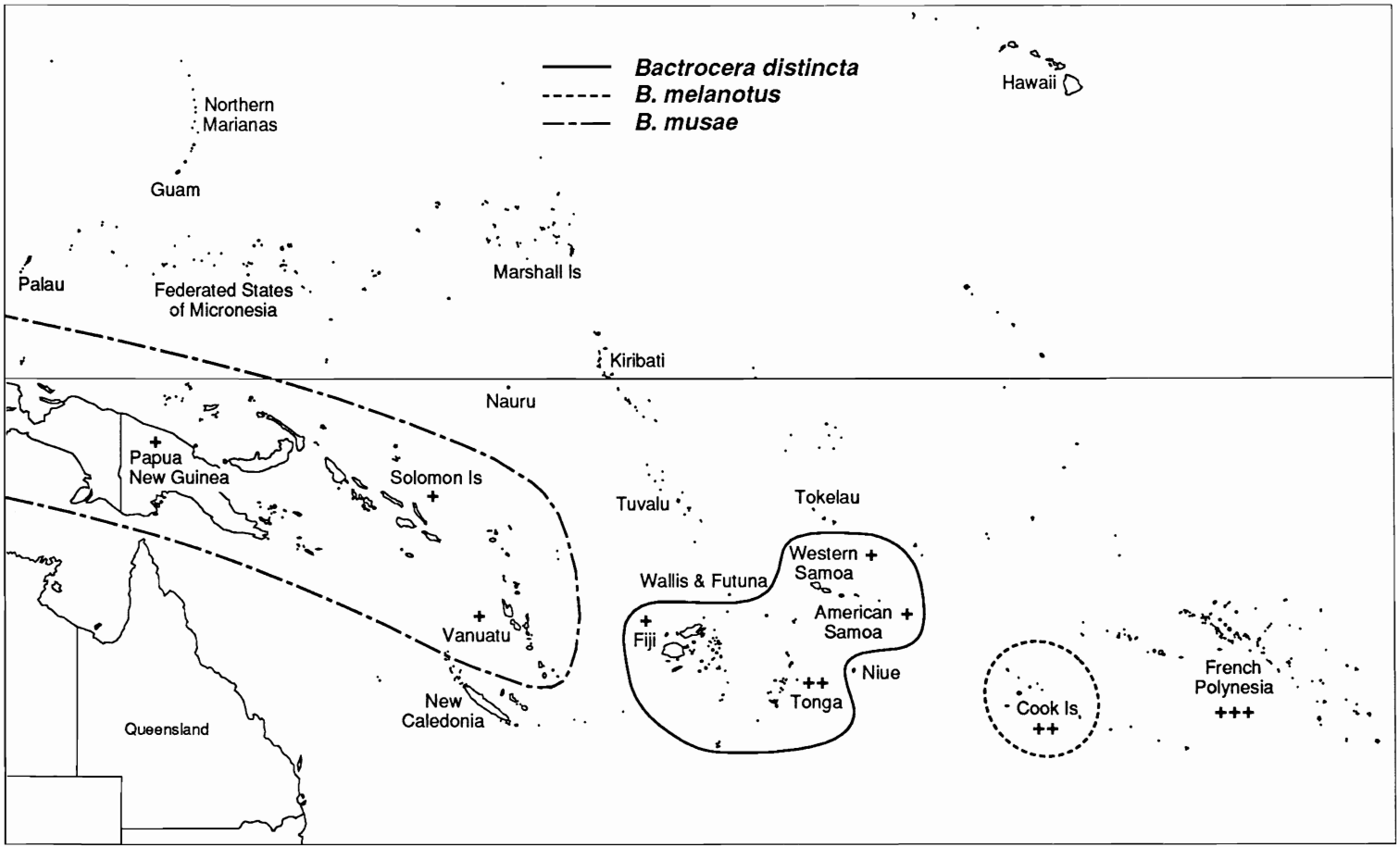

Figure 2.2 Distribution of pest fruit flies in the Pacific

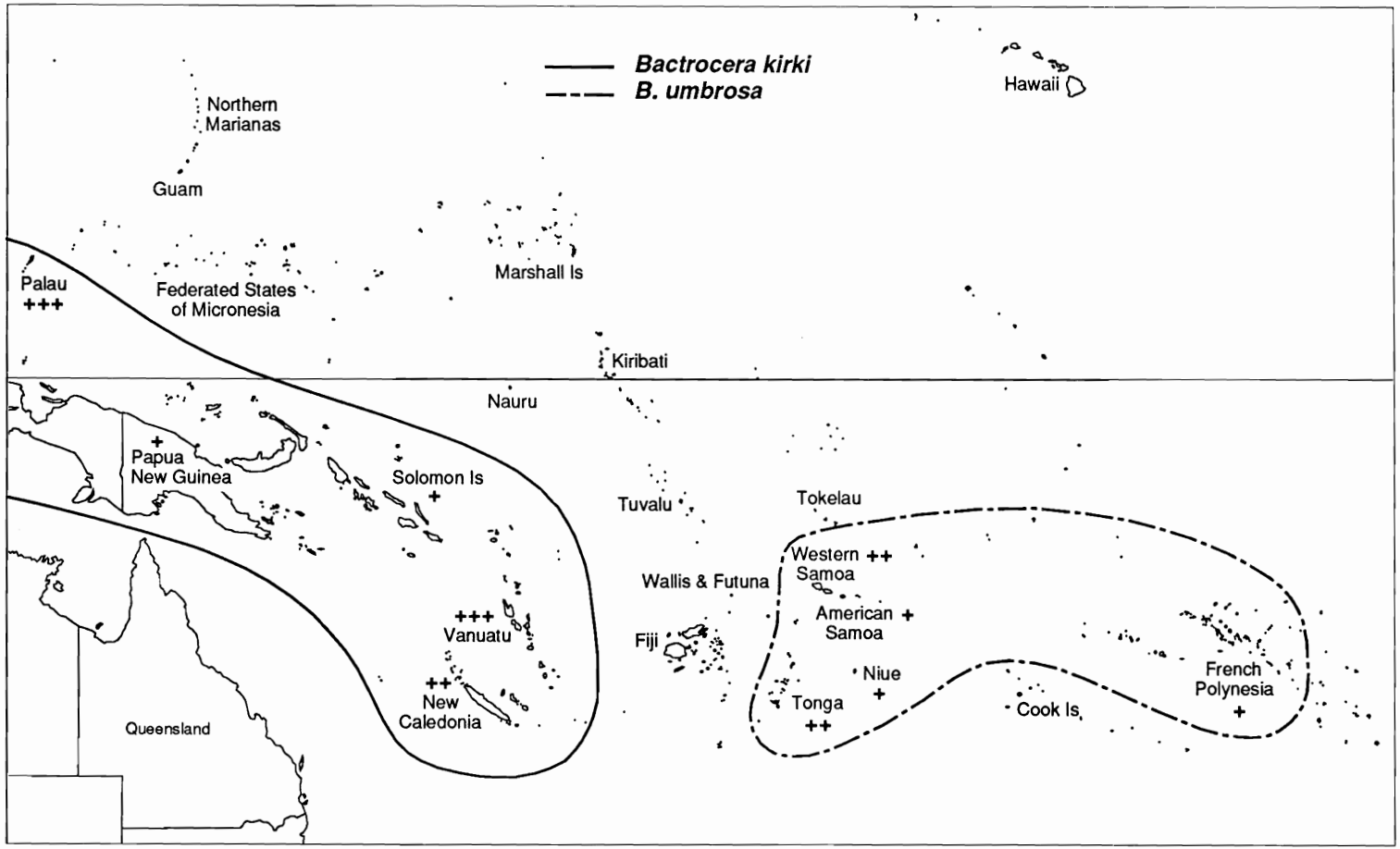

Figure 2.3 Distribution of pest fruit flies in the Pacific

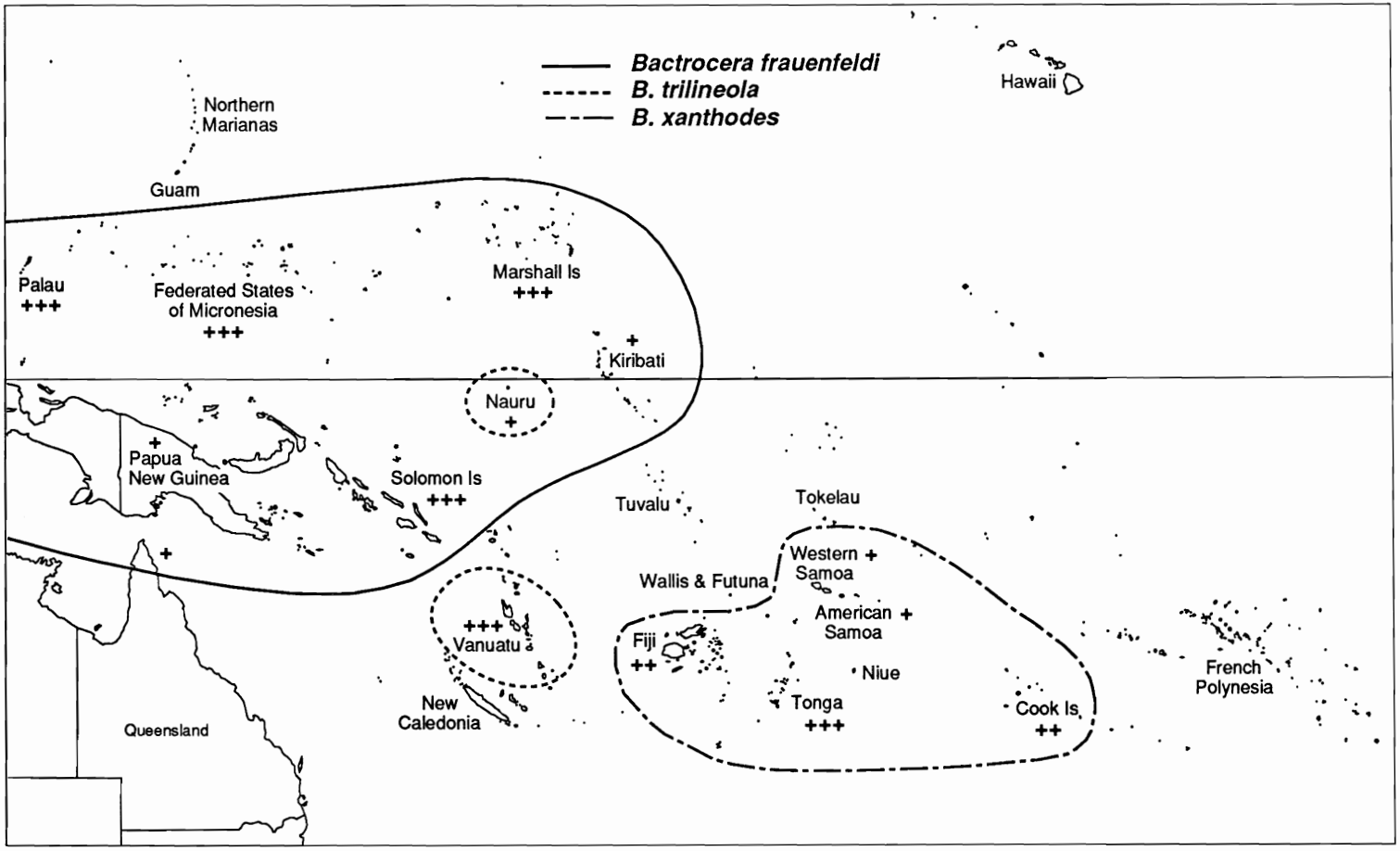

Figure 2.4 Distribution of pest fruit flies in the Pacific

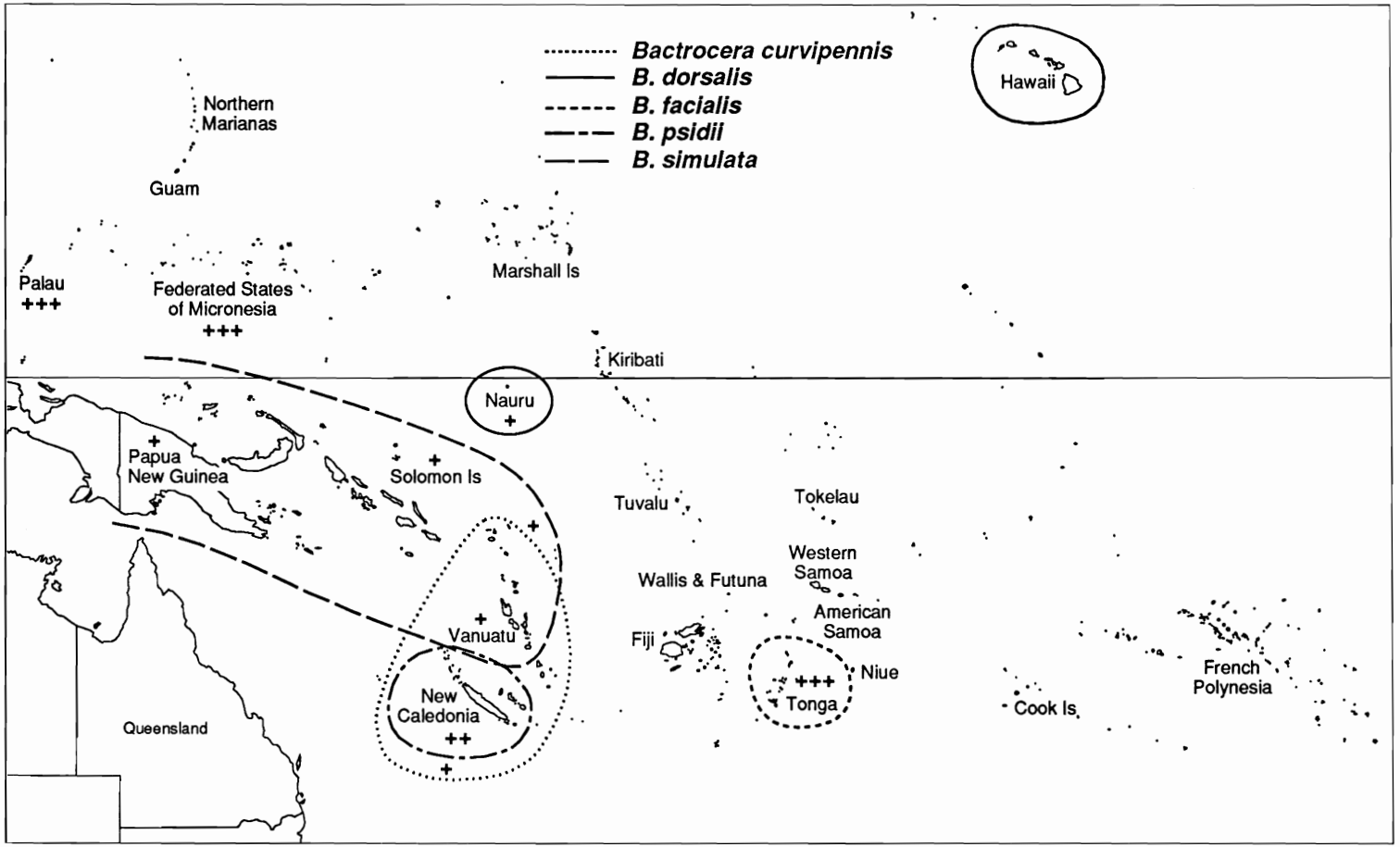

Figure 2.5 Distribution of pest fruit flies in the Pacific

2 Pest fruit flies in the oceanic Pacific

Precis

Tropical fruit flies have not, in general, proved to be good targets for biological control, a situation that is all the more unfortunate since more than a dozen damaging or potentially damaging native species occur in the oceanic Pacific. Nevertheless, biological control programs can result in significant reductions in fly populations.

The only really outstanding success has been achieved in Hawaii against two introduced species, the oriental fruit fly *Bactrocera dorsalis* of Indo-Malaysian origin and the Mediterranean fruit fly *Ceratitis capitata.* Populations have been reduced by up to 95% and several cultivated fruits, previously very heavily infested, have become practically free from attack. This result is due mainly to the establishment of the wasp *Fopius arisanus*, sometimes with an added effect from *Fopius vandenboschi* and to a lesser extent by *Diachasmimorpha longicaudata.* In more recent times, *Psyttalia incisi* has also contributed to fly mortality. On the other hand, after initial very promising results, only limited success has been achieved in Hawaii against the introduced melon fly *Bactrocera cucurbitae* of Indo-Malaysian origin. This fly is not susceptible to the four parasitoids mentioned above. However, it is attacked by *Psyttalia fletcheri*, although chiefly in wild hosts and only to a limited extent in commercial crops.

In Fiji, *Fopius arisanus* and to some extent *Diachasmimorpha longicaudata*, have provided moderate, but still inadequate, control of the two major native pest fruit flies, *Bactrocera passiflorae* and *Bactrocera xanthodes.* However, there are a number of unexplored possibilities.

In Australia, where the major pest species is the native Queensland fruit fly *Bactrocera tryoni*, only *Fopius arisanus* has become established, but with negligible effect.

Clearly some host fruit flies are far more susceptible than others to the particular parasitoids that happen to be available. In addition, the parasitoids often interact with each other when present in the same fruit fly larva. Thus *Fopius arisanus* can prevent the development of *Fopius vandenboschi* and *Diachasmimorpha longicaudata* in the oriental fruit fly larva housing them; and none of the three species can develop in melon fly larvae. Detailed studies of the biology, behaviour and host-parasitoid relationships are thus clearly essential if maximum success is to be achieved from attempts to establish exotic parasitoids against native fruit flies in the oceanic Pacific, since possible mismatches would diminish the chances of establishment.

All southwest Pacific nations and Australia are seriously threatened by the relatively recent intrusion into the region of the melon fly *Bactrocera cucurbitae*, first into Papua New Guinea and then into Solomon Is, Nauru and Christmas Is (Kiribati), although it appears to have been eradicated recently from Christmas Is. Its presence is menacing, since immature adults are known to disperse widely and even up to at least 265 km over water. No fruit fly attack has yet been recorded in many susceptible cucurbit hosts that occur in the threatened areas. In order to reduce the rate of spread by lowering melon fly populations in the known infested areas, it is imperative that at least *Psyttalia fletcheri*, the most effective parasitoid so far known, be introduced to Solomon Is and Papua New

Guinea. Efficient artificial dispersal of this parasitoid to keep up with that of the melon fly will also contribute to minimising damage in invaded areas. Other natural enemies (such as *Fopius skinneri* and appropriate strains of *Diachasmimorpha dacusii*) should also be considered. However, as a priority, parasitoids attacking melon flies infesting cultivated cucurbits should be investigated in the geographical centre of origin of this fly in the Indo-Malaysian region. The eradication of melon fly from Nauru should also be seriously considered.

1. Introduction

Flies of the family Tephritidae rank highly as major pests of many fruits and vegetables in much of the tropical and subtropical world, including the oceanic Pacific. Although home growers often use sound parts of infested fruit and vegetables after trimming, infested produce is usually unacceptable for home marketing, and it is rigorously banned by most importing countries. Losses may thus be due not to only crop damage and the cost of control measures but also to the restriction or loss of export markets. For many years most major importing countries have demanded that produce be free from viable eggs and living fruit fly larvae and this was formerly achieved by fumigation with methyl bromide or ethylene dibromide. However, these treatments are now viewed as unacceptable because of possible health risks from bromide residues in the treated produce. Other methods, mostly involving heat or cold, have been adopted or are under investigation, although difficulties are being experienced in achieving disinfestation without damage to some commodities.

Much effort has been invested in examining the possibility of eradication, using mass liberations of sterile males, poisoned protein baits for both males and females, poisoned lures for males and relatively persistent contact insecticides (some with systemic effects) applied to the surface of the produce requiring protection. Concern for risks to non-target species has led to the testing in Hawaii of continuing mass releases of parasitoids. This latter approach is intended for population suppression and not eradication and would be far too costly for most Pacific island nations to consider for routine control purposes.

Eradication has been achieved of several species over limited areas, but there have been many failures, the costs have generally been very high and the successes have, of course, involved the continuing need to protect the cleared area against re-infestation. When properly applied, various insecticidal measures are effective in protecting much or all of the crop, but they are expensive and some may involve application and residue problems. Poisoned protein baits are probably the most useful means of control available. Bagging is a non-insecticidal method that is effective, but very laborious and applicable only to easily accessible crops.

To add to exporting difficulties New Zealand, a fruit fly free country which is an important market for Pacific island nations, has stiffened its import restrictions to the point of requiring that produce should not contain even dead fruit fly eggs or larvae above a specified very low level (Baker et al. 1990). In practice, this means that produce for export must be uninfested when exposed by an exporting country to an effective commodity treatment. This requirement adds a strong incentive for countries to maintain populations of pest fruit flies at as low a level as possible. It is thus timely to consider whether biological control might play an important role in achieving this objective. At best, biological control will only lead to a substantial lowering of the population of a fruit fly species and not to its eradication. However, it is known that a substantial lowering of the fly population may lead to less-preferred hosts completely escaping attack (Clausen et al. 1965) and to a lower level of attack even on preferred hosts. Both effects should decrease the chances that dead eggs or larvae would occur in export produce. However, even if there are no other benefits, the traditional farmer would at least benefit, since less of his crop would require trimming or discarding.

This argument assumes that both the population density of the pest species and the number of hosts infested would be reduced. The lowering of infestation would, of course, have to be 'worthwhile' for biological control to be considered a success. Biological control programs are reported to have had effects on the populations of individual species ranging from major to very minor. Many natural enemies collected and imported into new countries have never been released. Some that have been released were never recovered from the field and others were recovered over a brief period but did not become established. The current level of effectiveness of most of the few parasitoids that are firmly established is, unfortunately, not known at all accurately. The time is ripe for a re-examination of the entire scenario.

2. Fruit flies in the oceanic Pacific

Information on natural enemies is now presented below that may be relevant to the biological control of fruit flies occurring in the oceanic Pacific, on previous attempts at biological control of relevant species and on the outcome of these attempts.

Throughout the world some 4,000 fruit fly species have been described in the family Tephritidae. The larvae of most develop in the fruiting bodies of plants, including those of many agriculturally important fruits and vegetables. About 150 species (including some 20 of major importance) are known to attack fruits that are either grown commercially or harvested from the wild (White and Elson-Harris 1992). The area of origin of introduced pest species (or of the nearest overseas relatives of native pest species in the Pacific) provides a valuable indication of the regions of the world where biological control agents might be sought.

Three pest genera occur in the oceanic Pacific (Drew 1989):

(a) *Bactrocera* (formerly included in the genus *Dacus*), most species of which are native to tropical Asia, Papua New Guinea, Australia and the south Pacific. A small number occur in Africa and warmer areas of Europe. The native hosts of most are tropical forest fruits, although a few, including members of the subgenus *Zeugodacus*, are almost exclusively associated with the fruits and flowers of Cucurbitaceae.

(b) *Dacus*, most species of which are native to Africa and breed in the flowers and fruits of Cucurbitaceae or in the pods of Asclepiadaceae. A single species (*D. solomonensis*, known only from Solomon Is and Bougainville Is) is of importance in the oceanic Pacific.

(c) *Ceratitis*, most species of which are native to tropical Africa, where they attack a wide range of fruits. Only one species (the Mediterranean fruit fly, *C. capitata*) which is present in the Hawaiian Is is established in the oceanic Pacific. Although Hawaii is outside the region of special concern to this account, the Mediterranean fruit fly poses a significant quarantine threat to other islands of the Pacific.

Drew (1989) has reviewed the 290 species of the genera *Bactrocera* (with 21 subgenera) and *Dacus* (with 4 subgenera) that occur in the region east of the Sulawesi and south of the equator, extending eastwards to the Society Is in French Polynesia. Representatives of these genera are absent from Easter Is, New Zealand and Norfolk Is, but present in most other places where there is a continuous supply of suitable hosts.

About a quarter of the 290 species occur in Australia and slightly over half in mainland Papua New Guinea and its major islands lying to the east (New Britain, New Ireland, Bougainville). About one fifth (57 species) occur in the southern Pacific (table 2.1). Where species are members of a closely related complex within a subgenus this is noted as it may be a relevant indicator when searching for useful parasitoids. Thirty four of these 56 species occur only in the southern Pacific with 29 of the 56 in Solomon Is, 10 each in Vanuatu and New Caledonia, 6 in Western Samoa and Tonga, 4 in American Samoa and Nauru, 3 in Fiji, French Polynesia and Niue and 2 in Cook Is.

Table 2.1 Fruit flies recorded in the oceanic south Pacific (mostly after Drew 1989).

Species	Location
Bactrocera (Afrodacus) aenigmatica	W. Samoa
B. (A.) minuta	Vanuatu
anthracina complex	
B. (Bactrocera) aterrima	Bougainville Is, Solomon Is
bryoniae complex	
B. (B.) epicharis	Solomon Is
B. (B.) quadrisetosa	Vanuatu
B. (B.) simulata	Bougainville Is, Solomon Is Vanuatu
B. (B.) varipes	Solomon Is
distincta complex	
B. (B.) anomala	Vanuatu
B. (B.) decumana	Bougainville Is, Solomon Is
B. (B.) distincta	Fiji, Tonga, A. Samoa, W. Samoa
B. (B.) unifasciata	Solomon Is
dorsalis complex	
B. (B.) dorsalis	Nauru
frauenfeldi complex	
B. (B.) caledoniensis	New Caledonia
B. (B.) frauenfeldi	Australia, PNG, Solomon Is, Kiribati, Kosrae, Nauru
B. (B.) trilineola	Vanuatu
musae complex	
B. (B.) musae	Australia, PNG, Bismarck Archipelago, Solomon Is
recurrens complex	
B. (B.) redunca	Bougainville Is, Torres St Solomon Is, Vanuatu
silvicola complex	
B. (B.) turneri	Torres St, PNG, Solomon Is
tryoni complex	
B. (B.) tryoni	Australia, Lord Howe Is, New Caledonia French Polynesia
Species not placed in complexes	
B. (B.) aithogaster	Solomon Is
B. (B.) atra	Austral Is
B. (B.) biarcuata	PNG, Bougainville Is, Solomon Is
B. (B.) curvipennis	New Caledonia, Vanuatu
B. (B.) ebena	New Caledonia
B. (B.) enochra	Bougainville Is, Solomon Is
B. (B.) facialis	Tonga
B. (B.) froggatti	Bougainville, Solomon Is
B. (B.) furvescens	PNG, Solomon Is
B. (B.) honiarae	Solomon Is
B. (B.) kirki	Tonga, A. Samoa, W. Samoa, Niue, Tahiti, Austral Is.
B. (B.) longicornis	New Ireland, Bougainville Is, Solomon Is
B. (B.) luteola	Society Is, Tuamotu Is
B. (B.) melanogaster	Bougainville Is, Solomon Is
B. (B.) melanotus	Cook Is
B. (B.) morula	Solomon Is
B. (B.) mucronis	New Caledonia

(continued on next page)

Species	Location
B. (B.) neonigrita	New Britain, New Ireland, Bougainville Is, Solomon Is
B. (B.) obscura	American Samoa, W. Samoa, Tonga, Niue
B. (B.) passiflorae	Fiji, Niue, Tonga (northern islands only), Tuvalu
B. (B.) penefurva	PNG, Solomon Is
B. (B.) pepisalae	Bougainville Is, Solomon Is
B. (B.) perfusca	Marquesas
B. (B.) picea	Bougainville Is, Solomon Is
B. (B.) psidii	New Caledonia
B. (B.) samoae	W. Samoa
B. (B.) setinervis	Henderson Is (Pitcairn Is)
B. (B.) umbrosa	SE Asia, Indonesia, PNG + Is Solomon Is, Vanuatu, New Caledonia
B. (B.) unipunctata	Solomon Is
B. (Notodacus) xanthodes	Fiji, Niue, A. Samoa, W. Samoa, Tonga, Cook Is, Nauru (?Vanuatu)
B. (Polistomimetes) pagdeni	Solomon Is
B. (Sinodacus) aneuvittata	New Caledonia
B. (S.) perpusilla	New Caledonia
B. (S.) strigifinis	Australia, PNG, Moluccas, Torres St., Solomon Is
B. (Zeugodacus) cucurbitae	SE Asia, PNG, Solomon Is, Nauru
B. (Z.) fulvifacies	New Caledonia
B. (Z.) gracilis	Vanuatu
Dacus (Callantra) solomonensis	Bougainville Is, Solomon Is

Most (39) of the 57 species listed in Table 2.1 have not been recorded from agriculturally important fruit or vegetables, although further sampling will doubtless add to the number of species occasionally attacking commercial hosts. Indeed the hosts of most species are unknown and are presumably endemic fruits. Studies that are currently in progress under Food and Agriculture Organisation/United Nations Development Programme/Australian International Development Assistance Bureau/South Pacific Commission and Australian Centre for International Agricultural Research projects will undoubtedly provide much valuable information on species present and on their abundance and economic significance. Many species are still restricted to the single island group where they are endemic, although a few of the economically important species appear to have extended their range in comparatively recent times.

The distribution and importance of the 18 species of actual or potential economic significance is shown in Table 2.2 and illustrated in Figures 2.1 to 2.5 (pages 4 to 8). The recent trapping of *Bactrocera dorsalis* on Nauru (B.S. Fletcher pers. comm. 1992) is worrying since, if it indeed proves to be capable of infesting commercial fruit, it would be the first extension of this major pest species into the south Pacific. The question mark in Table 2.2 against *Bactrocera xanthodes* in Vanuatu indicates specimens recorded as having been bred from *Barringtonia edulis*. This fruit is indeed host to an undescribed tephritid (not a dacine) which has also been reared from citrus, but there is no other record of *B. xanthodes*. Furthermore, constant trapping has never attracted *B. xanthodes* which responds to methyl eugenol lures (R. Weller pers. comm. 1990). The ratings for importance have been assigned by relevant authorities for each country. In some cases, the damage currently caused in a country is not major, although it would probably become so if availability of hosts were increased by additional plantings. The major concern at present relates to the cost and effectiveness of measures that have to be taken to meet export standards of freedom from fruit fly infestation.

Table 2.2 Economically important fruit flies in the oceanic Pacific.

+++ serious economic pest
++ economic pest
+ minor pest

	Cook Is	Fiji	French Polynesia	Kiribati	New Caledonia	Nauru	Niue	Papua New Guinea	American Samoa	Western Samoa	Solomon Is	Tonga	Tuvalu	Vanuatu	Australia	Lord Howe Is	Guam	Northern Marianas	Federated States of Micronesia	Marshall Is	Palau
Bactrocera cucurbitae						+		+++			+++						+++	+			
B. curvipennis					+									+							
B. distincta		+							+	+		++									
B. dorsalis						+															
B. facialis												+++									
B. frauenfeldi				+		+		+			+++				+			?	+++	+++	+++
B. froggatti								+			+										
B. kirki			+				+		+	++		++									
B. melanotus	++																				
B. musae								+			+				+						
B. passiflorae		+++					+					++	+								
B. psidii					++																
B. simulata								+			+			+							
B. trilineola														+++							
B. tryoni			+++		+++										+++	++					
B. umbrosa					++			+			+			+++							+++
B. xanthodes	++	++				+	+		+	+		+++		?							
Dacus solomonensis								+			+										

3. Biology of pest species

(a) General features

As far as known the life cycles of the Pacific species are quite similar. The females insert their eggs directly into the host fruit or vegetable. There are three larval instars and a prepupal stage, followed by pupation within the host (rarely) or near the surface of the ground beneath a host plant (commonly). Adults require a regular supply of water and carbohydrate to survive and protein to attain sexual maturity and develop eggs. Bacteria on the surface of the plant are an important source of nutrients (Drew and Lloyd 1989). Mating is necessary for the production of viable eggs.

As soon as the cuticle of the newly emerged adult has fully hardened and darkened, many species enter a dispersive phase, which may last a week before the completion of reproductive maturity. The presence of hosts during this period appears to have little influence on their movement, so that most adults leave the site where they emerged and disperse throughout the surrounding area, even if this involves flight through country without suitable hosts or even over open water. When these highly mobile adult flies approach maturity they start to seek appropriate ripening fruits or vegetables in which to oviposit. When they find a suitable host tree with fruit their behaviour changes. They remain on or near it and mate, typically at dusk, but at other times in some species. When host fruit disappear, or become unsuitable for oviposition, females again disperse in search of new hosts.

The important pest species pass through one generation after another throughout the year, as long as hosts are available and the temperature does not fall too low. In the latter event, the adults seek out sheltered refuges where they remain relatively inactive until temperatures rise again. Meanwhile they may search for food nearby if temperatures rise briefly above their activity threshold. There does not appear to be a true diapause.

The major pest species are polyphagous, infesting many hosts. However some pest species are oligophagous, having a more restricted host range, with the majority of hosts belonging to a single plant family.

Adults of the polyphagous pest species may live for many months and produce up to 500 or more eggs. The number of eggs laid per fruit seems to be influenced by the size of the host fruit. Species that, in their native state, utilise small fruits deposit one egg per fruit and then mark it with a pheromone to deter further oviposition. Species that infest larger fruits, or a variety of fruit sizes, lay larger numbers of eggs and some have a capacity for adjusting egg numbers according to fruit size. There is no evidence of a marking pheromone in the major pest species attacking larger fruits, and multiple ovipositions by different females may occur in the same fruit and often into the same oviposition puncture. Once larvae start to feed, a so-far-unidentified change occurs in the fruit which generally causes females to avoid it.

There are considerable differences between species in the speed of both egg and larval development, relative to the duration of the entire life cycle. In order to highlight the differences Carey (1989) and Carey et al. (1985) divide the life cycle into pre-adult (egg, larva and pupa) and adult stages. When conditions are favourable, for every melon fly *Bactrocera cucurbitae* adult there are 6 pre-adult stages, whereas for every oriental fruit fly *B. dorsalis* or Mediterranean fruit fly *Ceratitis capitata* adult there are 32 pre-adults. Only 43% (% eggs + % larvae) of *B. cucurbitae* populations are inside a host at any one time, but from 70 to 86% of the populations of the other species. A major reason for the low percentage of *B. cucurbitae* population in the egg and larval stages is the rapid development time from egg to pupation (5 days in zucchini) relative to the duration of its entire life (220 days) (Carey 1989). However the influence of factors such as these on the impact of parasitoids on fruit fly abundance is not yet clear. In addition, the figures apply only to the special case of populations with stable age distributions, that is to say rapidly expanding populations that are increasing at their innate capacity for increase, unlimited by shortage of resources and without immigration or emigration. It is entirely possible that, on occasion, young, rapidly expanding populations of *B. cucurbitae* will have higher proportions of pre-adults than aged and declining populations of *B. dorsalis* or *C. capitata.*

The males of many species are strongly attracted to specific chemical compounds known as male lures. Three such lures are relevant in our area of special concern: methyl eugenol which occurs naturally in the essential oils of a number of plants and two synthetics, cue lure (4- (p-acetoxyphenyl) butan-2-one) and Willison's lure, its hydroxy derivative (4-(p-hydroxyphenyl) butan-2-one). Male lures can be used to monitor presence or absence of males of reacting species and to provide an indication of levels of abundance. When incorporated in traps or in poisoned baits, they are powerful means of area control of some species. Females are seldom attracted unless the population of males has been reduced to a very low level.

(b) Features of the pest species

Some of the relevant features of the pest species listed in Table 2.2 are dealt with below, briefly except for those of the melon fly, which is currently attracting special attention because of its potential to spread to new countries. Records of the main commercial hosts that are attacked are taken mainly from Bateman (1988), Drew (1989) and White and Elson-Harris (1992). Additional records of many non-commercial hosts are given in Drew (1989) and from outside the Pacific by White and Elson-Harris (1992). The host lists will undoubtedly be considerably expanded and old records critically assessed by the current SPC/FAO/UNDP/ACIAR fruit fly projects. Little is known about the biology of the less important species, but knowledge of this aspect is also certain to expand greatly as a result of the foregoing projects.

Bactrocera cucurbitae (Fig. 2.1)

Males respond to cue lure

The melon fly is very widely distributed. In Asia it occurs in Iran (first recorded 1989), Pakistan, India, Sri Lanka, Nepal, Bangladesh, Myanmar, Thailand, Vietnam, Cambodia, Laos, Malaysia, Singapore, Brunei, Indonesia, Philippines, south China and Taiwan. It is native to the central portion of this region but little is known of its wild hosts there. It was first reported in Japan in 1919 (Shiga 1989) but, using sterile males, it was eradicated from Kume Is in 1979, Miyako in 1987 (Iwahashi 1977, Shiga 1989), Daito in 1989 and Okinawa in 1990 (Kawasaki 1991). It now occurs only in the Yaeyama Is, where sterile insect releases commenced in 1990 and are hoped to result in eradication by 1993. In the western Pacific it occurs in Irian Jaya, mainland Papua New Guinea, New Britain, New Ireland, Lihir Is, Bougainville Is, western Solomon Is, Nauru (1982) and, was present for a period in the mid eighties in Kiritimati Is (Kiribati). It was discovered in 1984 in the Shortland Is group of Solomon Is. Eradication was attempted (Eta 1986) but this was unsuccessful and it is now known also from Choiseul and Kolombangara. In 1988 it was found in Santa Isabel Is and, in 1991, throughout Western and Isabel Provinces, which represent about 45% of the total land area of Solomon Is. No melon fly has yet been detected in other Provinces (C. Eta pers. comm. 1992). Melon fly is present in Hawaii and occurred as a serious pest in Guam and some of the other Mariana Is (Rota, Tinian, Saipan) until eradicated from Rota, Tinian and Saipan using sterile males (Mitchell 1980). However it has reappeared as a serious pest in these islands following reintroduction from Guam during a typhoon. It occurs in the Indian Ocean in Mauritius and Réunion and in Africa in Egypt, Kenya and Tanzania. In North America it has been trapped in California, but successfully eradicated (Spaugy 1988).

The melon fly is one of the world's most active and serious fruit fly pests and the most important fruit fly pest of vegetables, especially of cucurbit crops. It has been recorded from more than 125 hosts, including members of a number of plant families other than the Cucurbitaceae. In Solomon Is it attacks cucumber, pumpkin, snake gourd and watermelon (Bateman 1988). In Hawaii it is a serious pest of watermelon, cantaloupe, pumpkin, squash, cucumber, tomato, capsicum, beans and passion fruit

(Harris and Lee 1989). At times it attacks cucurbit flowers and leaf stalks and stems of young plants (Clausen 1978b, Kapoor 1989). However, the varieties of avocado and banana grown in Hawaii are not attacked up to harvesting stage and pineapple has been shown to be an unsuitable host (Armstrong 1983, Armstrong et al. 1979, 1983, Armstrong and Vargas 1982).

Because it is attacked by more parasitoid species in India than elsewhere, Nishida (1963) postulated that to be the centre of origin of the melon fly. Moreover its general level of abundance was lower than in Hawaii. He expressed surprise to find that watermelon, cantaloupe and gourds could be grown at times without control measures, damage mostly occurring in localised areas. Lawrence (1950) also reported that its abundance was so low, particularly in the cool season, that the melon fly was not as serious a pest in India as in many other countries. In Pakistan less than half of cucurbits are generally infested (Syed 1971). Nevertheless Kapoor (1989) reports from India that it infests more than half of all vegetables and is active except for a short period during the coldest months. Its population expands when rainfall is adequate and contracts during dry periods (Nishida 1963). In Luzon (Philippines) melon fly damage ranges from 5 to 40% in cucurbits, tomato and eggplant (Iral et al. 1987).

After a preoviposition period of some 11 or 12 days, mating takes place at dusk. During oviposition the female punctures the plant tissue and inserts 1 to 40 relatively large eggs. Females do not use a marking pheromone, so repeated ovipositions may occur in the same host and even in the same oviposition puncture. Hatching time is short (a little over 24 hours) and larval and pupal stages cover 4 to 17 days and 7 to 13 days respectively. The length of larval life depends upon the temperature and on the host in which development occurs (Carey et al. 1985), being longer in thick-skinned hosts, such as pumpkin. Adults may be long-lived, normally up to 150 days, but under cool conditions 240 to 460 days. A female may lay more than 1000 eggs (Carey 1989, Carey et al. 1985, Clausen 1978b, Nishida and Bess 1957, Severin et al. 1914, Vargas et al. 1984). Larvae have been observed to leave one fruit and enter another close by (Bateman 1972).

Nishida and Bess (1957) observed that, shortly after emergence, adults left the areas where they were produced and were capable of very long dispersal flights. Steiner et al. (1962) recorded up to 65 km in the Marianas and Kawai et al. (1978) 34 to 56 km in Japan. The longest flight so far detected is about 265 km from Kikaijima Is to Tanegashima Is (Japan) (Kamiwada and Tanaka 1991). This capacity for long flights over water underlines the serious threat of dispersal to additional islands in the Solomons group and also from Papua New Guinea to the Australian mainland, just 150 km distant.

On a local scale, Nishida and Bess (1957) in Hawaii observed that, after dispersal, female melon flies move into cucurbit fields during the day to oviposit, returning to the surrounding vegetation before nightfall. There are peaks of oviposition in the morning and late afternoon.

Many papers on the ecology, behaviour and other aspects of the melon fly are listed in White and Elson-Harris (1992) and Syed (1971) deals with its natural enemies in Pakistan. Techniques for mass rearing are provided by Kakinohana and Yamagishi (1991) and Tokunaga et al. (1991).

Bactrocera curvipennis (Fig. 2.5)
Males respond to cue lure
This species has been bred from mandarins and other citrus in New Caledonia, where it is also recorded from grapes, guava, papaya and peach (Cochereau 1966a, Risbec 1942). It has also been reported earlier from Vanuatu, although it was not reared or trapped there during a survey conducted by the Department of Agriculture in the 1980s (R. Weller pers. comm. 1989). Its parasitoids are dealt with in records for New Caledonia (see section 4(i)).

Bactrocera distincta (Fig. 2.4)
Males respond to cue and Willison's lures
This species is abundant and widespread in Fiji, American and Western Samoa and Tonga, but the only commercial host from which it has been reared is sapodilla.

Bactrocera facialis (Fig. 2.5)
Males respond to cue lure
This potentially serious pest is known only from throughout the Tongan group of islands where it infests a range of fruits and vegetables including capsicum, citrus, guava, mango and especially tomato.

Bactrocera frauenfeldi (Fig. 2.2)
Males respond to cue and Willison's lures
This is a member of a complex of four species (*B. caledoniensis*, *B. frauenfeldi*, *B. parafrauenfeldi*, *B. trilineola*) which occur in parts of the region extending from northern Australia to New Caledonia. It was established in north Queensland in 1972. It occurs in large populations from Cape York (Queensland) to Papua New Guinea, including 15 of the Torres Strait islands. It is also known from the Bismarck Archipelago, Bougainville Is, Solomon Is, Stuart Is, Nauru and Kiribati (Drew 1989, G.S. Sandhu pers. comm. 1990). It also occurs in Micronesia, in the Federated States of Micronesia (Pohnpei, Chuuk, Kosrae, Yap), Marshall Is and Palau, but not in Guam. Although it is sometimes known as the mango fly it will also attack breadfruit, banana, citrus, guava, malay apple and papaya. It is common in papaya in Solomon Is where it and *B. cucurbitae* are the two most important species (C.H. Williams pers. comm. 1989). In Tarawa (Kiribati) it infests breadfruit and guava (G.S. Sandhu pers. comm. 1990). This is a very abundant species which is likely to increase further in importance if favoured host plants are planted in greater numbers (Drew 1978).

Bactrocera froggatti
Males respond to methyl eugenol
This apparently minor species is known from Solomon Is (Banika, Guadalcanal, Gizo, Russell, Shortland) and from Bougainville Is. It has been bred from mango.

Bactrocera kirki (Fig. 2.3)
Males respond to cue and Willison's lures
This species is widespread in the Pacific, occurring in French Polynesia (Austral Is and Tahiti) Niue, American and Western Samoa and Tonga. It has been bred from capsicum, citrus, guava, malay apple, mango, passionfruit, peach and starfruit.

Bactrocera melanotus (Fig. 2.4)
Males respond to cue lure
This species has been recorded only from Cook Is (Rarotonga, Aitutaki, Mangaia, Mauke) where it is a serious pest of citrus and also infests avocado, guava, mango and papaya. It is believed to mate in the morning.

Bactrocera musae (Fig. 2.4)
Males respond to methyl eugenol
The banana fruit fly is one of a complex of three species (*B. bancroftii*, *B. musae*, *B. prolixa*) occupying part or all of the region extending from coastal Queensland through the Torres Strait islands to Papua New Guinea, Bismarck Archipelago to the Solomon Is. *B. musae* occupies all of this range. It is a major pest of bananas in northern Queensland, and of cooking and ripe bananas in Papua New Guinea (F. Dori pers. comm. 1992).

The banana fruit fly has several generations a year. Females oviposit in both ripe and green bananas and may even sting young fruit as it appears on the bunch (Drew 1989). It also attacks guava and papaya. Females lay 7 to 12 eggs per fruit and hatching may be delayed for 7 to 10 days if the fruit is not ripe enough (Smith 1977). Fletcher (1989) postulates that the evolution of this mechanism permits females to lay in fruit in different stages of ripeness within a single bunch of bananas that might be discovered, before dispersing in search of other fruiting trees scattered widely within the rainforest.

Bactrocera passiflorae (Fig. 2.1)
Males respond to cue lure
The Fijian fruit fly occurs in Fiji, Niuatoputapu and Niuafo'ou Is of northern Tonga, and Niue, where it is known from citrus, granadilla, guava, mango and passionfruit. There are also unconfirmed records from breadfruit, egg plant and papaya. Parasitoids attacking it are dealt with in the section on Fiji (4(d)) and life cycle details are provided by Simmonds (1936).

Bactrocera psidii (Fig. 2.5)
Males respond to cue and Willison's lures
This species is known only from New Caledonia where it is an important pest. It has been reared from citrus, granadilla, guava and mango. Its parasitoids are dealt with in the section on New Caledonia (4(i)).

Bactrocera simulata (Fig. 2.5)
Males respond to cue and Willison's lures
This species is a minor pest in Papua New Guinea, Solomon Is and Vanuatu. It attacks chillis in Santa Cruz Is in the eastern Solomons (R. Macfarlane pers. comm. 1992).

Bactrocera trilineola (Fig. 2.2)
Males respond to cue and Willison's lures
This species is restricted to Vanuatu (Efate, Malekula, Espiritu Santo) where it is one of the two major species, the other being *B. umbrosa.* It has been reared from avocado, breadfruit, citrus (orange and pomelo), guava, mango and papaya.

Bactrocera tryoni (Fig. 2.1; Plate 1, Fig. 1)
Males respond to cue and Willison's lures
The Queensland fruit fly is native to eastern Australia and now occurs also in Lord Howe Is, New Caledonia, Austral Is (first recorded 1977) and a number of the islands in French Polynesia (eg Tahiti, Bora Bora). It has been recorded from Papua New Guinea, but is not established there and it has been eradicated from Easter Is (Bateman and Arretz 1973). *B. tryoni* is the most destructive pest of fruit and vegetable crops in tropical, sub-tropical and temperate eastern Australia. It infests many vegetables and all commercial fruit crops in eastern Australia except pineapples. It has been recorded from more than 100 hosts in Queensland alone and probably occurs in many more. Many of its hosts are wild plants which are responsible for permitting the development of very large populations particularly in forest areas (Drew 1978). Its life cycle, ecology, economic importance and control are the subject of many publications (e.g. Bateman 1968, 1977, Drew 1989, Fletcher 1987, 1989).

Bactrocera umbrosa (Fig. 2.3)
Males respond to methyl eugenol
This widespread species occurs throughout Southeast Asia where it attacks jackfruit, cempedak and custard apple. In Micronesia it is known from Palau and in the south Pacific from Papua New Guinea, Bismarck Archipelago, Bougainville Is, Solomon Is, Vanuatu and New Caledonia. It occurs in very large populations in lowland areas, particularly in disturbed situations. In the Pacific it has been reared from breadfruit and citrus and it is also known from jackfruit. Yukawa (1984) reports that it is a serious pest of breadfruit and jackfruit in Indonesia and Yunus and Ho (1980) that it breeds in cempedak in Malaysia. It is said to infest *Momordica charantia* in Kalimantan. Balthazar (1966) has recorded the braconid wasp *Phaenocarpa* (*Asobara*) *bactrocerae* from *B. umbrosa* in the Philippines but this wasp is a parasitoid of drosophilid larvae, which must have been present also.

Bactrocera xanthodes (Fig. 2.2)
Males respond to methyl eugenol
This important pest species (or group of species) occurs in Cook Is (Rarotonga, Aitutaki, Mangaia), Fiji, Nauru, Niue, American and Western Samoa, Tonga (except in the extreme north) and Vanuatu. Its host range in Cook Is is similar to that in Tonga, but different from that in Fiji and different again in Vanuatu. This suggests that closer examination may reveal at least three morphologically similar species. It was first recorded on Niue in the 1970s from granadilla and recently collected again after Cyclone Ofa (SPC 1990). Its hosts include breadfruit, jackfruit, mango, papaya and watermelon. It is considered as a potentially very serious pest. A 1986 record of *B. xanthodes* breeding in *Barringtonia edulis* in Vanuatu requires confirmation (specimens are in the DSIR Collection in Auckland) and, if correct, could indicate a recent introduction of economic significance (R. Weller pers. comm. 1989). Some details of its biology are given by Simmonds (1936). Parasitoids have not so far been reared from *B. xanthodes* in the current SPC/FAO/ACIAR fruit fly projects (A. Allwood pers. comm. 1992).

Dacus solomonensis
Males respond to cue lure
This species is known only from Bougainville Is and Solomon Is. It has been bred in the latter from cucumber and pumpkin and occasionally causes severe damage to snake gourd on Guadalcanal (C. Williams pers. comm. 1989).

4. Natural enemies and biological control

Since more has been learnt about natural enemies of fruitflies and their use in biological control from the extensive programs in Hawaii than anywhere else in the world, the experiences there will be dealt with first, followed by other countries in alphabetical order.

(a) HAWAII

Four pest fruit flies have been introduced to Hawaii, the melon fly *Bactrocera cucurbitae* (1895), the Mediterranean fruit fly *Ceratitis capitata* (1910) and the oriental fruit fly *Bactrocera dorsalis* (1946): in 1983 the less important *B. latifrons* was discovered attacking Solanaceae on Oahu.

Many papers have been written on the very large biological control programs conducted against the first three species and many aspects are well summarised by Clausen (1978b) and Clausen et al. (1965). The following is a brief account of the main results. The preferred names for many of the natural enemies differ from those used in the early papers and are shown in table 2.16. These have been adopted following the work of Beardsley (1989), Boucek and Narendran (1981), and particularly Wharton (1987, 1988, 1989a) and Wharton and Gilstrap (1983).

Biological control investigations, aimed at *Ceratitis capitata* in particular, commenced in 1912. These led to the introduction and establishment of the parasitic wasps *Psyttalia concolor* from South Africa, *Dirhinus anthracina* from West Africa and *Diachasmimorpha tryoni* from Australia. In 1914 *Biosteres fullawayi* and *Tetrastichus giffardianus* from West Africa were introduced, but apparently not successfully established.

By 1915 *Psyttalia concolor* had attained a high percentage parasitisation, but this species was replaced from 1916 onwards by *Diachasmimorpha tryoni.* Pemberton and Willard (1918) showed that *Psyttalia concolor* larvae were almost always destroyed by *Diachasmimorpha tryoni* or *Biosteres fullawayi* when they occurred together in the same host. The percentage parasitisation of Mediterranean fruit fly larvae in coffee berries, with their shallow pulp, ranged from 45.9 to 94.4, but was much lower in fruit with a thicker pulp, yearly averages over a 10 year period ranging from 4.0 to 23.1 in guava, 5.7 to 24.8 in mango and 3.5 to 12.8 in orange.

A larval parasitoid *Psyttalia fletcheri*, found attacking *Bactrocera cucurbitae* in India, Sri Lanka, Malaysia and Indonesia, was introduced from India and established in 1915-16 (see later). The discovery of the oriental fruit fly in Hawaii in 1946 immediately led to a massive program of search for, and importation of, parasitoids. This involved 14 field collectors, lasted some five years and embraced all of the major tropical and subtropical regions of the world where fruit flies occur. About 4.3 million puparia of more than 60 species of fruit fly yielded some 30 species of parasitoid, the majority belonging to the genera *Biosteres*, *Diachasmimorpha*, *Fopius* or *Psyttalia*. Insectary rearing in Hawaii provided more than 1.1 million adults for release during 1947-53 and a further 2.3 million during 1954-62 (Clausen et al. 1965). Seven species or varieties became established on the oriental fruit fly, namely *Fopius arisanus*, *F. vandenboschi*, *Diachasmimorpha longicaudata* var. *malaiensis*, var. *novocaledonicus* and var. *taiensis*, *Psyttalia incisi* and *Aceratoneuromyia indica*.

Diachasmimorpha longicaudata var. *malaiensis* became abundant in 1948-49, but was rapidly replaced by *Fopius vandenboschi* which, in turn, was superseded by *Fopius arisanus*. Thereafter, *F. arisanus* dominated the scene, producing about 70% parasitisation of *Bactrocera dorsalis* in guava, the main reservoir of this species (Bess 1953, Bess et al. 1961). The underlying causes for this sequence of events have been convincingly demonstrated by van den Bosch and Haramoto (1953). Eggs of *Diachasmimorpha longicaudata* were inhibited in their development in hosts that contained either *F. arisanus* or *F. vandenboschi*. When these two species were present in the same host, larvae of *F. arisanus* prevented those of *F. vandenboschi* from developing. When more than one larva of any one species was present, all except one larva of *Diachasmimorpha longicaudata* were killed mechanically. In addition to hosts killed by the developing parasitoid larvae, many host eggs (perhaps 50%) were killed as a result of transmission of microorganisms by *Fopius arisanus* at the time of oviposition, usually increasing fruit fly mortality to more than 95%. It is interesting that a fourth species *Psyttalia incisi* is now at least as abundant as *Fopius vandenboschi* (Wong et al. 1984).

Sampling of guava showed substantially lower numbers of *Bactrocera dorsalis* larvae from 1950 onwards and several cultivated fruits (e.g. avocado, banana, papaya, persimmon), previously very heavily infested, became practically free from attack. Even infestation of mango, a favoured host fruit, declined greatly, seldom exceeding 10%. Indeed, an overall 95% reduction in both fly populations and pest damage was claimed for the decade after 1948 (Bess and Haramoto 1958, 1961, Clausen et al. 1965, Haramoto and Bess 1970). A more recent sampling of *B. dorsalis* in guava on Oahu (Chaudhry 1989) indicated 29.6 to 48.8% parasitisation. No *Ceratitis capitata* were produced from these fruits. Assuming a mortality of eggs of about 50% due to microbial infections caused by *Fopius arisanus* probing (Bess et al. 1963), these figures would equate to an overall mortality of 65 to 75%. Clearly there continues to be substantial biological control of the oriental fruit fly.

It is interesting that, under village conditions in Malaysia, mortality of *Bactrocera dorsalis* caused by parasitoids was *Fopius arisanus* 24%, *F. vandenboschi* 8.7%, *Diachasmimorpha longicaudata* 3.3% and other species 0.4%. However 'soil factors' were responsible for most of the mortality of immature stages (Serit and Tan 1990). *Fopius arisanus* proved to be an equally effective parasitoid of the Mediterranean fruit fly which, except where coffee is growing in lowlands, has tended to become restricted to higher elevations following the introduction of the oriental fruit fly.

Without wishing to play down the importance of *F. arisanus*, it should be pointed out that most sampling programs are biased in its favour. This is because, as soon as fruit are collected, the last bit of opportunity is removed for parasitoids of larvae to attack additional hosts.

Attempts at biological control of the melon fly *Bactrocera cucurbitae* are now dealt with in somewhat greater detail, because of serious concern that it will, if unchecked, spread into the southwestern Pacific and Australia.

The melon fly is native to the Indo-Malaysian region and occurs throughout Southeast Asia, southern China and Taiwan. It invaded Hawaii in 1895, Guam in 1936 and, in more recent times, it has spread to Papua New Guinea (1980) and the northwestern part of Solomon Is (1984) where it is now present throughout the Western and Isabel Provinces. It is recorded from Nauru (1982) and also become established briefly in Kiritimati Is (Kiribati), being first recorded in 1987. It attacks more than 80 types of vegetables and fruits, the most important from an economic point of view being various cultivated cucurbits and tomatoes. Favoured non-economic hosts are wild melons of the genus *Momordica*, of which up to 100% may be infested. Where melon fly does not occur in the Pacific, cucurbits are often free, or substantially free, from fruit fly attack. However *Dacus solomonensis*, known only from Solomon Is and Bougainville Is, attacks cucumber, pumpkin and snake gourd and, in Tonga, *Bactrocera xanthodes* occasionally attacks watermelon, particularly if the fruit surface is damaged.

Many of the parasitoids already mentioned in relation to the campaigns against the oriental and Mediterranean fruit flies were tested to determine whether they could develop successfully in the melon fly (Table 2.3, Clausen et al. 1965). It is clear that none of the most effective parasites for the other pest species were able to complete their development in *Bactrocera cucurbitae*. Eggs of *Fopius arisanus* frequently hatched, but the larvae died at an early stage, whereas the eggs of *Diachasmimorpha longicaudata*, *Fopius vandenboschi* and *Psyttalia incisi* were encapsulated by phagocytes and failed to develop (Marucci 1951, Nishida and Haramoto 1953). Contrary to the information in table 2.3, the record of *P. incisi* emerging from *Bactrocera cucurbitae* in India (Kapoor and Agarwal 1983) must indicate either (i) different strains of host or parasitoid (ii) that the parasitoid, in fact, emerged from another host in a mixed group of larvae, or (iii) a parasitoid misidentification, since *P. incisi* and *P. fletcheri* are so similar. Also, in more recent tests, 1.6% parasitisation was obtained of *B. cucurbitae* eggs by *F. arisanus*, although parasite development was unusually slow (Ramadan et al. 1992).

Table 2.3 Ability of fruit fly parasitoids to develop in laboratory colonies of *Bactrocera cucurbitae* in Hawaii (Clausen et al. 1965, Marucci 1951, Nishida and Haramoto 1953).

Successful	Unsuccessful
BRACONIDAE	BRACONIDAE
Diachasmimorpha albobalteatus	*Biosteres fullawayi*
Diachasmimorpha dacusii	*B. giffardii*
*Diachasmimorpha hageni?**	*Diachasmimorpha longicaudata*
Psyttalia fletcheri	*D. l. malaiensis*
	D. l. novocaledonicus
CYNIPIDAE	*Fopius arisanus*
Aganaspis daci	*Fopius vandenboschi*
	Psyttalia incisi
	EULOPHIDAE
	Aceratoneuromyia indica
	Tetrastichus dacicida
	T. giffardianus

* only males produced

As indicated earlier, the braconid wasp *Psyttalia fletcheri*, a widespread parasitoid of melon fly in India, was introduced to Hawaii in 1916. Even in north India, parasitisation of *B. cucurbitae* by *P. fletcheri* did not exceed 3% (Nishida 1963) or 4.5% (Chaturvedi 1947) and in Borneo parasitisation of melon fly did not exceed 1% (Clausen et al. 1965). *P. fletcheri*, however, soon became established throughout Hawaii (Fullaway 1920). As part of the oriental fruit fly project it was introduced again in 1950-51, together with *Diachasmimorpha dacusii* and *D. albobalteatus*. However, neither of these latter two species became established, although both developed in the melon fly in the laboratory (Table 2.3) and both were mass reared and released over many generations (Bess et al. 1961, Clausen 1978b). Clancy (1952) recorded a few recoveries of *D. dacusii* in 1950, the year that more than 114,000 adults had been released. However about 50% of the larvae entered diapause and the species did not survive the winter (Marucci 1952). It is recorded that more *Diachasmimorpha dacusii* (383) than *Psyttalia fletcheri* (17) were reared from the same batch of fly-infested *Luffa* (Cucurbitaceae) from northern India. The actual host of *D. dacusii* is not certain, however, since the *Luffa* produced mixed populations of *Bactrocera cucurbitae*, *B. nubilus* and *Dacus ciliatus*. However the main host was assumed to be *Bactrocera cucurbitae* because of the ready propagation of *D. dacusii* on melon fly in Hawaii and because it had been reared from field collections of melon fly in Sri Lanka. *D. dacusii* was absent from summer (April to July) collections in North India, appearing only later (August to November). Neither it nor *Psyttalia fletcheri* was amongst the 488 parasitoids (*Spalangia* spp., *Dirhinus* spp., *Pachycrepoideus vindemiae*) emerging from 11,636 melon fly puparia collected in south India (Clausen et al. 1965). *Diachasmimorpha albobalteatus*, which also failed to establish, had been obtained only from Sabah. The original shipments received in Hawaii averaged 27.5% females, but breeding in the laboratory, only with some difficulty, produced 12% females, so its natural host may be some other fruit fly associated with melon fly in the mixed lots of puparia received in Hawaii. It oviposited readily in *Bactrocera dorsalis* and *Ceratitis capitata*, but only male progeny emerged from the latter (Clausen et al. 1965). Additional parasitoids emerging from fruit in India from which *B. cucurbitae* was produced included the chalcidids *Dirhinus himalayanus*, *Spalangia afra*, *S. endius*, *S. grotiusi* and *S. stomoxysiae* (Kapoor and Agarwal 1983, Narayanan and Chawla 1962). Syed (1971) did not record *Psyttalia fletcheri* from Pakistan and found only exceedingly low levels of parasitisation of melon fly by *Psyttalia* sp. and *Spalangia* sp..

Within a few years of its establishment in Hawaii *Psyttalia fletcheri* was causing 50% parasitisation of the melon fly in commercial crops and up to 100% in the specially-favoured wild *Momordica* melons. Indeed Fullaway (1920) reported that it was again possible to grow melons successfully, the infestation per fruit having been reduced from 4.0 to 6.5 larvae to 0.3 or fewer larvae per fruit. Under the most favourable circumstances the population of melon fly was reduced to such low levels that it virtually ceased to be a pest.

Unfortunately this happy situation deteriorated over ensuing years. Newell et al. (1952) reported maximum parasitisation of 44.1%, with mean annual figures ranging from 19.8 to 22.7% and infestations of 3.1 to 4.0 larvae per *Momordica* fruit. These infestation levels approached those existing before the introduction of *Psyttalia fletcheri*. Disappointing levels of biological control were also reported for 1951 by Nishida (1955) in cultivated vegetables and fruit. Parasitisation proved to be much lower in cultivated than in wild hosts, namely 0 to 0.1% in tomatoes in 1951, 0.2 to 6.5% in cucumber and 0 to 15.6% in melons whereas, in *Momordica* in adjacent uncultivated areas, it ranged from 20.0 to 37.8%.

The natural enemies causing melon fly mortality in Hawaii in the 1950s are shown in Table 2.4. Its eggs were attacked by *Fopius arisanus* (the major parasitoid of *Bactrocera dorsalis* and *Ceratitis capitata*), but generally only where the habitat of these species overlapped as in papaya groves (Nishida and Haramoto 1953). Although *Fopius arisanus*

cannot develop in the melon fly, it oviposits in melon fly eggs and, in so doing, kills them. In drier situations, as in cucurbit vines, eggs were taken by ants. Melon fly larvae were attacked in the host fruit by four parasitoids (in particular by *Psyttalia fletcheri*), by an earwig and by a staphylinid beetle. Ant attack occurred mainly on fully-fed larvae as they left the fruit to pupate. Pupae in the soil were attacked by three species of parasitoid, by ants and probably by mice. Adults were preyed upon by spiders and a reduviid bug. However, control of melon fly was not considered to be satisfactory.

Table 2.4 Natural enemies killing *Bactrocera cucurbitae* in Hawaii in the mid fifties (Nishida 1955).

Species	Stage attacked			
	egg	larva	pupa	adult
Parasitoids				
BRACONIDAE				
*Fopius arisanus**	+			
Diachasmimorpha dacusii		+		
Psyttalia fletcheri		+++		
CHALCIDIDAE				
Dirhinus anthracina			+	
Spalangia endius			+	
S. hirta			+	
EULOPHIDAE				
Tetrastichus giffardianus†		+		
T. dacicida		+		
Predators				
ARAENIDAE				
Argiope spp.				+
CHELISOCHIDAE				
Chelisoches morio		++		
REDUVIIDAE				
Zelus renardii				++
FORMICIDAE				
Pheidole megacephala	++	++	++	
Solenopsis geminata	+	+	+	
STAPHYLINIDAE				
Philonthus turbidus		++		

\+ rare, ++ occasional, +++ common

* adult oviposits and kills host eggs, but the parasitoid does not develop

† *P. fletcheri* must already be present in the same host for it to develop (Pemberton and Willard 1918)

It was pointed out (Nishida 1955) that changed agricultural practices had greatly decreased the amount of uncultivated land where *Momordica* grew abundantly. Earlier, the common wild melons served as a reservoir for pest and parasitoid populations alike, both of which moved into the cultivated fields. The progressive shrinking of the *Momordica* reservoir led to the cucumber fly population becoming dependent upon cultivated hosts, which are clearly not conducive to high levels of parasitisation by *Psyttalia fletcheri*.

It is probable also that the increasing use of pesticides would have been detrimental to the parasitoids. However, observations on melons and cucumbers in areas where insecticides were not used did not indicate a high level of parasitisation there either. Furthermore, low levels were already evident in earlier times when pesticide use was low, so pesticides are evidently not responsible for the general situation.

A further possibility is that *P. fletcheri* in Hawaii is now less 'fit' than it was on first introduction, perhaps as a result of a virus (or other pathogen) or a genetic change. Although there is no evidence to support this suggestion and the possibility might appear remote, there may nevertheless be justification for considering whether any introductions to Solomon Is or Papua New Guinea should be from India rather than from Hawaii. The fact that *P. fletcheri* from Hawaii, now established in Guam, is providing negligible control of *Bactrocera cucurbitae* there (see 4(f)) provides some justification for this suggestion. It should, however, be pointed out that Clausen et al. (1965) expressed surprise that only 284 adult *Psyttalia fletcheri* had been reared from at least 0.5 million *Bactrocera cucurbitae* puparia collected in north India, Sri Lanka, Malaysia and the Philippines. It was not obtained from melon fly puparia from south India, Thailand, Sabah, south China or Taiwan so, if present, its numbers must have been very low. Nevertheless, it is reported to have been introduced during 1932 to 1934 into the Ryukyu Is from Taiwan (Clausen 1978b) so it must have been present in Taiwan in reasonable numbers at that time.

The establishment of *Psyttalia fletcheri* in the Ryukyu Is is said to have led to a significant reduction in melon fly damage to cucurbits (Yashiro 1936), but later details do not appear to be available. In Sri Lanka the native *P. fletcheri* produced a maximum of 10% parasitisation of melon fly in four different cucurbit hosts and a small number of *Spalangia* species were also produced (Clausen et al. 1965). It is clear that this level of control was not considered adequate, since *Dirhinus anthracina* and *Spalangia* sp. were imported in 1936 from India and Malaysia respectively. Both became established (Hutson 1939), but their effects on the level of parasitisation of melon fly are not recorded .

The level of biological control of melon fly in Hawaii does not appear to have improved since the mid fifties and, in at least some places, it has even deteriorated. Thus, a survey of bitter melon and commercial cucurbits on the island of Molokai from 1978 to 1980 revealed heavy infestations (about 22 larvae per kg). No parasitoids were reared from over 8,000 fruits which produced 2,432 melon fly puparia. It was postulated that high winds on west Molokai where most cucurbits are grown were unfavourable to the survival of *Psyttalia fletcheri* (Harris and Lee 1989).

To sum up, the most effective natural enemy of *Bactrocera cucurbitae* so far known is *Psyttalia fletcheri* which causes a moderate level of mortality of larvae in *Momordica* melons, but only limited mortality of larvae in cultivated fruit. Of the other recorded parasitoids of melon fly, further studies of *Diachasmimorpha albobalteatus* and especially *D. dacusii* might be warranted. However higher priority should perhaps be given to a further search for additional parasitoids that are effective against the melon fly in cultivated plants within the natural range of the fly (Nishida 1955).

(b) AUSTRALIA

Of the more than 60 species of fruit flies that occur in Australia, the Queensland fruit fly, *Bactrocera tryoni* causes by far the greatest economic damage in eastern Australia (with *B. neohumeralis* in second place, but a long way behind in importance). The introduced Mediterranean fruit fly *Ceratitis capitata* is of major importance in Western Australia where, until the appearance of *B. tryoni* in 1988 (later eradicated (1990)), it has been the only fruit fly attacking commercially grown fruits.

C. capitata was first recorded in Western Australia in 1895 but did not appear in eastern Australia until 1898. From time to time over the next 40 years it caused extensive economic damage in the east until it disappeared completely in 1941. This was possibly as a result of competitive interaction between its adults and those of *B. tryoni* for oviposition sites, combined with an inability of its larvae to compete successfully in fruits. The latter is suggested by the results of Keiser et al. (1974) who showed in the laboratory that

C. capitata larvae suffered high mortality when larvae of the oriental fruit fly were present in the same fruit. However both species emerged from the same pieces of a range of fruits in the field in Maui (Hawaii), more *C. capitata* than *Bactrocera dorsalis* emerging at higher elevations. Furthermore, in individual peach fruit, the larvae of one species caused no apparent reduction in the number of larvae of the other species (Wong et al. 1983).

Only four of the fruit fly species present in Australia also occur in the oceanic south Pacific, namely *B. frauenfeldi*, *B. musae*, *B. strigifinis* (all in Solomon Is) and *B. tryoni* (in French Polynesia, Lord Howe Is and New Caledonia). Of these, *B. frauenfeldi* the mango fruit fly was first recorded in the Cape York region of Australia in 1972 and is presumed not to be an endemic species.

The native parasitoids reared from many samples of mainly commercial fruits collected from 1960 to 1962 in eastern Australia north from Sydney are listed in Table 2.5 (Snowball and Lukins 1964). Five additional species had earlier been reported for Queensland (May and Kleinschmidt 1954), namely two species of *Bracon* (unidentified) and of *Psyttalia* (*P. africanus*, *P. fijiensis*) and one of *Opius* (*O. froggatti*). However their identity requires confirmation. The overall incidence of native parasitoids in the 1960 to 1962 rearings was low, generally averaging between 5 and 12% of the insects emerging from all samples at any one site, although it did rise to 80% in one individual sample. The conclusion reached was that native parasitoids were of little importance in regulating the abundance of their fruit fly hosts (Snowball 1966).

Table 2.5 Native parasitoids of fruit flies in eastern Australia (after Snowball and Lukins 1964).

Parasitoids	Hosts
BRACONIDAE	
Diachasmimorpha kraussi	*B. cacuminata*, *B. jarvisi*, *B. krausii*, *B. neohumeralis*
Diachasmimorpha tryoni	*B. tryoni*
Fopius deeralensis	*Bactrocera jarvisi*, *B. neohumeralis*, *B. kraussi*, *B. pallida*, *B. tryoni*
Opius perkinsi	*B. tryoni*
Psyttalia fijiensis *	*B. cacuminata*, *B. jarvisi*, *B. kraussi*, *B. neohumeralis*

* This is almost certainly not the true *P. fijiensis* from Fiji and Tonga (R.A. Wharton pers. comm. 1992)

The intensive studies of Bateman (1968) over a seven year period in an orchard some 90 km south of Sydney also produced extremely few parasitoids, the majority being *Diachasmimorpha tryoni* (M.A. Bateman pers. comm. 1989) a species that had been reported by Allman (1939) many years earlier. When a grass sward was allowed to develop in the orchard, ant colonies increased in abundance and ants were responsible for at least 10% mortality of fruit fly larvae and puparia in the soil. Mortality was also caused by predaceous beetles and a millipede.

Fullaway (1951) listed a number of additional natural enemies of fruit flies in Australia but nothing is known of their effectiveness. They were, Hymenoptera: *Aganaspis daci* Weld (Cynipidae), *Dirhinus* sp. (Chalcididae), *Spalangia* sp. and *Pachycrepoideus vindemiae* (Pteromalidae), *Galesus* sp. (Diapriidae); Coleoptera: *Thyreocephalus albertisi* (Staphylinidae).

Early attempts at biological control of the Queensland fruit fly *Bactrocera tryoni* involved the release in New South Wales in 1932 to 1933 of several thousand *Tetrastichus giffardianus* and small numbers of *Psyttalia concolor* and *Biosteres fullawayi* (Table 2.6). During 1937 and 1938 some 205,000 *Aceratoneuromyia indica* were liberated in New South Wales and a number in Queensland. Those liberations did not lead to any establishments (Noble 1942).

Table 2.6 Liberations of parasitoids for the biological control of *Bactrocera tryoni* in Australia.

Parasitoid	Liberated	From	Result	Reference
BRACONIDAE				
Biosteres fullawayi	1933	Hawaii	-	Noble 1942, Wilson 1960
Diachasmimorpha longicaudata	1956, 1957	Hawaii	-	Snowball & Lukins 1964
	1958, 1959	Hawaii	-*†	
Fopius arisanus	1956, 1957	Hawaii	-	Snowball & Lukins 1964
	1958, 1959	Hawaii	+	
F. vandenboschi	1958, 1959	Hawaii	-*	Snowball & Lukins 1964
Psyttalia concolor	1932, 1933	Hawaii	-	Noble 1942, Wilson 1960
P. incisi	1958, 1959	Hawaii	-	Snowball & Lukins 1964
CHALCIDIDAE				
Dirhinus anthracina	1958, 1959	Hawaii	-	Snowball et al. 1962a,b, Snowball & Lukins 1964
EULOPHIDAE				
Aceratoneuromyia indica	1937, 1938	India	-	Noble 1942, Wilson 1960
	1958, 1959	Hawaii	-	Snowball et al. 1962a,b
Tetrastichus giffardianus	1932, 1933	Hawaii	-	Noble 1942, Wilson 1960
	1958, 1959	Hawaii	-	Snowball & Lukins 1964

* established briefly then died out
† still present on Lord Howe Is in 1962 (Snowball and Lukins 1964)

Following success against the oriental fruit fly in Hawaii and after it had been shown that *Fopius arisanus*, *F. vandenboschi* and *Diachasmimorpha longicaudata* would parasitise both the Queensland fruit fly and the solanum fruit fly *Bactrocera cacuminata* arrangements were made for their introduction from Hawaii. A stimulus for this decision was that two of these species had biological characteristics previously unknown in Australian parasitoids of fruit flies. *Fopius arisanus* oviposits in the host egg or recently hatched larva and *F. vandenboschi* in the first instar larva (van den Bosch and Haramoto 1951). Eggs and young larvae of *Bactrocera tryoni* occur close to the skin of the host fruit, but older larvae are less accessible in the deeper layers, particularly of commercial fruits. These two parasites are thus more likely to be able to locate hosts than are those, like *Diachasmimorpha longicaudata*, that oviposit only in older larvae (Snowball et al. 1962b).

In 1956 and 1957, 1,700 *Fopius arisanus* and 21,000 *D. longicaudata*, bred in Sydney from material introduced from Hawaii, were liberated at Coffs Harbour in northern New South Wales, but establishment was not achieved (Snowball et al. 1962b).

In 1958 and 1959 the following numbers of foreign parasitoids were bred in Hawaii, carefully screened there and again in Sydney to exclude all fellow travellers (Snowball et al. 1962a) and liberated in the field: *Fopius arisanus* 229,200, *Diachasmimorpha longicaudata* complex 198,700, *Fopius vandenboschi* 28,100, *Psyttalia incisi* 27,100, *Dirhinus anthracina* 2,500, *Aceratoneuromyia indica* 3,200, *Tetrastichus giffardianus*

2,500. The liberations were made at 25 locations in New South Wales, 59 in Queensland, 6 on Lord Howe Is, all against *Bactrocera tryoni*, and 12 liberations were made in Western Australia against the Mediterranean fruit fly (Snowball et al. 1962b).

Extensive sampling of fruits in eastern Australia between 1960 and 1962 revealed only *Fopius arisanus* still established on the mainland and that, at places, it had dispersed up to a maximum of 5 miles in the 4 years since liberation. It was present on Lord Howe Is from late 1959 to early 1961, but then died out. *Diachasmimorpha longicaudata* was still present in low numbers on Lord Howe Is on the last sampling occasion in 1962. The sampling of fruits did not provide information on *Dirhinus anthracina*, which is a pupal parasite and hence would only be found by sampling pupae in the soil. More recently, from an examination of somewhat limited material Wharton (pers. comm. 1992) has not been able to determine whether *D. longicaudata* is established in Queensland or whether there is a closely related native species intermediate between *D. longicaudata* and the native *D. kraussi*.

A ratio of 1.5 females per male indicated that, under Australian conditions, *Fopius arisanus* mated satisfactorily in the field. It was bred from *Bactrocera barringtoniae*, *B. cacuminata*, *B. neohumeralis*, *B. tryoni* and possibly *B. jarvisi* and *B. kraussi* which, between them, were infesting 14 types of fruit. *Fopius arisanus* exhibited marked preferences for certain fruits, but these varied in different years and in different localities. The most consistent was for infested star fruit *Averrhoa carambola* in north Queensland. *Fopius arisanus* showed no preference for utilising more heavily, rather than less heavily, infested fruit. A review of climatic factors indicated that maximum winter temperatures of less than 15°C (attained at approximately the latitude of Brisbane) were unfavourable to the continued existence of *F. arisanus*. There was no indication that native parasitoids were displaced by *F. arisanus*, as had occurred in Hawaii with the previously established *F. vandenboschi* and *Diachasmimorpha longicaudata* (van den Bosch et al. 1951).

In Hawaii, levels of parasitisation by *Fopius arisanus* ranged up to 70% in guava (Bess and Haramoto 1958) and now averages about 60% (W.C. Mitchell pers. comm. 1992). In Australia, they reached 78% for the most favoured fruits but, for others, ranged between 0 and 35%. The high levels of parasitisation in favoured fruits in northern Australia were thus often offset there by the production of many flies from fruits not favoured by the parasitoid. The data obtained by Snowball (1966) and Snowball and Lukins (1964) indicated that the introduction of *F. arisanus* had reduced the number of flies produced per fruit, but had not had much effect on the percentage of fruit infested.

In relation to predation, Drew (1987) studied, in their endemic rainforest habitat in southeast Queensland, the effects of fruit-eating birds and rodents on two fruit flies, *Bactrocera cacuminata* and *B. halfordiae*. In spring and summer, 66% of *Solanum mauritianum* fruit (host to *Bactrocera cacuminata*) were eaten by the brown pigeon, *Macropygia phasianella*, the amount increasing to 77% during the main summer breeding season of the fly. Parasitisation of *Bactrocera cacuminata* by *Fopius arisanus* and *Diachasmimorpha kraussii* never exceeded 17%. Rodents consumed 78% of the fallen fruit of *Planchonella australis*, a major host of *Bactrocera halfordiae*. It was postulated that fruit-eating vertebrates were the major cause of reduction in fruit fly populations in their natural habitat, an effect brought about by the ingestion of fruit fly infested fruits leading to the destruction of fruit fly eggs and larvae. Even when uninfested fruits were eaten, this made them unavailable as a fruit fly breeding resource. By comparison with the vertebrates, the hymenopterous parasitoids were not major enemies of fruit flies in their endemic habitat and appeared to have limited value for fruit fly control in cultivated host fruits.

(c) COOK IS

Small numbers of six parasitoids from Hawaii or Fiji were liberated against *Bactrocera melanotus* between 1927 and 1938, but there was no evidence of establishment (Table 2.7)

(Rao et al. 1971). Walker and Deitz (1979) listed nine introductions between 1927 and 1938, but the absence of voucher specimens, possible misidentifications and changes in nomenclature do not permit meaningful additions to Table 2.7. Several hundred *Diachasmimorpha longicaudata* from Fiji reached the Cook Is in good condition in 1954, but no information is available on their fate (O'Connor 1954). Although there is no record of its introduction *Fopius arisanus* has recently (1991) been recovered, at times reaching a parasitisation level of 60%. It occurs in a wide range of host fruit (P. Joseph pers. comm. 1992).

Table 2.7 Attempts at biological control of fruit flies in Cook Is.

Parasitoid	Liberated	From	Result	Reference
BRACONIDAE				
Diachasmimorpha longicaudata	1954	Fiji	?	O'Connor 1954
D. tryoni	1927	Australia via Hawaii	-	Rao et al. 1971
Psyttalia concolor	1927	Hawaii	-	Rao et al. 1971
CHALCIDIDAE				
Dirhinus anthracina	1938	Africa via Fiji	?	Lever 1938b, Rao et al. 1971
EULOPHIDAE				
Aceratoneuromyia indica	1938	Fiji	?	Lever 1938b, Noble 1942 Rao et al. 1971
Tetrastichus sp.	1927	Hawaii	-	Rao et al. 1971
T. giffardianus	1938	Fiji	?	Lever 1938b, Rao et al. 1971

Table 2.8 Native enemies of fruit flies in Fiji.

	Stage attacked	Reference
Parsitoids		
BRACONIDAE		
Diachasmimorpha hageni	larva	Hinckley 1965
Psyttalia fijiensis	larva	Hinckley 1965
Phaenocarpa leveri		Lever 1938b, Nixon 1939
CHALCIDIDAE		
*Spalangia endius**	mature larva	Clausen et al. 1965
PTEROMALIDAE		
Pachycrepoideus vindemiae	pupa	Hinckley 1965, Lever 1945
Predators		
LYGAEIDAE		
Germalus pacificus	egg	Simmonds 1936
FORMICIDAE		
unidentified species	larva, pupa	Simmonds 1936
STAPHYLINIDAE		
unidentified species	egg, larva, pupa	Simmonds 1936

* probably introduced

(d) FIJI

As early as 1916, a braconid wasp was reared from fruit flies infesting granadilla, and in 1921 one was again found in 25% of larvae in guava. From what is now known of the endemic parasitoids (Table 2.8), it is probable that these were *Diachasmimorpha hageni* and *Psyttalia fijiensis*. In April 1935, 5% parasitisation was recorded of larvae in guava and, by June, double that value. In cherry guava it is probable that the level was over 20% (Simmonds 1936). In 1937 12.5% parasitisation was recorded (Simmonds 1937).

In the hope of achieving an even greater degree of suppression of any or all hosts, introductions of fruit fly parasitoids took place from Hawaii in 1935. Two African species were introduced, *Tetrastichus giffardianus*, which became established, and *Psyttalia concolor* which failed (Table 2.9). Up to 20% parasitisation by the former was recorded in guava. Recoveries were also made from fruit fly puparia of the pteromalid *Spalangia cameroni*, which had been introduced from Hawaii in 1927 for control of the housefly (Simmonds 1929). It was later mistaken by Lever (1938c) as an endemic species. In 1937 the pupal parasitoid *Dirhinus anthracina* was introduced from Hawaii (Simmonds 1937), but did not become established. Next, *Aceratoneuromyia indica*, sent from Australia but originally from India, was released between 1938 and 1942 and, although initially thought to have failed, it was later (1952) recovered in large numbers.

Following reports in the early fifties of the very considerable recent success in the biological control of *Bactrocera dorsalis* in Hawaii, introductions to Fiji were resumed. Between 1951 and 1954, four species of braconid were released (Table 2.9). Of these, only two, *Fopius arisanus* and *Diachasmimorpha longicaudata*, were later recovered in the field (O'Connor 1954). By 1959 rearings from orange and grapefruit, yielding 21.4% *F. arisanus* and 0.3% *D. longicaudata*, were reported by O'Connor (1960) who added that, in the opinion of H.W. Simmonds who had 'made a study of local fruit flies over the years, infestation of fruits is now very much less than it was ten years ago. It seems likely that *Opius oophilus* (= *Fopius arisanus*) has been responsible for a considerable measure of control of fruitflies'. Rao et al. (1971) stated that *F. arisanus* 'appears to have played a significant part in controlling the fruit flies'.

A collection of 46,492 fruit fly puparia sent to Hawaii in 1952 produced 3,241 adults of five different parasitoids (Table 2.10). About 94% of these were *Aceratoneuromyia indica*, which normally produces from 10 to 25 or more adults per host. The least abundant parasite was *Fopius arisanus*, of which eight adults emerged from *Bactrocera passiflorae* infesting guava (Clausen et al. 1965). Sixteen years later *Fopius arisanus* was recovered in greater numbers, together with *Diachasmimorpha longicaudata* (Arambourg and Onillon 1970).

Hinckley (1965) found that overall levels of parasitisation in the period 1961 to 1963 were lower in rearings from native than from introduced fruits. Averages ranged from 4.5% for dawa (*Pometia pinnata*) to 9.4% for ivi (*Inocarpus fagiferus*), compared with a range from 21.7% for citrus and 24.2% for guava (*Psidium guajava*) to 61.3% in cherry guava (*P. cattleianum*). *D. longicaudata* was the predominant parasitoid in rearings from ivi and vutu (*Barringtonia*), but parasitised no more than 8% of larvae in either host. *Diachasmimorpha hageni* reared from ivi was the only native parasite recovered. *Psyttalia fijiensis* had apparently been displaced, at least in the study area, although it had been present in the 1951 rearings (Table 2.10), which were probably from another location. Hinckley (1965) concluded that the increase in percentage parasitisation was largely due to the more effective attack of *Fopius arisanus* on the eggs of *Bactrocera passiflorae* in guava and citrus. Earlier, Simmonds (1936) had reported combined parasitisation by the native species as 5% in guava and 14% in cherry guava, about a quarter of that achieved by the introduced parasites. *Fopius arisanus* has, nevertheless, been less effective on *Bactrocera passiflorae* and *B. xanthodes* in Fiji than on *B. dorsalis* in Hawaii. Thus, on guava in Hawaii, average levels of parasitisation of *B. dorsalis* were reported to be 76% on Oahu, 61% on Maui and 44% on Hawaii (Haramoto 1957). This compares with 22% in Fiji (Hinckley 1965).

Table 2.9 Attempts at biological control of fruit flies in Fiji.

Parasitoid	Introduced	From	Result	Reference
BRACONIDAE				
Diachasmimorpha longicaudata var. *formosanus* var. *novocaledonicus* var. *taiensis*	1951, 1954	Hawaii	+	Clausen 1978b, Hinckley 1965, O'Connor 1954, 1960
Fopius arisanus	1951, 1954	Hawaii	+	Clausen 1978b, Hinckley 1965, O'Connor 1954, 1960
F. vandenboschi	1951	Hawaii	-	Clausen 1978b, Cochereau 1966a,b, 1968, O'Connor 1954, 1960
Psyttalia concolor	1935	Hawaii	-	Cochereau 1970, Clausen 1978b, Simmonds, 1936
P. fletcheri	Present in 1938, no record of introduction			Lever 1938b
P. incisi	1951, 1954	Hawaii	-	Cochereau 1966a,b, 1968, Hinckley 1965, O'Connor 1960
CHALCIDIDAE				
Dirhinus anthracina	1937	Hawaii	-	Hinckley 1965, Lever 1938a, Simmonds 1937
EULOPHIDAE				
Aceratoneuromyia indica	1938, 1941	India via Australia	+	Clausen et al. 1965, Hinckley 1965, Lever 1938a,b, Noble 1942
Tetrastichus giffardianus	1935	Hawaii	+	Clausen 1978b, Hinckley 1965, Lever 1938a, Simmonds 1936
PTEROMALIDAE				
Spalangia cameroni	1929	Hawaii	+	Lever 1938c, Simmonds 1929
*S. endius**	?	?	+	Clausen et al. 1965

* Although treated by Clausen et al. (1965) as native, it is almost certainly an introduced species

Table 2.10 Parasitoids reared from Fiji fruit flies.

	1951 (Clausen et al. 1965)	**1968** (Arambourg and Onillon 1970) 19,000 fly emergences
Aceratoneuromyia indica	3036	168
Diachasmimorpha hageni	29	44
Diachasmimorpha longicaudata var. *taiensis*	-	178
Fopius arisanus	8	182
Psyttalia fijiensis	66	-
Spalangia endius	102	-
Spalangia sp.	-	18

Collections of infested fruits in Fiji in 1968 yielded 30% parasitisation by *Fopius arisanus* of fruit flies in cherry guava, but only 2.6% in *Inocarpus* and 1.8% in *Barringtonia*. On the other hand, *Diachasmimorpha longicaudata* was recovered from 8.4% of the fruit flies in *Barringtonia*. One batch of cherry guavas produced 2% parasitisation by *Aceratoneuromyia indica* (Cochereau 1968). All of the *Barringtonia* fruit and almost all of those of cherry guava were collected from the ground, which may have influenced the parasitisation levels, especially those of *F. arisanus* (P. Cochereau pers. comm. 1992). In 1951 *Aceratoneuromyia indica* had emerged in large numbers (Table 2.10), but a decade later it was comparatively rare (Arambourg and Onillon 1970, Hinckley 1965). The same situation applies to *Tetrastichus giffardianus*. It is not known whether this reduced abundance is due to the presence of *Fopius arisanus* and *Diachasmimorpha longicaudata*, which Hinckley (1965) postulated may have caused a reduction in the abundance of the native *Psyttalia fijiensis* and *Diachasmimorpha hageni*. However, *P. fijiensis* survives competition with *F. arisanus* in Tonga and levels of parasitisation by *D. longicaudata* and *A. indica* (which have been recovered from Fiji but not Tonga) are generally low (R.A. Wharton pers. comm. 1992).

In addition to parasitisation, mortality of *Bactrocera dorsalis* eggs resulting from infection, introduced through ovipositor punctures made by *Fopius arisanus* without egg laying, was 88% in Hawaii, compared with only 9% for *Bactrocera passiflorae* eggs in Fiji. Hinckley (1965) considered it improbable that the pathogens which entered the eggs in Hawaii could be absent from Fiji, but offered no explanation for the difference. One possible factor may be the reported reluctance of *Fopius arisanus* to search for eggs in fallen fruit (Haramoto 1957), which must reduce its effectiveness in Fiji, since *Bactrocera passiflorae* has no hesitation in ovipositing in fruit on the ground. Hinckley (1965) remarked that only on cherry guava, the fruits of which remain on the tree long after ripening, do the oviposition habits of *Bactrocera passiflorae* and *Fopius arisanus* coincide.

Amongst the native fruit fly predators (Table 2.8), the polyphagous lygaeid bug *Germalus pacificus* was observed sucking the contents from fruit fly eggs. It was considered by Simmonds (1936) to be the most important single factor in reducing fruit fly abundance in Fiji at that time. An unidentified staphylinid beetle and, under some circumstances, ants were also observed attacking eggs and larvae. Numbers of eggs and larvae were also probably destroyed by the eager attack of flying foxes on most ripening fruits. The result was that, towards the end of the guava season, fruit fly numbers were suppressed to such an extent that the last fruits were practically free from infestation (Simmonds 1936).

The overall conclusion of Hinckley (1965) was that infestation levels of *Bactrocera xanthodes* in vutu and *B. passiflorae* in guava and various native fruits remained at an unsatisfactorily high level in Fiji. However, there seems little reason to doubt that the levels would have been considerably higher in the absence of introduced parasitoids.

A survey for fruit fly parasitoids in 1985/86 revealed that 30 to 35% of fruit fly larvae were parasitised, mainly by *Fopius arisanus*, but also by *Diachasmimorpha longicaudata* (M.L. Autar pers. comm. 1989). In recent (1991 and 1992) sampling, two eulophids and three braconids have been recovered from *B. passiflorae* but not from *B. xanthodes*. Of the eulophids, *Aceratoneuromyia indica* was recovered from infested *Syzgium* and an unidentified species from *Artocarpus*. The first of the braconids, a single specimen of the native *Psyttalia fijiensis* was reared from *Bactrocera passiflorae* on *Citrus maxima*, but none from five collections of strawberry guava, *Psidium littorale* (which yielded 21 fruit flies) or from two collections of infested *Terminalia* fruit. Over the same period, *P. fijiensis* has been reared in Tonga from both guava *Psidium guajava* and *Terminalia*. The native *Diachasmimorpha hageni* was not recovered, although it had been bred by earlier workers from infested *Barringtonia*, *Ochrosia* and *Inocarpus*. Strangely, no parasitoids at all were recovered from heavily infested *Barringtonia* (A. Allwood pers. comm. 1992, R.A. Wharton

pers. comm. 1992). Wharton (pers. comm. 1992) points out that it would be important for biological control to test competition between *Diachasmimorpha longicaudata* and *Psyttalia fijiensis* on several fruits and fruit fly hosts. It would also be valuable to compare the habitat from which *P. fijiensis* was collected in Tonga with that in which larvae infesting *Terminalia* and guava in Fiji were not being parasitised. Differences in rainfall, proximity to native forests, or even wind exposure may prove to be important factors, but seasonality should not be, since *Terminalia* was collected at about the same time in both Tonga and Fiji.

The other two braconids recovered were the commoner *Fopius arisanus* (recovered from at least 10 fruits and notably from guava) and the less common *Diachasmimorpha longicaudata* (from 7 fruits and also most commonly on guava). Several samples of infested fruit yielded both parasitoid species (R.A. Wharton pers. comm. 1992).

(e) FRENCH POLYNESIA

Both *Bactrocera kirki* and *Bactrocera tryoni* infest papaya, mango and some less important fruits in French Polynesia. *Diachasmimorpha tryoni* was introduced, but failed to become established.

(f) GUAM

Bactrocera dorsalis was first recorded on Guam in 1948, although it may have been present about the same time in 1935 that it was reported on Saipan. *B. dorsalis* was eradicated from Guam (and also from Rota, Agiguan, Tinian and Saipan) in 1965 and has not been trapped there since (Mitchell 1980). Only two species of fruit fly were present on Guam in 1989, the melon fly and *Bactrocera ochrosiae*, which also responds to cue lure. The latter is endemic to the Marianas and does not attack cultivated fruit or vegetables. Earlier reports of the presence of *B. frauenfeldi* are in error: there are no specimens in collections and it is not there now (D. Nafus pers. comm. 1989).

Three species of parasitoid were introduced between 1937 and 1967 from Hawaii to control *B. cucurbitae*, which was first discovered in Guam in 1936 (Swezey 1946) (Table 2.11). Of these only *Psyttalia fletcheri* became established, causing 6.1% mortality near the point of release shortly after liberation. However, this population died out and six more introductions were made between 1950 and 1967. It was recovered in 1971, so it eventually became established. No record is available of the introduction of the muscid fly *Atherigona orientalis*, which is commonly seen investigating oviposition holes made by *Bactrocera cucurbitae* whose larvae are often not found in fruit where this activity is observed (D. Nafus pers. comm. 1989). *A. orientalis* is recorded as draining the contents of melon fly larvae (Bohart and Gressitt 1951), but is also capable of attacking both sound and damaged fruit.

In 1989 *Psyttalia fletcheri* was present at very low levels and *Bactrocera cucurbitae* was very abundant and causing substantial economic damage to cucumbers, bitter melons, cantaloupe and watermelon. The level of control was not considered adequate (Nafus and Schreiner 1989). Many melon flies, but no parasitoids, were bred from several hundred *Momordica* melons in 1991/1992 (Nafus and Schreiner pers. comm. 1992).

Seven parasitoids were introduced from Hawaii to control *Bactrocera dorsalis* (Table 2.11). Although these included *Fopius arisanus*, *F. vandenboschi* and *Diachasmimorpha longicaudata*, which at that time were producing valuable control of oriental fruit fly in Hawaii, and in spite of the fact that substantial numbers of parasitoids were liberated, establishment was not achieved. The only parasitoid that became established was the eulophid wasp *Aceratoneuromyia indica*. By 1962 an eradication campaign against the oriental fruit fly in the Marianas had proved successful so, unless *A. indica* can maintain itself on *Bactrocera ochrosiae*, it may not have survived, since it cannot develop in *B. cucurbitae* (table 2.3) (Nafus and Schreiner 1989).

It is of interest to note that a colour variety of *Diachasmimorpha longicaudata* had been reared as early as 1937 from *Bactrocera ochrosiae* larvae in *Ochrosia* and *Ximenia* fruits (Fullaway 1946). However, this parasitoid was not recorded during the 1950s when extensive sampling was carried out for recoveries of the Hawaiian introductions (Clausen et al. 1965).

Table 2.11 Introductions from Hawaii for the biological control of fruit flies in Guam (Nafus and Schreiner 1989).

Parasitoid	Liberated	Result
A. *Bactrocera cucurbitae*		
BRACONIDAE		
Diachasmimorpha dacusii	1950-1952	-
Psyttalia concolor	1937	?
P. fletcheri	1937	T†
	1950, 1953, 1955, 1959	+
	1960, 1967	(but little effect)
B. *Bactrocera dorsalis*		
BRACONIDAE		
Diachasmimorpha longicaudata	1952	-
*var. *compensans*	1952	-
*var. *formosanus*	1952, 1955	-
*var. *longicaudatus*	1959, 1960	-
*var. *malaiaensis*	1952	-
*var. *novocaledonicus*	1955	-
Fopius arisanus	1955, 1959*, 1960	-
*Fopius vandenboschi**	1950	-
*Psyttalia incisi**	1950	-
CHALCIDIDAE		
*Dirhinus anthracina**	1959, 1960	-
EULOPHIDAE		
Aceratoneuromyia indica	1952, 1955, 1959, 1960	+
Tetrastichus giffardianus	1959, 1960	?

* These liberations also made on Saipan
† T = established briefly, then died out

Table 2.12 Parasitoids emerging in Hawaii from puparia of *Bactrocera curvipennis*, *B. psidii* and *Bactrocera* sp. from New Caledonia (Clausen et al. 1965).

Parasitoid	Number
BRACONIDAE	
Diachasmimorpha longicaudata var. *novocaledonicus*	922
Psyttalia fijiensis	284
Opius froggatti (?)	4
PTEROMALIDAE	
*Spalangia endius**	91

* probably not native

(g) KIRIBATI

In 1987 *B. cucurbitae* was discovered on Kiritimati (Christmas Is) and a host-free period was established until 1989. Since then, cucurbits have again been grown, but no melon flies have been detected (G.S. Sandhu pers. comm. 1992).

(h) NAURU

Larvae of *B. cucurbitae* were found in a ribbed gourd (*Luffa acutangula*), in a house garden in 1982 (R. Muniappan pers. comm. 1992) and one adult male was attracted to cue lure in October 1992. At that time *B. frauenfeldi* was abundant and both *B. xanthodes* and *B. dorsalis* were trapped (B.S. Fletcher pers. comm. 1992).

(i) NEW CALEDONIA

As part of the world wide search for parasitoids that would attack the oriental fruit fly in Hawaii, twenty five shipments totalling 69,029 puparia of three species of *Bactrocera* were sent in 1950 from New Caledonia to Hawaii (Table 2.12). A colour variety of *Diachasmimorpha longicaudata*, described as *novocaledonicus*, was the most abundant parasitoid reared from both *Bactrocera psidii* and *B. curvipennis* and both of these hosts produced smaller numbers of *Psyttalia fijiensis*. *P. fijiensis* showed an apparent preference for *Bactrocera psidii* infesting guava. Four adults of a possible colour form of *Opius froggatti* also emerged from *Bactrocera psidii* (Clausen et al. 1965). However in extensive studies on New Caledonian fruit flies, Cochereau (1970) did not encounter *O. froggatti*, so doubt must be cast on the validity of the Clausen et al. (1965) record.

The pupal parasitoid *Spalangia endius* was present, but less abundant, in the puparia sent to Hawaii than either *Diachasmimorpha longicaudata* or *Psyttalia fijiensis* (Clausen et al. 1965). These collections gave an overall parasitisation rate of slightly less than 2%. In 1965 Cochereau (1966a) obtained only a single parasitoid from infested guavas, so the percentage parasitisation was negligible at that stage. In 1968, samples of fruit fly infested guava and cherry guava yielded an average of about 8% parasitisation of a mixed infestation of fruit fly species, but mainly *Bactrocera psidii*. *Diachasmimorpha longicaudata* was the more abundant of the two parasites produced, with *Psyttalia fijiensis* occasionally contributing as much as 45% of parasites emerging in the high country, but no more than 9% in the warmer moister lowlands. Cochereau (1970) concluded that parasitoids exercised only a low level of biological control of fruit flies in New Caledonia.

Table 2.13 Introductions for the biological control of fruit flies in New Caledonia (from Cochereau 1966b, 1970).

Parasitoid	Introduced	From	Result
BRACONIDAE			
Fopius arisanus	1966	Fiji	- dead on arrival
Psyttalia concolor	1966	France	-
EULOPHIDAE			
Tetrastichus giffardianus	1936	Fiji	- doubtful record

In this regard it is interesting to note the unsuccessful attempts to introduce and establish parasites (Table 2.13), although it is clear from the accounts that quite inadequate effort was expended. According to Risbec (1942) the pupal parasitoid *Tetrastichus giffardianus* was sent from Fiji in 1936, but Cochereau (1970) reported that he had been unable to trace any record of this introduction and that this parasitoid was not present in any of his rearings. The report of this introduction must, therefore, be regarded

as questionable. *Fopius arisanus* adults sent on two occasions from Fiji in 1966 died in transit. Three consignments of *Psyttalia concolor*, the well known Mediterranean parasite of the olive fly *Bactrocera oleae* were received from France in 1966. Although females would not parasitise New Caledonian fruit flies in the laboratory, adults were liberated near Noumea, but the species failed to become established (Cochereau 1970).

(j) NORTHERN MARIANAS

Bactrocera dorsalis was first reported on Saipan in 1935 (Esaki 1952) and then spread to the other islands. It was eradicated from the Mariana Is in 1965 (Mitchell 1980).

Bactrocera cucurbitae was first recorded in 1943 on Saipan, Tinian and Rota, having probably spread there from Guam (Esaki 1952). Portion of the consignments of four of the parasitoids introduced in the fifties from Hawaii to Guam against the oriental fruit fly were liberated on Saipan (Table 2.11), but there is no information on the result (Nafus and Schreiner 1989). Eight adults of a colour variety of *Diachasmimorpha longicaudata* emerged from 125 puparia of *Bactrocera ochrosiae* sent from Saipan to Hawaii in 1949, three years before any attempt was made to colonise other subspecies of *D. longicaudata* sent from Hawaii. This parasite was reared from the same host in Guam (Clausen et al. 1965).

The only other fruitfly present is *B. ochrosiae* which is abundant on all islands. It breeds in *Ochrosia marianensis* fruit and, although not regarded as a pest species, it has also been reared from Surinam cherry on Saipan (A. Moore pers comm. 1992).

Bactrocera frauenfeldi has been reported from the Northern Marianas in the past, but recent surveys have failed to locate it. It may have been eradicated at the same time as the oriental fruit fly (D. Nafus pers. comm. 1989).

B. cucurbitae was eradicated from the Northern Mariana Is (but not from Guam) in 1965 (Mitchell 1980), but re-introduced to Saipan in 1986, possibly from Rota which had earlier been re-infested from Guam. It is also again present on Tinian and Aguigan. Soon after it reappeared in Saipan, its populations increased greatly, cue-lure traps catching more than 10 per day in 1988. Nevertheless, by 1991, the population had diminished to such a low level that 50 cue-lure traps caught no *B. cucurbitae* (but many *B. ochrosiae*) during 6 weeks in summer. The cause of the population crash is unknown. However about 200 wild and commercial melons yielded many adults of the fly *Atherigona orientalis*, which has predaceous larvae (see section on Guam) but no parasitoids (A. Moore, pers. comm. 1992). A sterile male eradication campaign for *B. cucurbitae* is currently being planned for Guam and the Northern Marianas.

(k) PAPUA NEW GUINEA

No fruit fly parasitoids have been introduced (F.M. Dori pers. comm. 1989). The only records of fruit fly parasitoids appear to be (i) *Diachasmimorpha* sp. nr *longicaudata* from *Bactrocera frauenfeldi* (Froggatt 1939) (ii) *Opius* sp. from *B. frauenfeldi* in guava (Ismay and Dori 1985) and *Opius* sp. probably from *Bactrocera strigifinis* in *Cucurbita maxima* (Greve and Ismay 1983). The earwig *Chelisoches morio* is recorded as a predator of *Bactrocera musae* larvae (Ismay, undated).

In New Britain, to the east, 54 adults of three parasitoid species emerged from 3,487 puparia of *Bactrocera frauenfeldi* collected near Rabaul and sent to Hawaii, giving a parasitisation rate of 1.5%. The parasitoids comprised 10 *Fopius deeralensis*, 30 *Diachasmimorpha longicaudata* and 14 *Psyttalia fijiensis*. The first and second of these species showed slight atypical colour differences which may be of taxonomic significance (Clausen et al. 1965).

(l) WESTERN SAMOA

Three parasitoids were introduced to Western Samoa between 1935 and 1938, but only *Aceratoneuromyia indica* became established (Clausen 1978b, Noble 1942) (Table 2.14). *Fopius arisanus* was reared from *Bactrocera kirki* and *B. obscura* in 1991 from a wide range of fruits (A. Allwood pers. comm. 1992), although there is no record of its introduction.

Table 2.14 Attempts at biological control of fruit flies in Western Samoa.

Parasitoid	Introduced	From	Result	Reference
CHALCIDIDAE				
Dirhinus anthracina	1935-38	Fiji	?	Clausen 1978b
	1938	Fiji	?	Lever 1938b
EULOPHIDAE				
Aceratoneuromyia indica	1938	Fiji	+	Clausen 1978b,
	1938	India via Australia		Noble 1942
Tetrastichus giffardianus	1935-38	Fiji	?	Clausen 1978b
	1938	Fiji	?	Lever 1938b

(m) SOLOMON IS

No fruit fly parasitoids have been introduced and *Bactrocera frauenfeldi* is reported to suffer less than 5% parasitisation. *Diachasmimorpha kraussii* was bred from infested Guadalcanal mangos from which *B. frauenfeldi* adults were produced (C. Williams pers. comm. 1989).

(n) TONGA

There are no early records of fruit fly parasitoids (O. Fakalata pers. comm. 1989), although *Fopius arisanus* and *Psyttalia fijiensis* were reared from *Bactrocera facialis* or *B. kirki* in 1991. Neither *B. distincta* nor *B. xanthodes* produced parasitoids. A few specimens of the pupal parasitoid *Spalangia* sp. were also reared (A. Allwood pers comm. 1992). Table 2.15 shows that the distribution of six fruit flies throughout the island groups of the Kingdom is not uniform (Litsinger et al. 1991), a timely reminder that uniformity cannot be assumed, either, for other island groups.

Table 2.15 Distribution of the six fruit fly species within the island groups of Tonga (Litsinger et al. 1991).

Species	Southern Group		Central Group	Northern Group	
	Tongatapu	'Eua	Ha'apai	Vava'u	Niuas*
Bactrocera distincta	+	+	+	+	+
B. facialis	+	+	+	+	+
B. kirki	+	+	+	+	+
B. obscura	-	-	-	+	+
B. passiflorae	-	-	-	-	+
B. xanthodes	+	+	+	+	-

* Niuatoputapu and Niuafo'ou Islands

(o) VANUATU

Parasitoids, possibly a *Biosteres* sp., have been reared mainly from *Bactrocera trilineola*, but the parasitisation rate is low (possibly 1%). It appears that a record of the presence of *Bactrocera xanthodes* may refer to a different species in a morphologically similar complex. According to Risbec (1942), Simmonds (1936, 1937) recorded the despatch of *Tetrastichus giffardianus* from Fiji to Vanuatu in 1936 (Cochereau 1970), but there is no mention of this in the papers of Simmonds referred to, so the record may be in error. In any event, there is no evidence of this species being present in Vanuatu (R. Weller pers. comm. 1989).

5. Major Parasitoids involved in Pacific Fruit Fly Programs

A great deal of confusion exists in the literature because of many changes to the nomenclature of many of the parasitoids and Table 2.16 sets out the present position (van Achterberg and Maeto 1990, Wharton 1987, 1988, 1989a,b, Wharton and Gilstrap 1983). The most important parasitoids have proved to be opiine Braconidae. At least 42 species of this group have been recognised from the large number of names applied to this group of parasitoids collected in biological control programs directed against tephritid fruit flies in the Pacific (Wharton and Gilstrap 1983). A few Chalcididae, Eulophidae and Pteromalidae are also involved. Although much of the taxonomy, based mainly on morphological characters, now seems to have stabilised, there is reason to believe that there may be 'strains' within some species that are far better adapted than others to particular hosts. In addition, the genus *Opius* is still a 'dumping ground' for the species of Opiinae that cannot at the moment be placed elsewhere. These factors may necessitate further nomenclatorial changes in the future and care must be taken in biological control projects not to discard a species prematurely because one of its 'strains' is ineffective.

The valid species that are most likely to be of concern in the oceanic Pacific are dealt with serially below. Distribution and host records are based mainly on Wharton and Gilstrap (1983). Host records for most field collected species are assumed hosts, based on association of fly and parasitoid produced from the same batch of fruit. In some instances the association may not be correct, since two or more fly species have been reared from the same batch. Furthermore all specimens of a particular fly species in a mixed infestation may have been killed by the parasitoids exploiting them as hosts, leading to an incorrect association being made of host-parasite relationship. Irrespective of whether oviposition occurs in the egg or the early, middle or later instar larva, all of the important fruit fly parasitoids complete their development in, and emerge from, the puparium (Clausen et al. 1965). A number of records of fruit fly parasitoids have been published by Narayanan and Chawla (1962). Methods for the mass rearing of parasitoids of tephritid fly larvae have been reviewed by Wong and Ramadan (1991).

Biosteres fullawayi

Cameroon, Guinea, Nigeria, Senegal, Zaire. Native hosts include *Ceratitis capitata.* Introduced to Hawaii and established, but recovered rarely since 1949 (Bess 1953, Bess et al. 1961). Introduced unsuccessfully to Spain, Puerto Rico and Australia. This species has a diapause.

Diachasmimorpha albobalteatus

Sabah. Reared from *Luffa acutangula* (Cucurbitaceae) infested with *Bactrocera cucurbitae*, *B. tau* and *Dacus smieroides*. Introduced to Hawaii, reared on *Bactrocera cucurbitae* and released, but did not become established (Clausen et al. 1965). It prefers large 3rd instar larvae for oviposition, but will oviposit in smaller larvae when forced to (Marucci 1952). It appears that, in Sabah, it may have parasitised *Bactrocera nubilus* and *Dacus smieroides*, since its presence was correlated with these in rearings, indicating a possible forced breeding and imperfect adaptation to melon fly as a host (Clancy 1952).

Diachasmimorpha dacusii

North India, Sri Lanka. Native host probably *Bactrocera cucurbitae*. Introduced (as *Opius watersi*) to Hawaii, mass reared on melon fly and *Ceratitis capitata*, released, recovered (Bess et al. 1961) but apparently did not become established.

Diachasmimorpha hageni

Fiji. Brought to Hawaii but not released. Native host *Bactrocera passiflorae* but reared with difficulty in the laboratory on *Ceratitis capitata, Bactrocera cucurbitae* and *B. dorsalis*. Mostly males were produced.

Table 2.16 Present names and previous combinations for some tephritid parasitoids.

Preferred	Previously used
BRACONIDAE	
Biosteres fullawayi† (Silvestri)	*Diachasma*, *Opius*
Biosteres giffardi† (Silvestri)	*Opius*, *Hedylus*
Diachasmimorpha albobalteatus (Cameron)	*Biosteres* (or *Opius*) *angaleti* (Fullaway)
Diachasmimorpha dacusii (Cameron)	*Biosteres* (or *Opius*) *watersi* (Fullaway)
Diachasmimorpha hageni (Fullaway)	*Biosteres*, *Opius*
Diachasmimorpha kraussii (Fullaway)	*Biosteres*, *Opius*
Diachasmimorpha longicaudata (Ashmead)	*Biosteres* (or *Opius*) *comperei* (Viereck)
	Biosteres (or *Opius*) *formosanus* Fullaway
	Biosteres (or *Opius*) *longicaudatus* Ashmead
	Opius l. var. *chocki* Fullaway
	Opius l. var. *novocaledonicus* Fullaway
	Opius l. var. *malaiensis* Fullaway
	Opius l. var. *taiensis* Fullaway
Diachasmimorpha tryoni (Cameron)	*Biosteres*, *Diachasma*, *Opius*
Fopius arisanus (Sonan)	*Biosteres* (or *Opius*) *oophilus* (Fullaway)
	(M)*Biosteres* (or *Opius*) *persulcatus* (Silvestri)
	Biosteres arisanus Sonan
Fopius carinatus (Szépligeti)	*Biosteres*
Fopius deeralensis (Fullaway)	*Opius*, *Biosteres*
Fopius skinneri (Fullaway)	*Opius*, *Biosteres*
Fopius vandenboschi (Fullaway)	*Opius*, *Biosteres*
	(M)*Biosteres* (or *Opius*) *persulcatus* (Silvestri)
Opius froggatti Fullaway	
Opius perkinsi Fullaway	
Psyttalia concolor (Szépligeti)	*Opius*
Psyttalia fijiensis (Fullaway)	*Austroopius*, *Opius*
Psyttalia fletcheri (Silvestri)	*Opius*
Psyttalia humilis (Silvestri)	*Opius*
Psyttalia incisi (Silvestri)	*Opius*
CHALCIDIDAE	
Dirhinus anthracina Walker	(M)*Dirhinus auratus* Ashmead
	(M)*Dirhinus giffardii* Silvestri
Dirhinus himalayanus Westwood	*Dirhinus luzonensis* Rohwer
CYNIPIDAE	
Aganaspis daci (Weld)	*Trybliographa daci* Weld
EULOPHIDAE	
Aceratoneuromyia indica (Silvestri)	*Melittobia*, *Syntomosphyrum*
Tetrastichus dacicida	
Tetrastichus giffardianus Silvestri	
Tetrastichus giffardii Silvestri	
PTEROMALIDAE	
Pachycrepoideus vindemiae (Rondani)	*Pachycrepoideus dubius* Ashmead
Spalangia endius Walker	*Spalangia philippinensis* Fullaway

(M) = misidentification

† These do not really belong to *Biosteres* and taxonomic revision is required (R.A. Wharton pers. comm. 1992)

Diachasmimorpha kraussii
Australia (Queensland), Solomon Is (C. Williams pers. comm. 1989). Introduced to Hawaii, released, recovered, but apparently not established.

Diachasmimorpha longicaudata (Plate 1, Fig. 3)
Southeast Asia. Established in Hawaii under several varietal and specific names, also in Australia, Fiji, Mexico, Costa Rica, Florida and Trinidad. Also introduced to northwestern USA and Guam but not established; introduced to Greece, but outcome unknown.

Its native hosts include the *Bactrocera dorsalis* complex and in the laboratory it will breed on *Ceratitis capitata, Bactrocera frauenfeldi, B. curvipennis, B. psidii* and *B. tryoni,* amongst others. One 'strain' was reported not to be able to develop in *B. cucurbitae* in Hawaii (Clausen et al. 1965) but it is reported to have been reared from *B. cucurbitae* in Thailand (Meksongsee et al. 1991).

This species oviposits in the nearly fully grown host larvae, puncturing the fruit skin to so do. Its fully grown larvae are capable of diapausing. It visits fruit on the tree and also on the ground where breaks in the fruit skin often give good access to older fruit fly larvae (Bess and Haramoto 1961). Fruit size and volatiles, but not colour, are probably responsible for its greater attraction to some fruit (eg. grapefruit) than others (eg. mango, orange, peach) although greater percentage parasitisation of most larvae was recorded in the latter group. This may be due to length of ovipositor, depth of the fruit pulp and behaviour of the host larvae (Leyva et al. 1991). Mass rearing is possible in the laboratory and rearing and life history studies are reported by Bess and Haramoto (1961) and Greaney et al. (1976). The following (mostly colour) varieties, although they may be sibling species, are mentioned in the literature:

var. *longicaudata*	Philippines
(prob. = *chocki*)	
var. *comperei*	South India
(prob. = *compensans*)	
var. *formosanus*	Taiwan
var. *malaiaensis*	Malaysia
var. *novocaledonicus*	New Caledonia
var. *taiensis*	Thailand

Diachasmimorpha tryoni
Eastern Australia. Established in Hawaii. Released, but did not become established, in Algeria, California, Canary Is, Egypt, Fiji, Israel, Italy, Puerto Rico, Spain, Tahiti, Western Australia. Native hosts include *Bactrocera tryoni,* but bred in the laboratory on *Ceratitis capitata, Bactrocera passiflorae* and *B. xanthodes.* This species was the most important parasitoid of *Ceratitis capitata* in Hawaii before *Bactrocera dorsalis* was introduced and it is still abundant in some areas on some fruits (Bess 1953, Bess and Haramoto 1958). Both Bess et al. (1961) and Haramoto and Bess (1970) state that it cannot develop in *B. dorsalis* as its eggs become encysted in the host larva soon after deposition. However Wharton (1989b) has reared it from that host in Hawaii. It seems, however, that *D. tryoni* can only be reared from *B. dorsalis* after the latter has been parasitised by another parasitoid (T. Wong unpub.). It has a larval diapause at cooler temperatures and adults search for hosts in fallen fruit. *D. tryoni* oviposits preferentially into larvae of middle and late third instar (Wong et al. 1990). More than one egg may be deposited in a host larva. The first instar larva is cannibalistic in habit and is almost invariably dominant in competition with other species of the same genus (Clausen 1978b). The period from egg to adult occupies 18 to 20 days in summer and field collected material

had a ratio of ♂:♀ = 1.7:1.0 (Pemberton and Willard 1918). It can be mass reared in the laboratory (Ramadan et al. 1989).

Fopius arisanus (Plate 1, Fig. 2)
South India to Taiwan. Reared from many hosts including *Bactrocera dorsalis*. Established (as *Opius oophilus*) in Australia, Costa Rica, Fiji, Hawaii and Mauritius. Also introduced to northwestern USA, Guam, Mexico and Italy, but not recovered (Wharton and Gilstrap 1983). The genus *Biosteres* was used briefly in the 1980s, until van Achterberg and Maeto (1990) pointed out that species of *Biosteres* parasitise, almost exclusively, the subgenus Anthomyiidae and Agromyzidae. They elevated *Fopius* (Wharton 1987) to generic rank for *arisanus*, the species believed to be the major factor in the reduction of oriental fruit fly in Hawaii and which probably reduced Mediterranean fruit fly populations also. Attempts to obtain similar results in other countries or on other hosts have not been as successful.

F. arisanus is the only species so far known that oviposits in the eggs of its host (van den Bosch and Haramoto 1951). The female inserts her ovipositor through the oviposition puncture made by the host fruit fly and may spend an hour or more probing to reach as many eggs or freshly hatched larvae as possible. Host eggs that are probed suffer high mortality, even without receiving a parasitoid egg. After the first instar larva has hatched from the egg it ceases development until the host pupates, whereupon development proceeds rapidly. Superparasitism is common, up to 3 eggs being deposited in a single host egg. At optimum temperatures the life cycle occupies 18 to 20 days: 28 to 35 hours for egg incubation, 5 to 8 days for the pupal stage and a variable period for larval life depending upon the rate of development of the host larvae. *F. arisanus* larvae prevent the development of *F. vandenboschi* and *Diachasmimorpha longicaudata* larvae when they occur together in the same *Bactrocera dorsalis* larva (van den Bosch and Haramoto 1953). There is a premating period for the male of 5 to 6 days. Adults reared from field collected material show a ratio ♂:♀ of 1:1.8. Females are rarely seen on fallen fruit (van den Bosch et al. 1951). It can be mass reared in the laboratory and details are given by Chong (1962) and Ramadan et al. 1992. Behaviour is dealt with by van den Bosch and Haramoto (1951) and biology by Bess and Haramoto (1961).

Fopius carinatus
Cameroon, Guinea, Kenya, Sierra Leone, Zaire. Introduced to Hawaii, but not recovered.

Fopius deeralensis
Australia, Papua New Guinea, New Britain. Native hosts include *Bactrocera frauenfeldi*, *B. musae* and *B. tryoni*. Introduced to Hawaii but not established.

Fopius skinneri
Philippines. Bred from *Bactrocera cucurbitae* (Rejesus et al. 1991). Introduced to Hawaii but failed to become established. Unlike *Fopius arisanus* and *Fopius vandenboschi* it prefers to attack tephritid larvae in cucurbits rather than those in fruit on trees or bushes (Clausen et al. 1965).

Fopius vandenboschi
Northern India, Thailand, Malaysia, Philippines, Taiwan. Introduced and established in Hawaii and introduced but not established in Australia, Costa Rica, Guam, Fiji and Mexico. Native hosts include *Bactrocera dorsalis*, but it has been bred in the laboratory on, amongst others, *Ceratitis capitata* and *Bactrocera tryoni*. It can be readily mass reared in the laboratory.

Oviposition occurs through the fruit fly oviposition puncture into the newly hatched fruit fly larvae rather than into the eggs. After hatching, the first instar larva does not moult again until the host larva pupates. Adult females are rarely seen on fruit on the ground and appear to concentrate their attention on mature green and ripe fruit on the tree. The proportion of the sexes in field collected material was ♂:♀ = 1:1.8.

Opius froggatti
Northeastern Australia, New Caledonia. Introduced to Hawaii but not released. Native hosts include *Bactrocera psidii*. Apparently more host specific than most opiines (Clausen et al. 1965).

Opius perkinsi
Northeastern Australia. One of its native hosts is *Bactrocera tryoni*. It was introduced to Hawaii, but could not be reared. Apparently more host specific than many other opiines (Clausen et al. 1965).

Psyttalia concolor
Africa. Established in Hawaii and Bermuda. Introduced to Australia, Algeria, Egypt, Fiji, New Caledonia, Costa Rica, Puerto Rico, Spain, Italy and Greece, but apparently not established. Native hosts include *Ceratitis capitata*; bred in the laboratory on hosts including *Bactrocera passiflorae*. Oviposition generally takes place into the fully grown fruit fly larva, although younger larvae may be successfully parasitised. Oviposition can start on the day that the female emerges and 250 eggs or more may be laid in the next 3 weeks. The female may live for 3 or more months. The period from egg to adult is 15 to 17 days at optimum summer temperatures and there is no larval diapause (Pemberton and Willard 1918). In the Mediterranean, the life cycle details are somewhat different with adult survival only 15 to 20 days and a pre-oviposition period of 4 to 5 days (Biliotti and Delanoue 1959).

Psyttalia fijiensis
Northern Australia, Papua New Guinea, New Britain, Fiji, New Caledonia. Introduced to Hawaii, but not established. Native hosts include *Bactrocera frauenfeldi*, *B. musae*, *B. tryoni*, *B. passiflorae*, *B. xanthodes*. Can be reared in the laboratory on *B. dorsalis*.

Psyttalia fletcheri
India, Thailand, Malaysia, Philippines, Sri Lanka. It was not reared from a number of *Bactrocera cucurbitae* puparia from South China, Taiwan or Sabah (Clausen et al. 1965). Established in Hawaii, Guam, Philippines, Ryukyu Is (Japan). Released in Puerto Rico, but not recovered. Native hosts include *Bactrocera cucurbitae* in northern India. In Thailand reared from *B. cucurbitae* in egg plant and ivy gourd (*Coccinia grandis*).

After a preoviposition period of 2 to 5 days, eggs are inserted in larvae that are at least half grown and development is completed in the puparium. There is no larval or pupal diapause. There is a slightly higher proportion of females, which may live for up to 4 months, although most eggs are deposited in the first 3 weeks (Willard 1920). Oviposition behaviour is dealt with by Nishida (1956). It can be mass reared in the laboratory.

Psyttalia incisi
India, Thailand, Malaysia, Borneo, Philippines. Established in Hawaii; released in Australia and Mexico, but not recovered. Native hosts include the *Bactrocera dorsalis* complex and it can be mass reared in the laboratory. It could not be bred successfully in *B. cucurbitae* (Table 2.3). The female has a moderately short ovipositor and this species is recovered mainly from small host fruits.

Dirhinus anthracina
East and West Africa. Established in Hawaii against *Ceratitis capitata*, but also found to parasitise *Bactrocera cucurbitae* (up to 17%) and *B. dorsalis* (Nishida 1955). Introduced to Fiji but not established. It was recorded amongst parasitoids reared in 1949/50 from Australian fruit flies (Clausen et al. 1965), although not reported in the 1960/62 surveys of Snowball and Lukins (1964) which did not sample field puparia. For rearing of this pupal parasitoid see Chong (1962).

Aceratoneuromyia indica
South India, Sri Lanka, Malaysia, Sabah, Indonesia, Philippines. Native hosts include the *Bactrocera dorsalis* complex. It can also be reared on *Ceratitis capitata* and *Bactrocera tryoni*. Eggs are laid in mature larvae from the day of emergence. It enters the infested fruit through breaks in the skin to search for fruit fly larvae, depositing 15 or more eggs in the posterior end of the body, often being dragged into the fruit pulp during this process by the burrowing host larva. Up to 35 individuals may mature in a single host. Adult females are short lived (not more than 27 days) and may lay 100 or so eggs. Under optimum conditions the egg to adult period is 15 to 16 days, and the progeny are predominantly (75%) female. Noble (1942) provides details of the biology of this parasitoid.

Pachycrepoideus vindemiae
North and south India, Thailand, Sabah, Philippines, southern China, Taiwan. This is a nearly cosmopolitan pupal parasitoid of many Diptera. It is apparently non-specific and attacks with almost equal readiness the puparia of most Tephritidae. It was introduced to Hawaii from Australia in 1914 as a dung fly parasitoid.

Spalangia cameroni
Possibly Fiji. Bred in very small numbers from fruit fly puparia in Fiji where it has also been reared from housefly puparia.

Spalangia endius
Philippines. Established in Hawaii to control the horn fly, this pupal parasitoid has been reared from puparia of *B. cucurbitae* and *B. dorsalis* as well as from those of the horn fly and the housefly.

Spalangia hirta
North America. Although this pupal parasitoid has been present in Hawaii at least since 1901, it was not reported to parasitise *Bactrocera cucurbitae* until 1914 (Severin et al. 1914). In USA it attacks housefly pupae.

Tetrastichus dacicida
Africa. Established in Hawaii, this larval parasitoid has been reared in large numbers from *B. cucurbitae* in *Momordica* melons and guavas infested with *B. dorsalis*.

Tetrastichus giffardianus
South Africa. Introduced and established in Hawaii to combat *Ceratitis capitata*. It also attacks *Bactrocera dorsalis*. If *T. giffardianus* oviposits in *B. cucurbitae* larvae the parasite is unable to develop. However, if *Psyttalia fletcheri* oviposits in *B. cucurbitae* larvae before *T. giffardianus*, the latter is able to develop normally (Pemberton and Willard 1918). Information on its biology in Hawaii is provided by Ramadan and Wong (1990).

Aganaspis daci

Australia, Malaysia, Sabah. This cynipid larval parasitoid was reared in large numbers in Queensland from several fruit flies including *Bactrocera tryoni*. It was released in Hawaii, but failed to become established (Clancy 1952), although laboratory tests showed that it could be reared in *B. cucurbitae* (Clausen et al. 1965), but with some difficulty (Clancy 1952). It emerged from melon fly larvae collected in the field in Malaysia. *A. daci* was liberated in Mauritius for the biological control of melon fly on cucumber (Roy 1977) but there is no information on its effects nor is there from a release of this parasitoid in Florida.

6. Discussion

Tropical fruit flies have not, in general, proved to be good targets for classical biological control. This is partly because several features of their life histories make conditions very difficult for parasitoids. Adults of many species disperse widely on emergence, leaving parasitoids behind. Next, fly numbers increase rapidly when suitable fruit is found, but adults again disperse widely to other areas as soon as fruit disappears, once more leaving parasitoids behind. Of at least 82 species of parasitoid that have been reared from tephritids during exploration programs it appears that only 44 have been released and only 20 are known to have become established (Wharton 1989a). Many of the early failures have been attributed to transportation and rearing difficulties and Wharton (1989b) considers that efforts should be renewed to reintroduce and liberate adequate numbers of some of these species. It is thus relevant to examine what practical advantages might be expected to result from the establishment of additional parasitoids that attack oceanic Pacific fruit flies.

It is improbable that there are any native species already occupying the egg-early larval niche where the most effective of the parasitoids introduced to Hawaii, namely *Fopius arisanus*, operates. This appears to be the only species that has so far been shown to exhibit this behaviour. However, Wharton (1989a) points out that the Afrotropical *Rhynchosteres caudatus* group is similar morphologically to the Indo-Pacific group of species containing *Fopius arisanus*. There are at least 11 species in these groups (*arisanus*, *bevisi*, *carpomyiae*, *caudatus*, *desideratus*, *niger*, *ottotomoamus*, *persulcatus*, *silvestrii*, *skinneri*, and *vandenboschi*), but taxonomic uncertainties and rearing problems have so far prevented the use of most species. The morphology of the ovipositor of at least two species suggests that, like *F. arisanus*, they may be egg-larval parasitoids. *Rhynchosteres caudatus* (which is one of the two species), and *Opius perproximus* alternate seasonally as major parasitoids of ceratitine fruit flies in West Africa. The true *Biosteres persulcatus* from India has an ovipositor similar to *F. arisanus* (R.A. Wharton pers. comm. 1992). Further studies of possible egg larval parasitoids are clearly desirable.

Another group of potential importance is formed by the Indo-Pacific species of the genus *Diachasmimorpha*. Several species were introduced to Hawaii, but only two (*D. longicaudata* and *D. tryoni*) became firmly established. The various colour morphs of *D. longicaudata*, described as separate varieties, may well be adapted to different hosts or specific micro-habitats. If so, those that became adapted to Hawaiian conditions may not necessarily be best suited for quite different tephritid hosts in other situations (Wharton 1989a).

Parasitoids that oviposit into the puparium have been largely neglected because of sampling difficulties and they also deserve further attention.

Under favourable conditions and with a suitable host (the oriental fruit fly) *F. arisanus* can achieve parasitisation levels up to 70%. When the larval parasitoids *Fopius vandenboschi*, *Diachasmimorpha longicaudata* and *Psyttalia incisi* are also present they

are capable of causing a little additional mortality, with other species, such as *Tetrastichus giffardianus* and *Aceratoneuromyia indica*, together causing useful but even lower mortality. This guild of parasitoids assembled in Hawaii is reported to have caused such a significant reduction in the population of the oriental fruit fly that some poorly favoured hosts, which were formerly attacked when fly densities were high, became entirely free from damage and even a proportion of usually favoured hosts escaped attack (Clausen et al. 1965). Nevertheless, poisoned protein bait sprays and male lures, together with systemic surface sprays are used both by commercial growers and backyard gardeners to achieve a high level of freedom from fruit fly attack. Such measures are too expensive for routine use by most traditional farmers in Pacific countries.

Over the decade following the establishment of *Fopius arisanus* and *Diachasmimorpha longicaudata* in Fiji, fruit damage (mainly caused by *Bactrocera passiflorae* and *B. xanthodes*) is reported to have diminished, although not to the same extent as with *B. dorsalis* in Hawaii. One possibility is that *B. passiflorae* and *B. xanthodes* are less suitable hosts for the parasitoids than *Bactrocera dorsalis*. Another is that the Fijian fruit flies may be less effectively attacked in some host fruits than in others, for example through the well known habit of *Fopius arisanus* paying little attention to fallen fruit. Thus any fruit fly species that oviposits in fallen fruit, as does *Bactrocera passiflorae*, is likely to escape attack there by this species. A less likely third possibility that remains to be explored, is that the mortality produced by the introduced parasitoids has little more than replaced that caused earlier by native parasitoids. An even lower impact than in Fiji has been reported on the Queensland fruit fly following the establishment of *Fopius arisanus* in Australia. Any or all of the three possible explanations discussed above may also apply in this case.

The conclusion emerging from the foregoing is that it would not be possible to predict the effects of introducing parasitoids to the oceanic Pacific without more information on such matters as (i) whether the target fruit flies are suitable hosts for the candidate parasitoids (ii) what level of parasitisation, if any, is already being achieved by native or already introduced parasitoids, (iii) whether the target fruit flies commonly oviposit in fallen fruit and (iv) what are the major hosts of the target fruit flies. Nevertheless, if parasitoid establishment does occur, it is logical to assume that there will be a reduction in abundance of adult fruit flies, whether or not this is of practical significance.

These considerations should next be examined in the context of the three situations in which fruit fly control is desired by Pacific countries.

1. Export produce. Complete freedom from living fruit fly stages is demanded and, to achieve this, it is essential either to eradicate all fruit flies that infest export produce or to have some effective and acceptable commodity treatment that kills all eggs and larvae, but does not damage the produce. Commodity treatment may take the form of fumigation, heat, cold, radiation treatment or a combination of these. Biological control will not eliminate the need for an effective treatment, but any decrease in adult abundance (and hence intensity of attack on host fruit) will provide some added security that the treatment will be effective, since fewer eggs and larvae are likely to be present.

2. Produce for the local market. Freedom from fruit fly attack is highly desirable, but not essential. This standard of freedom may be achieved by the farmer selecting for sale produce that is, or appears to be, sound, by picking it green and so still insusceptible to fruit fly oviposition, by bagging it on the tree or vine before ripening, or (probably less frequently) by chemical means. Any reduction in adult fruit fly abundance that leads to lessened oviposition in favoured hosts, or to freedom from oviposition in less favoured hosts, will be valuable.

3. Produce for home or village consumption. Biological control of fruit flies will be of greatest value in this situation, where sound portions of infested fruit are often eaten and chemicals seldom used. This is also the situation where levels of parasitisation are likely to be highest, firstly because insecticides are unlikely to be present to have an adverse effect on the parasitoids and secondly, because of lack of synchrony of plantings, all stages of fruit fly hosts are likely to be available for parasitisation over extended periods. This encourages the build up of parasitoids to maximum attainable levels.

To sum up, the establishment of fruit fly parasitoids in the oceanic Pacific will almost certainly result in **some** reduction in the abundance of the target pest(s) but, with existing knowledge, it is not possible to predict whether the degree of reduction will be really valuable (as in Hawaii), useful but not really adequate (as in Fiji) or of little significance (as in Australia). There is no evidence to suggest that parasitoid establishment would result in any adverse effects. Establishment of parasitoids is likely to be of greatest value to the traditional farmer, of some value for reducing infestation in produce destined for the local market, but of far more limited value for export produce.

If biological control is to be attempted, one of the essential first steps would be to establish whether each target species will serve as a suitable host for each candidate parasitoid. If not, there would be no justification for releasing it in the field against that species. Although it would be desirable to establish a laboratory colony of the flies for this purpose, infested fruit collected in the field and exposed to the parasite in the laboratory will serve to establish whether parasitisation occurs and whether high levels can be attained. Depending upon the parasitoid species involved, it will be necessary to supply fruit containing eggs or young or older larvae. Of course, this rather artificial test will not indicate whether the parasitoid's behaviour will permit it to search, for example, in fallen fruits or cucurbits on the ground. It is thus only a first step to exclude clearly irrelevant species on such grounds as whether the host encapsulates the parasitoid egg, or is nutritionally or otherwise unacceptable. A further problem is that a number of tephritid parasitoids have been uncooperative under caged conditions, even when supplied with their native hosts.

The situation with the melon fly *Bactrocera cucurbitae* is rather different from that of fruit flies native to the Pacific. This is because its main attack is on Cucurbitaceae, which are not hosts of most other Pacific fruit fly species, although *B. xanthodes* has caused problems in Tonga in export watermelons which were not sound. Probably because of the lack of significant competition for the hosts that it prefers, *B. cucurbitae* has spread successfully to a number of countries (Hawaii 1895, Guam 1936, Papua New Guinea 1980, Nauru 1982, Solomon Is 1984, Kiribati 1987). In Solomon Is it will doubtless spread still further eastwards and southwards, providing a very serious threat to Vanuatu and the southwest Pacific. Any impediment to this spread, such as eradication from Nauru and reduction of populations elsewhere by the establishment of parasitoids, may be economically rewarding. It is clear that, under some circumstances, as demonstrated initially in Hawaii, the establishment of *Psyttalia fletcheri* can produce a valuable reduction in host infestation. A useful level of impact may be possible on melon fly in Papua New Guinea and Solomon Is. There thus appear to be sound reasons for giving serious consideration to establishing *P. fletcheri* (and perhaps other melon fly parasitoids) in both countries. Of other possible parasitoids, *Diachasmimorpha dacusii* produces significant parasitisation of melon fly in India and thus might be considered seriously, in spite of the fact that the release of some 100,000 adults in Hawaii failed to result in its establishment. Other melon fly parasitoids that might merit further study are *Diachasmimorpha albobalteatus* and *Fopius skinneri*. Then again, if *F. arisanus* were

established in both Papua New Guinea and Solomon Is it would doubtless parasitise a small number of *Bactrocera cucurbitae* eggs and kill others without parasite development, particularly when its fruit fly hosts occurred in the same vegetables or fruits as the melon fly. However, higher priority should clearly be given to a thorough search within the natural range of the melon fly for parasitoids that colonise it effectively in cultivated plants, or its puparia in the soil in cultivated areas.

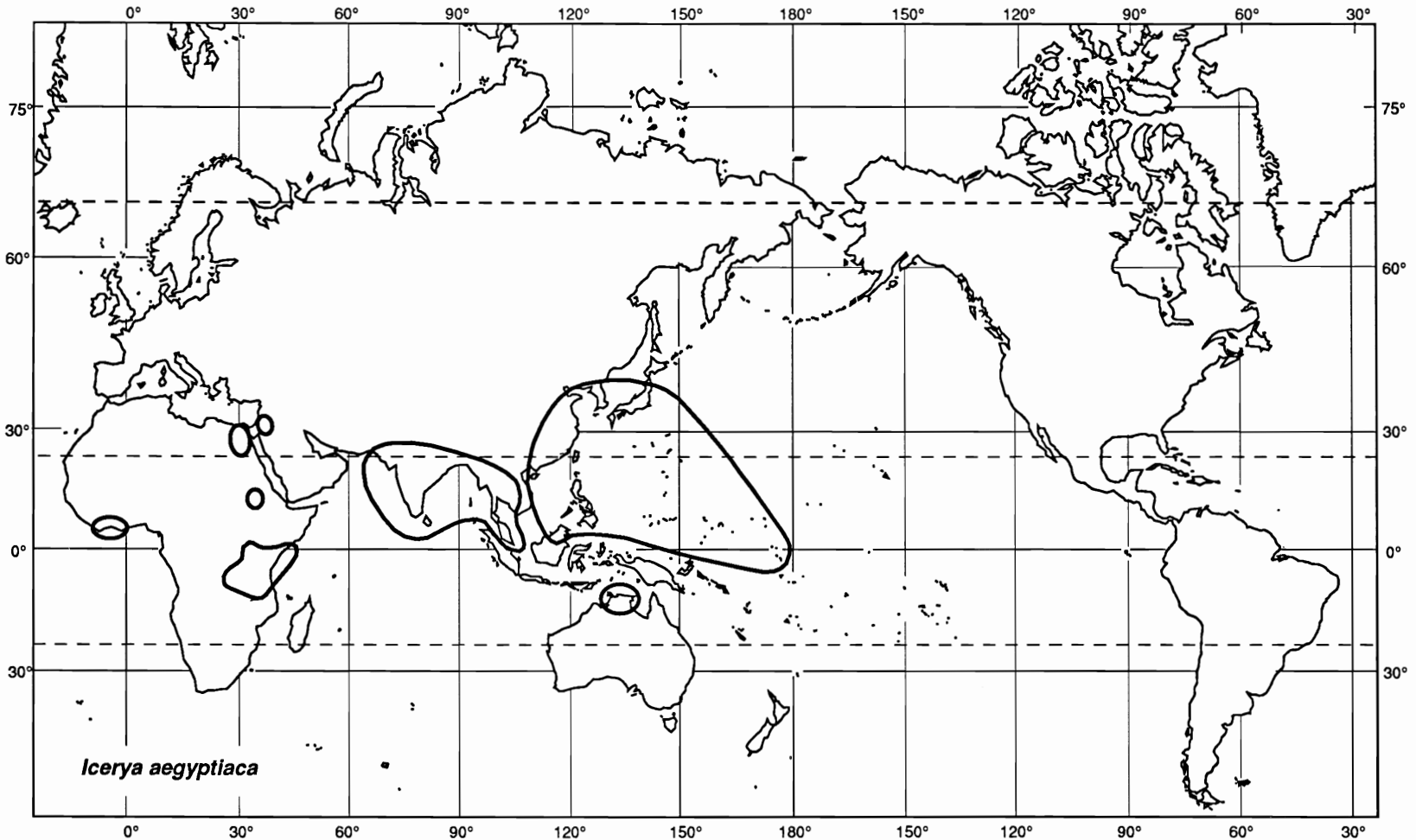

Figure 3.1 World distribution of *Icerya aegyptiaca*

3 *Icerya aegyptiaca* (Douglas)

Hemiptera: Margarodidae
breadfruit mealybug, Egyptian fluted scale, Egyptian mealybug.

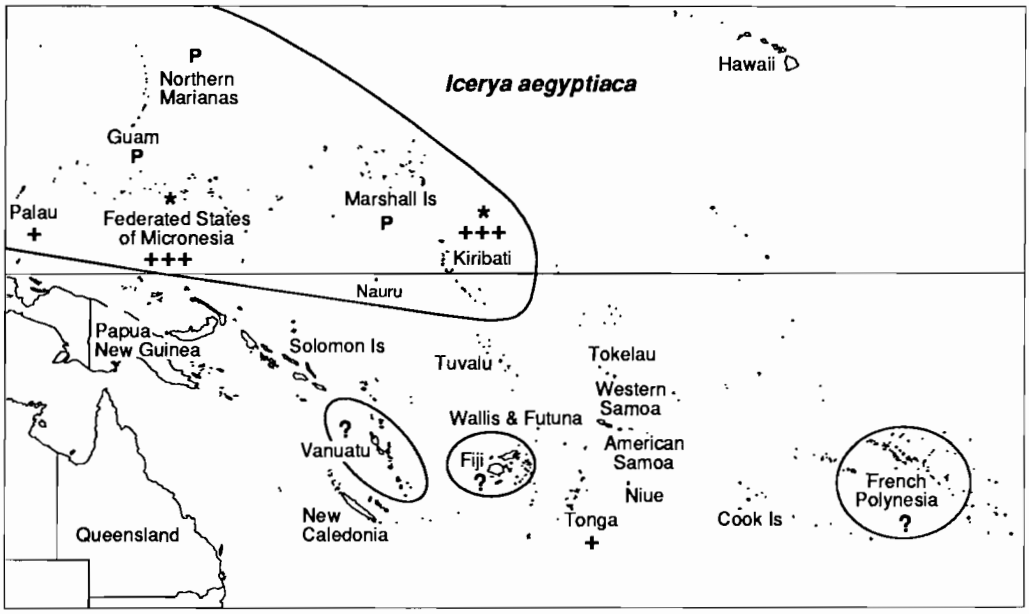

Figure 3.2 Pacific distribution of *Icerya aegyptiaca*

Icerya aegyptiaca is probably of Indian or Oriental origin. It is widespread in Asia and also present in a number of tropical and subtropical countries in Africa. It is uncommon in northern Australia, widespread in Micronesia and a major pest in Kiribati and several atolls in the Federated States of Micronesia.

It is specially damaging to breadfruit in the Pacific, but also attacks avocado, banana, citrus, taro and many other plants of food or ornamental importance. On breadfruit the mealybug is usually found along the midribs and larger veins on the undersides of the leaves, and also on the fruit. Heavy infestations reduce yield and may even kill the tree. Copious amounts of honeydew are secreted which provide a substrate for an abundant growth of sooty moulds which seriously interferes with photosynthesis.

In the western part of its presumed native range (Pakistan and India) it is preyed upon by at least two native coccinellid beetles, *Rodolia breviuscula* and *Pullus coccidovora*, and attacked by at least two promising parasitoids, especially the fly *Cryptochetum grandicorne*, but also a wasp *Tetrastichus* sp.. In the eastern part of its native range (China) there is a further coccinellid predator, *Rodolia pumila*, which has been used effectively for biological control in the high islands of Micronesia. *R. pumila* is believed to be specific to *Icerya* spp. and closely related scales and appears to be the species of choice for biological control of *I. aegyptiaca* in the Pacific. However, it appears to have died out from substantial segments, at least, of a number of low coral atolls, possibly after reducing the abundance of its hosts so low that it starved to death. If this sequence is confirmed, it would be well worth while to investigate one or more of the parasitoids and the other predators mentioned, since they may be better able to co-exist with the host at low densities.

Origin

This species is probably of Indian or Oriental origin. It was described by Douglas in 1890 from females collected the previous year from a serious outbreak on fruit trees in Alexandria, Egypt but, in spite of its specific name, it is not native to Egypt.

Distribution

I. aegyptiaca now occurs in tropical and subtropical Africa, Asia, Australia and certain Pacific islands (Figures 1 and 2). Except for the region extending from West Pakistan to Micronesia, its occurrence appears to be contained within relatively limited areas. Apart from a report from Kew Gardens, England (Green 1917), it is not known from Europe or the Americas, although it has been intercepted occasionally at United States ports (Anon. 1960).

In Asia the mealybug is known from China, Hong Kong, India, Israel, Japan, Malaysia, Myanmar, Pakistan, Philippines, Sarawak, Sri Lanka, Taiwan and Thailand (Anon 1960, 1966).

In Africa it is present in Egypt, Ivory Coast, Kenya, Somalia, Sudan and Tanzania (Anon. 1966).

In Australia it is recorded from New South Wales (Froggatt 1906, 1921, Maskell 1894), Northern Territory (P. Gullen pers. comm. 1990) and Queensland (Brimblecombe 1959). However, it is probable that the mealybug occurs continuously only in far northern Australia, since recent intensive searches have failed to find it in southern Queensland (D. Sands pers. comm. 1992).

In the oceanic Pacific it is known from Micronesia. This includes the Federated States of Micronesia (Palau, Yap, Chuuk, Pohnpei, Kosrae), the Marianas (Agiguan, Anathan, Cocos, Guam, Pagan, Rota, Saipan, Tinian), Marshall Is, Wake Is, Kiribati and Nauru (Anon. 1960, Beardsley 1966, Esguerra 1991, Maddison 1976, Oakley 1946, 1953, Waterhouse 1991a, Williams 1985b). It does not appear to be present in Tuvalu (T. Teii pers. comm. 1989). Although it has been recorded from Fiji, specimens labelled Fiji in the British Museum (Natural History) were intercepted there from Kiribati. There are no specimens of *I. aegyptiaca* among the enormous collection in the British Museum of scales from Melanesia and Polynesia (D.J. Williams pers. comm. 1989). This throws serious doubt (Williams and Watson 1990) on the correct identification of its presence in Vanuatu (Bennett et al. 1976), French Polynesia (Tahiti) (Doane and Hadden 1909) and American Samoa (Dumbleton 1957). It seems probable that it was confused with the related *Icerya seychellarum.*

Beardsley (1955) suggests that *I. aegyptiaca* may have gained entry into Micronesia from Taiwan, but just when is not documented. It was often intercepted in quarantine prior to 1922 in Yokohama on plants from the Marshall islands (Kuwana 1922) and pre-1928 records are available for Palau (Federated States of Micronesia), Saipan and Tinian (Mariana Is) (Beardsley 1955, Esaki 1940a, b, Sakimura 1935, Takahashi 1939). However, Swezey (1940) did not record its presence in Guam during his 1936 survey of pests of cultivated plants, including breadfruit, so it may not yet have been introduced there at that time.

The first record for Kiribati (Butaritari, Makin, Tarawa) is 1953 (Hall 1953), for Fiji 1961 (Anon. 1966), for Nauru 1980 (Williams 1985b) and for French Polynesia (Tahiti) 1908 (Doane and Hadden 1909). The earliest record for the general region is 1893 for New South Wales (Maskell 1894).

Life Cycle

The life cycle and anatomy of *I. aegyptiaca* has been studied in some detail in Egypt (Azab et al. 1969). Only females occur and most stages are present all year round. The duration of the life cycle stages, when grown on sprouting potato tubers, is shown in Table 3.1 with, in brackets, the temperatures at which the observations were made. The

duration of the life cycle ranged from an average of 105.4 days at 26.4°C to 87.2 days at 28.7°C. Each year there were two full generations and a partial third, with a peak in adult abundance in summer. After a pre-oviposition period of 10 to 20 days, females laid an average of 70 eggs at 24.1°C, or 143 at 27.3°C (or 150 to 200 eggs, Anon. 1960), into a waxy egg sac (average length 4.4 mm). attached ventrally to the tip of the abdomen. The yellowish-orange eggs are oval and average 0.65 mm x 0.34 mm. The egg sac is ruptured by the emerging first instar larvae (nymphs). These bright orange crawlers settle within a day and become covered by a waxy covering within two days. Near the anus there develops a long, waxy, thread-like filament which receives droplets of honeydew as they are discharged. Antennae are six-segmented. The second instar larvae are yellow to orange, oval, average 1.43 mm x 0.98 mm and are soon covered with a white mealy secretion. They are fringed with 21 snow-white waxy processes. One process comes from the midpoint of the posterior end of the abdomen, six from either side of the abdomen and four from either side of the thorax. Antennae are six-segmented. Third instar larvae average 2.2 mm x 1.5 mm. They are yellow to orange and are covered with a white mealy secretion and their 21 stout, tapering, snow-white processes are about 2.5 mm long. Antennae are nine (rarely eight)-segmented. The deep orange adult (Plate 1, Fig. 5) is broadly oval, and averages 3.1 mm x 2.2 mm (or 5 to 7 mm x 3 to 4 mm, Rao 1950). Its abdomen is slightly convex dorsally and flattened ventrally. The legs are blackish and the antennae are 11-segmented. The dorsal surface is covered with cushions of white mealy secretion, mingled with granular wax. Through this waxy covering the body appears salmon-pink. Of the 21 waxy processes, those on the thorax reach 3 mm in length and are considerably stouter than the 8 paired abdominal processes, which average 4 mm (Azab et al. 1969).

Table 3.1 Life cycle details of *I. aegyptiaca* (after Azab *et al.* 1969).

Stage	**Days (Average) at (°)**		
Preoviposition	16.6(22.9°)	14.2(25.6°)	15.0(29.0°)
Oviposition	33.5(24.2°)	42.3(27.3°)	
Egg incubation	10(24.0°)		8.6(29.7°)
1st instar			19.0(29.6°)
2nd instar			9.8(29.6°)
3rd instar			20.7(29.3°)
Duration of life cycle		105.4(26.4°)	87.2(28.7°)
Adult longevity	102(23.7°)		66.0(28°)
Number of eggs/female	70(24.1°)	143(27.3°)	

The cuticle of the dorsum is covered with many hairs of several sizes, those of the margins of the abdomen being larger and arranged in small groups. A few long setae are present in the anal region (Rao 1950). Details of the wax-secreting and other glands and morphological characteristics of *I. aegyptiaca* and other species of *Icerya* that occur in the Orient are provided by Green (1932) and Rao (1950).

Although there is casual mention, in brief accounts (Bodenheimer 1924, O'Connor 1969), of male *I. aegyptiaca*, only females are recorded by many other authors and no males have been found in extensive collections (D.J. Williams, pers. comm. 1990). Adult *I. aegyptiaca* females are parthenogenetic and not hermaphroditic (Hughes-Schrader 1963). On the other hand, the notorious cottony cushion scale *Icerya purchasi* is a self-fertilising hermaphrodite, externally seemingly female, but having an ovotestis. In *I. purchasi*, males are produced very occasionally, so that cross-fertilisation is possible

(White 1979). Alate males occasionally develop also in the related *I. seychellarum* and it is suggested that hermaphroditism may exist in this species also (Williams and Watson 1990).

Pest status

The greatest economic impact of *I. aegyptiaca* in the Pacific is on the breadfruit tree *Artocarpus altilis*, of which many taxa are grown in the region. On many of the low coral atolls in the Pacific, which necessarily have a very limited agricultural potential, breadfruit is second only in value to the coconut. So important is the crop in Micronesia that, at harvest, excess breadfruit is pounded into a paste and stored in rock-lined pits for future use. In addition, Micronesian peoples traditionally depend on breadfruit timber for making ocean-going canoes for fishing and travel (Beardsley 1955).

Although it may infest the fruit, *I. aegyptiaca* is usually situated along the midribs (Plate 1, Fig. 4) and larger veins on the undersides of the breadfruit leaves. The large quantities of sap removed by the mealybugs cause immature leaves and stems to dry up and die. Heavy infestations may, in fact, kill even mature breadfruit trees (Clausen 1978a, Pemberton 1954), but more usually the trees are partially defoliated and the crop reduced, sometimes by 50%, or more. In addition to these direct effects, the mealybugs produce large quantities of honeydew, which provide a substrate for an abundant growth of sooty moulds, covering the upper surfaces of all but the youngest leaves of heavily infested trees and seriously interfering with photosynthesis (Beardsley 1955). Prolonged dry weather appears to favour the build-up of heavy infestations and, partly due to this factor, populations of *I. aegyptiaca* may vary considerably in abundance from year to year. In the Pacific important economic plants other than breadfruit that may suffer from heavy mealybug attack include avocado, banana and citrus, and infestations may also occur on taro (*Colocasia esculenta* and *Alocasia macrorrhiza*), pandanus and young coconut palms. Some widely cultivated ornamentals are also hosts. These include roses, *Acalypha wilkesiana, Codiaeum variegatum* and *Pseuderanthemum* sp.. Several common weeds, such as *Cassia mimosoides* and *Jatropha gossypifolium* are commonly infested (Beardsley 1955). In the Gilbert and Ellice Is (probably referring to Kiribati) Manser (1974) listed as hosts not only breadfruit (*Artocarpus altilis*), but also banana, citrus, coconut, *Calophyllum inophyllum, Casuarina equisetifolia, Cyrtosperma chamissonis* (babai), *Ficus tinctoria* (wild fig, te boro), *Ipomoea tuba, Pluchea odorata* and *Scaveola frutescens*. Letters on file indicate that pandanus and papaya are hosts and the worst affected ornamental is a red-leaf *Coleus* sp. (G.S. Sandhu pers. comm. 1989). Maddison (1976) added tomato and Williams and Watson (1990) *Lugwigia capitata, Musa paradisiaca, Pemphis acidula, Pluchea indica, Scaveola koenigi, Synedrella nodiflora* (tearama), *Vernonia* sp. and *Zea mays*. On Butaritari, infestations on breadfruit may be serious enough to prevent them from bearing any crop (Teuriaria 1988). Although it has been recorded in Tahiti for at least 35 years it has not yet been found on breadfruit. However, it may have been mistaken for *Icerya seychellarum*, so the record needs confirmation. The mealybug was recorded from *Acacia, Citrus, Coffea*, locust, *Psidium*, and roses (Doane and Hadden 1909, Rao 1950), but it is not an important pest and is seldom found (R. Putoa pers. comm. 1989).

I. aegyptiaca is generally uncommon in Australia, but continues to be reported from time to time in the Northern Territory from *Acalypha* sp., *Andrographis paniculata*, coconut, croton, mango and *Mimosa pigra* (P. Gullen pers. comm. 1990). In the Darwin area it can be a minor pest from time to time of decorative plants, particularly palms. It seems probable that the few records from further south are due to the mealybug surviving temporarily on plants brought from the north or on host plants to which these mealybugs transferred. Many additional host plants are reported in other countries. Examples of economic host plants include: East Africa: coffee, date palm, fig, mulberry, rose (Fiedler

1950, Lindinger 1913, Newstead 1917, Ritchie 1929, 1930), Egypt: citrus, fig, guava, mango, rose (Abul-Naser et al. 1976, Azab et al. 1969, Hall 1924, Tawfik 1969), Pakistan: coffee, fig, guava, tea (Mahdihassan 1976, Muzaffar 1970), India: breadfruit, citrus, custard apple, fig, guava, jackfruit, mulberry, rose (Ayyar 1919, Glover 1935, Rao 1950, Siddapapaji et al. 1984), Bangladesh: jackfruit, hizol, croton, sunflower, guava, pomegranate, rose (Ullah and Chowdhury 1988), Sri Lanka: pomegranate, rose (Hutson 1929, Speyer 1918), Japan: citrus (Rao 1950), China: citrus (Silvestri 1929), Taiwan: citrus, tea (Shiraki 1920, Takahashi 1937), Philippines: citrus, mulberry (Rao 1950). Although a few of these records indicate economic damage as a result of *I. aegyptiaca* infestation, the majority simply list its presence without special mention of its importance. In some instances, *I. purchasi* and/or *I. seychellarum* were also noted as being present.

It is possible that there may be strains of *I. aegyptiaca* with different host preferences. Thus Esaki (1940a) recorded it as a major pest of citrus in Micronesia, but made no mention of its occurrence on breadfruit on Guam or Palau, although he listed other breadfruit pests, and Swezey (1940) also made no mention of it attacking breadfruit in Guam in his survey there in 1936, once again listing other breadfruit pests. It is still rare on breadfruit and other hosts in Guam (D. Nafus pers. comm. 1990) Takahashi (1936b) recorded it in Saipan on avocado and in Tapocho on cotton, but in neither place from breadfruit. However, in 1941 he recorded it in Chuuk on breadfruit.

In what is probably its native range, the abundance of *I. aegyptiaca* varies considerably from place to place. Thus, in Pakistan it was recorded only in coastal and subcoastal areas around Karachi and Thatta, being more abundant in the former area, possibly because of a preference for a comparatively mild and damp climate (Muzaffar 1970). In Taiwan Takahashi (1937) states that it was not found in the mountains, although it was common at low elevations.

Control Measures

There are very few papers dealing with the chemical control of *I. aegyptiaca.* Early reports (Beshir and Hosny 1939, Glover 1935, Shafik and Husni 1939) indicated that tar distillate, kerosene soap or mineral oil emulsions were effective. More recently, Yadav and Reddy (1982) found that monocrotophos gave effective control of the mealybug on *Ficus glomerata.* White oil has been used in Kiribati and also a commercial mixture of pirimiphos methyl and permethrin (G.S. Sandhu pers. comm. 1989). Paucity of recommendations for chemical control suggests either that damaging outbreaks are sporadic in most countries, or that effective biological control is frequently attained.

Natural enemies

The main natural enemies of *I. aegyptiaca* are shown in Table 3.2. It appears that the most important are predaceous coccinellids of the genus *Rodolia* (Plate 1, Fig. 6), although too little is known about the effectiveness of the two dipterous and three hymenopterous parasitoids listed. In addition to these records there is a comment by Maskell (1894) that specimens of *I. aegyptiaca* obtained from Madras were accompanied by parasitoids which, unfortunately, were not identified.

The most comprehensive papers on the natural enemies are those of Muzaffar (1970, 1974) for the coastal and subcoastal areas around Karachi and Thatta (West Pakistan) . Of the two predatory beetles present, *Rodolia ruficollis* fed voraciously on all stages of *Icerya* and invaded heavy infestations, whereas *Pullus coccidivora*, whose feeding capacity was reported to be low, turned its attention particularly to eggs and first instar larvae in both low and high host densities. One *R. ruficollis* was reported present for every 500 to 2,700 mealybugs on *Phoenix dactylifera* as plant host and one to three *P. coccidivora* were found feeding in 2 to 5% of *Icerya* egg clusters. The parasitisation rate by the fly

Cryptochetum grandicorne on the 4 plant hosts on which it attacked *I. aegyptiaca* in the coastal area was 3 to 22% on *Erythrina* sp., *Morus alba* and *Phoenix dactylifera* and 5.4 to 38.4% on *Rosa indica*. *C. grandicorne* was not present in subcoastal areas, possibly due to lower humidity. Attack by the wasp *Tetrastichus* sp. and the predator *P. coccidivora* occurred on all kinds of host plant infested by *I. aegyptiaca*, whereas *C. grandicorne* and the predator *R. ruficollis* were absent from several plant species.

Table 3.2 Main natural enemies of *Icerya aegyptiaca*.

Insect	Location recorded	Reference
Neuroptera		
CHRYSOPIDAE		
Chrysopa spp.	Micronesia	Beardsley 1955
Chrysopa basalis	Kiribati	Manser 1974
Chrysoperla carnea	Egypt	Azab et al. 1969
Coleoptera		
COCCINELLIDAE		
Coelophora inaequalis	Likiep	Beardsley 1955
Cryptolaemus montrouzieri	Saipan, Palau, Yap	Esaki 1940a, Schreiner 1989
Harmonia octomaculata (= *H. arcuata*)	Likiep, Jaluit	Beardsley 1955
Menochilus sexmaculatus	Bangladesh	Ullah and Chowdhury 1988
Pullus coccidivora	Pakistan	Muzaffar 1970, 1974
Rodolia breviuscula	India	Chapin 1965, Glover 1939, Subramaniam 1954
R. cardinalis	Egypt	Azab et al. 1969, Marchal 1908
	Guam	Dumbleton 1957
	Kiribati	Dumbleton 1957
	Malta	Borg 1930
	Palau	Esaki 1940a
	Saipan	Esaki 1940a
	Society Is	Dumbleton 1957
R. pumila	see Table 3	
R. ruficollis	Pakistan	Muzaffar 1970, 1974
Rodolia sp.	Palau	Dumbleton 1957
Scymnus sp.	India	Siddapapaji et al. 1984
Diptera		
CRYPTOCHETIDAE		
Cryptochetum grandicorne	India	Subramaniam 1949
	Pakistan	Muzaffar 1970, 1974
TACHINIDAE		
Masicera sp.	Sri Lanka	Hutson 1922
Hymenoptera		
EULOPHIDAE		
Tetrastichus sp.	Pakistan	Muzaffar 1970, 1974
Tetrastichus purpureus	Bangladesh	Ullah & Chowdhury 1988
PTEROMALIDAE		
Oricoruna arcotensis (=*Pachycrepoides coorgensis*)	India	Bouček 1978 Mani & Kurian 1953

Parasitisation by *Tetrastichus* sp. was higher in the subcoastal than the coastal area and occurred on all plants, irrespective of the degree of infestation. Thus, it parasitised 5.4 to 14.5% of mealybugs on *Psidium guajava* in the subcoastal and 1.6 to 5.4% in the coastal area. Parasitisation was highest on *Morus alba*, being 13 to 19% in the subcoastal area. An average of 2 *Tetrastichus* sp. adults could develop in a second instar mealybug, 5 in a third instar, and 12 in an adult female.

In India collections of *I. aegyptiaca* from rose and croton showed up to a maximum of 90% parasitisation by *Cryptochetum grandicorne*, with a lower level of 20% (Subramaniam 1949). This suggests that, under appropriate conditions, this parasitoid can be very important.

In Bangladesh *I. aegyptiaca* is attacked by the parasitoid *Tetrastichus purpureus*, the ladybird *Menochilus sexmaculatus* and probably by spiders. Nevertheless, it is sometimes regarded as a pest of guava and croton (*Codiaeum variegatum*) (Chowdhury pers. comm. 1992, Ullah and Chowdhury 1988).

I. aegyptiaca occurs, together with *I. purchasi* and *I. seychellarum* in the Darwin area of northern Australia. No parasitoids have been reared from *I. aegyptiaca* in current preliminary surveys, although two species of *Cryptochetum* and other parasitoids have emerged from the other two mealybugs. All three species are preyed upon by *Rodolia* spp. (D. Sands pers. comm. 1992).

Attempts at Biological Control

EGYPT

I. aegyptiaca was reported as a serious pest of citrus, figs and shade trees in Egypt about 1890. With the recently recorded spectacular success against *I. purchasi* of *Rodolia cardinalis* in mind, that predator was introduced from California in 1892 and, with a nucleus of only six beetles, establishment was obtained. This resulted in successful biological control (Clausen 1978a, Marchal 1908).

ISRAEL

Neither the fly *Cryptochetum iceryae* nor the South African coccinellid *Rodolia iceryae* were able to develop on *Icerya aegyptiaca*, although the latter was successfully attacked by *Rodolia cardinalis* (Mendel and Blumberg 1991).

MICRONESIA

The documentation of the many attempts at biological control of *I. aegyptiaca* in Micronesia is far from complete (Tables 3.3, 3.4). Three factors contribute to uncertainty regarding what actually happened. One is the absence of information on when this mealybug arrived in the various regions, a situation complicated by confused identifications caused by the presence, at times, of *I. purchasi* (now known to have been in Guam, Wake Is, Eniwetok and Kwajalein (Marshalls) and Tarawa (Kiribati)) and of *I. seychellarum* in Palau, Yap, Caroline atolls, Ocean Is, Kiribati and Tuvalu (Beardsley 1966, D.J. Williams pers. comm. 1989). Another is that *R. cardinalis* was obtained from Hawaii and released in Guam in 1926 against *I. purchasi* (but not against *I. aegyptiaca*) (Nafus and Schreiner 1989, Vandenberg 1928). This introduction resulted in extremely low populations of both pest and predator, leading Vandenberg (1928) to suggest that reintroductions of the predator might be necessary every few years. However, an outbreak of *I. purchasi* in Guam in 1929 was quickly brought under control by the predator, thereby lessening those fears (Vandenberg 1931). Nevertheless, it is interesting that *R. cardinalis* was last recorded in the region in 1945 (Chapin 1965, Nafus and Schreiner 1989). The disappearance of *R. cardinalis* is possibly correlated with the establishment (see below) of *R. pumila* (D. Nafus pers. comm. 1990).

Table 3.3 Introductions of *Rodolia pumila* to Micronesia against *Icerya aegyptiaca*. Schreiner (1989) source of all records not otherwise referenced.

Release Site	Source	Year	Established (recovery date)	Comments
FEDERATED STATES OF MICRONESIA				
Palau State				
Fais	Palau	1954	?	Beardsley 1955
	Ulithi	1971	?	
Ulithi atoll	Saipan	1948	+(1950)	Beardsley 1955
	Palau	1954	+(1957)	but serious outbreak in 1964
	Palau	1964	+	but serious outbreak in 1984
Truk State				
Mortlock Is	Palau	1964	?	
Losap	?	pre 1941	+	Beardsley 1955
Nama	Pis islet	1949	+(1950)	Beardsley 1955
	Losap	1950	?	
	Losap	1954	+	Beardsley 1955, but later reported absent
	Losap	1964	?	
Namoluk	Palau	1960	?	
Nomwin	Palau	1954	+(1954)	Beardsley 1955
Pis	Rota	1947	+(1949,1954)	Beardsley 1955
Ponpeh State				
Ngetik	Palau	1970	?	
	Palau	1977	?	
Kosrae State	Palau	1976	-	died in transit
	Palau	1977	+(1984)	
Mariana Is				
Anathanan	Belau	1959	-	Nafus & Schreiner 1989
Rota	?	?	+(1947)	Pemberton 1948
Saipan	Taiwan	1928	+	Beardsley 1955
Marshall Is				
Alinglaplap	Guam	1949	+(1950)	Beardsley 1955
Aur	Palau	1977	?	
Jaluit	Palau	1953	+(1954)	Beardsley 1955
	Palau	1954	-	
	Palau	1958	-	
	Palau	1961	+	but eliminated by typhoon
	Palau	1964	+	
Kwajalain	Guam	1949	+	but then disappeared, Beardsley 1955
	Palau	1953	+(1958)	present in 1959, Beardsley* 1959
	Palau	1965	?	
	Palau	1980's	?	not seen in 1987
Lac	Palau	1953	?	
Majuro	Kwajalein	1963	-	
	Palau?	1964	+	declined even before scales gone: perhaps present in 1970
	Palau	1971	?	
	Palau	1972	+	
	Palau	1980's	?	
Rongelap	Palau	1972	+	but scale outbreaks reported later
	Palau	1973	?	

* The record in this paper of the presence also of *Rodolia breviuscula* is due to a misidentification of *R. pumila* (J. Beardlsey pers. comm. 1990)

Table 3.4 Introductions of natural enemies of *Icerya aegyptiaca* other than *Rodolia pumila*.

Agent & Location	Source	Year	Established	Reference
Cryptolaemus montrouzieri				
Mariana Is				
Saipan	?	?	+(1940)	Esaki 1940a
Federated States of Micronesia				
Palau	?	?	+(1940)	Esaki 1940a
Rodolia breviuscula				
Mariana Is				
Guam	India	1948	-	Chapin 1965, Dumbleton 1957 Pemberton 1954 Subramaniam 1954
Marshall Is				
Majuro	India	1948	-	Chapin 1965, Pemberton 1953
Uliga	India	1948	-	Chapin 1965
Rodolia cardinalis				
Egypt	California	1892	+	Marchal 1908
Kiribati				
(Butaritari)	Fiji	1953	?	Hall 1953
Mariana Is				
Guam	Hawaii	1926	+	Dumbleton 1957
Saipan	Taiwan	1928	?	Dumbleton 1957
Marshall Is				
Kwajalein	?	1958	-	Clagg 1959, Schreiner 1989
Likeap	?	1958	-	Schreiner 1989

The third factor is that *R. pumila*, the only widespread coccinellid now attacking *I. aegyptiaca* in Micronesia, was brought in at some time before 1941 to Saipan, probably from Taiwan, but was at that time referred to as *R. cardinalis*, although it lacked the latter's characteristic spots (Beardsley 1955). There are no records of *R. pumila* being intentionally moved within the Marianas at that time, although it has since been suggested that it must either have spread accidentally or have been widely distributed by the occupying Japanese forces. Indeed, a Chuuk islander recalled a red beetle being released about 1940 in Losap (Chuuk State) (Beardsley 1955). It is interesting that *R. pumila* was introduced from China to Hawaii in 1895 against *I. purchasi*, but apparently failed to establish (Lai and Funasaki 1986).

The outcome of these releases (Table 3.3) was that *R. pumila* had been established on most of the high islands of Micronesia by the 1950s (Beardsley 1955, Chapin 1965) and that *Icerya* is no longer considered as a pest there (Schreiner 1989). More recently, *R. pumila* was introduced (in 1977) to the high island of Kosrae (Federated States of Micronesia), its presence recorded in 1984, and mealybugs reported to be uncommon in 1986 (Schreiner 1989).

In contrast with these results on high islands are those for atolls, where fragmentary information suggests that *R. pumila* has been less successful, As can be seen in Table 3.3, it has been repeatedly introduced to some atolls, but it is seldom clear whether it has really become established, whether it has died out at some time after temporary establishment, or whether it might have been present ever since the first introduction. Schreiner (1989)

suggests that, on very small atolls, some of which have areas of only a few hectares, *R. pumila* may have died out once scale populations were reduced to very low levels. Since *Rodolia* is reported to be a specific predator of *Icerya* and related scales, and since it requires to consume a number of hosts in order to develop, this is quite possible. She also suggests that typhoons may have played a part in eliminating the predator.

Although *R. pumila* was reported on Kwajalein (Marshall Is) in 1950, it could not be found in 1953, possibly due to the liberal use there of DDT to control flies and mosquitoes. With the exception of Kwajalein, *I. aegyptiaca* is no longer a serious problem on any of the larger islands where *R. pumila* has been introduced. However, on the low island of Jaluit it was abundant in 1989 and *R. pumila* could not be found, although it had been introduced and established several times previously (Table 3.3). *I. aegyptiaca* was also common on Majuro and Likiep, but so was *R. pumila* (D. Nafus pers. comm. 1990). *R. pumila* is also known to control *Steatococcus samaraius* in the Palau Is and may be largely responsible for the scarcity of *Icerya seychellarum* in both Yap and Palau (Beardsley 1955).

Rodolia breviuscula was introduced in 1948 from India to Guam, but the few individuals liberated failed to establish the species (Table 3.4). Another coccinellid *Cryptolaemus montrouzieri* was established in Saipan and Palau in 1940 (Esaki 1940a). This species has occasionally been observed attacking *I. aegyptiaca* in the Mariana Is (Beardsley 1955). Two coccinellids that have found their way into the Pacific are recorded as attacking *I. aegyptiaca* in the Marshall Is, *Coelophora inaequalis* at Likiep and *Harmonia octomaculata* at both Likiep and at Jaluit Atoll (Beardsley 1955). The former is predominantly a predator on aphids.

Adults and larvae of green lacewings (*Chrysopa* spp.) were observed at Likiep preying on *I. aegyptiaca* and greatly reducing their numbers. They also brought about considerable reduction on Fais (Palau State) and Lae (Marshall Is). At Fais many *Chrysopa* pupae were attacked by a hymenopterous parasitoid, possibly *Isodromus* sp. (Beardsley 1955).

Entomogenous fungi may also play an important part in the natural control of *Icerya* spp., particularly during wet weather, although few details are available (Beardsley 1955).

KIRIBATI

I. aegyptiaca was first reported in 1953 on the two northernmost islands of the group, Makin and Butaritari (where the Americans had a station) and some months later was found on Tarawa. It now ocurs on all 16 islands in the Tungaru group, extending from Makin to Arorae (G.S. Sandhu pers. comm. 1989). In 1953, very shortly after it was first reported, *R. cardinalis* from Fiji was liberated on Butaritari (Hall 1953) (Table 3.5). It increased very rapidly in numbers and spread extensively. In September 1955, 12 adult

Table 3.5 Introductions to Kiribati of biological control agents aginst *I. aegyptiaca*.

Species	Origin	Year	Established	Comment
Rodolia cardinalis	Fiji	1953	+	On Butaritari. Established but died out later.
	Hawaii	1962	+	On Marakei. Established, but died out later.
R. pumila	Marianas	(?1971)	+	Recommended by CIBC in 1971. Observed by Simmonds in 1975
	Guam	1975	?	From R. Muniappan
		1978	-	From R. Muniappan
	Palau	1977	-	From Otobed. Dead on arrival.
	Palau	1979	+	From Otobed, released on Butaritari. Later could not be found.

ladybirds were transferred to Betio (on Tarawa) and in May 1956 some were sent to Fiji for identification. They proved not to be *R. cardinalis*, but another widespread species, possibly *Harmonia octomaculata* (= *Coccinella arcuata*). In April 1957 it was reported that *R. cardinalis* could no longer be found on Butaritari. *R. cardinalis* was again introduced in 1962, this time to Marakei from Hawaii (Simmonds 1976). A decade later, only one individual was found in 1971-72 by Manser (1974) and *I. aegyptiaca* was reported to be a serious pest, so *R. cardinalis* is clearly unable to maintain high enough populations to be an effective natural enemy.

Meanwhile, in 1971 the introduction of *R. pumila* was recommended by CIBC (Teuriaria 1988) and in 1975 larvae (and pupae) of a presumed *Rodolia* sp. were seen on a number of mealybug infestations on breadfruit on Butaritari (Simmonds 1976). Mealybug numbers were generally low, although abundant sooty mould was present. Whether mealybugs were being controlled by the *Rodolia* sp. or whether they were affected by a preceeding long rainy period was not determined.

Ten living *R. pumila* from Guam were liberated on Butaritari in May 1975, but their fate is not recorded (letters on Kiribati files). A small consignment of *R. pumila* from Palau in 1977 arrived with all individuals dead; and one from Guam in 1978, failed to establish. A further shipment from Palau in 1979 was released on infested breadfruit trees on Butaritari, where adults were seen close to the release site two months later (Teuriaria 1988). However no coccinellids were present in September 1989 (N. Teuriaria pers. comm. 1989).

Careful examination of heavy mealybug infestations on breadfruit on Abemama, Butaritari and Tarawa in October 1992 failed to locate coccinellids. It might have been assumed from this that any beetles that had been present at an earlier stage must have died out. However, after careful searching elsewhere, localised (often only small) populations of *I. aegyptiaca* were found, together with larvae and pupae of both *R. cardinalis* (on Tarawa) and *Rodolia pumila* (on Butaritari) (D.P. Sands and G.S. Sandhu pers. comm. 1992). Regular observations, which would present considerable logistic problems, would be necessary to establish whether these coccinellid populations were in the course of disappearing, or whether they were viable; and, if the latter, how soon they would disperse and locate the dense mealybug infestations; also, how rapidly the latter would be reduced to scattered individuals.

Chrysopa basalis was seen preying on the mealybug (Manser 1974) and a few empty cocoons of a chrysopid were reported by Simmonds (1976). This green lacewing is a very common predator, but is unable to control the mealybug (G.S. Sandhu pers. comm. 1989).

There is a record of *Icerya seychellarum* from Kiribati (Williams and Watson 1990) and, although *I. purchasi* has been recorded (Beardsley 1966, Manser 1974), it appears to be very rare (G.S. Sandhu pers. comm. 1989).

POLYNESIA

AMERICAN SAMOA

A note on the file of the Entomologist of the Trust Territory suggests that *Rodolia pumila* was sent from Palau to American Samoa and established in 1961 (D. Nafus pers. comm. 1990).

MELANESIA

VANUATU

An unpublished observation by P. Cochereau to the effect that *I. aegyptiaca* had been (probably early 1970s) controlled by the introduction of *R. cardinalis* to Efate is mentioned by Bennett et al. (1976) but, until specimens are available for confirmation, this must be considered a doubtful record.

Major natural enemies

Rodolia spp.

The genus *Rodolia* is a small one of Indo-Australian origin. Of the three species introduced to the oceanic Pacific (Tables 3.3, 3.4, 3.5) one, *R. pumila*, is widely established, another, *R. cardinalis* (Table 3.6), appears to be known now only from Hawaii and a third, *R. breviuscula*, failed to establish. It is true that *R. cardinalis* became established in Guam for a period after its introduction in 1926, but it has not been seen since 1946. An introduction of this species from Fiji in 1953 is said to have resulted in its establishment in American Samoa (Dumbleton 1957), but doubt must be cast on the authenticity of this record.

Table 3.6 Introductions of *Rodolia cardinalis* in the oceanic Pacific against *Icerya purchasi* and *I. seychellarum*.

Host and Location	Source	Year	Established	Reference
A. *Icerya purchasi*				
Federated States of Micronesia				
Palau	Taiwan	1928	+	Dumbleton 1957
			-	Chapin 1965
Mariana Is				
Guam	Hawaii	1926	+	Chapin 1965
Marshall Is				
Einwetok	Hawaii	1958	?	Pemberton 1958
Kwajalein	Hawaii	1958	+	Beardsley 1962, Clagg 1959
Hawaii				
	Australia	1890	+	Lai & Funasaki 1986
B. *Icerya seychellarum*				
Society Is				
Tahiti	USA	1902	?	Dumbleton 1957
	?	1948	?	Dumbleton 1957
American Samoa				
Tutuila	USA	1952	?	Dumbleton 1957
	Hawaii	1953	?	Bianchi 1954*, Dumbleton 1957
	Fiji	1953	+	Dumbleton 1957

* Mistakenly said to be against *I. aegyptiaca* which does not occur in American Samoa (J. Beardsley pers. comm. 1990)

Some authors (Dumbleton 1957, Gardner 1958) mention introductions of, or the presence of, a closely related *Rodolia* sp. in the Palau Is, but this was *R. pumila* (J.W. Beardsley pers. comm. 1989).

R. pumila can be distinguished from *R. cardinalis* by the uniformly reddish-brown upper surface of the former, compared with the deep red and black upper surface of the latter. The black coloration of *R. cardinalis* occurs on the head, basal margin of the pronotum, the scutellum and markings on the elytra. Adult *R. pumila* are 3.0 to 3.6 mm long and prey on *Icerya* spp. and related scales. They are known to occur naturally in China, Taiwan and Hongkong. Since their assisted distribution, they are also known from Bonin Is (Chichi Jima), Mariana Is (Saipan, Tinian, Rota, Guam, Cocos Is), Palau State

(Babelthuap, Kayangel, Koroi, Ngurukdabel, Ulebsehel, Malakal. Ngerkabesang, Peleliu, Angaur), Yap State (Yap), Chuuk State (Nomwin, Fananu, Tol, Wena, Pis, Nama), Ponpehi State (Ponpehi) and Marshall Is (Kwajalein) (Chapin 1965). However, it is not clear whether populations continue to survive in all these locations. It is interesting that *R. pumila* was introduced in 1895 from China to Hawaii against *Icerya purchasi*, but the outcome is unknown (Lai and Funasaki 1986).

There are records on the Trust Territory Entomologist's files to suggest that *R. pumila* was sent to American Samoa and may have become established in 1961 (D. Nafus pers. comm. 1990) but, if so, this must have been against *I. purchasi* and/or *I. seychellarum* and not *I. aegyptiaca*.

In view of its widespread dispersal for biological control it is strange that there appear to be no publications dealing with the life history of *R. pumila* or methods for rearing it. Its biology is presumably similar to that of *R. cardinalis*, of which there are many accounts (see Quezada and De Bach 1973). The adult *R. pumila* released by Beardsley on Nomwin were laboratory-reared from adults collected in Koror (Palau) supplemented by adults that had been collected on Cocos Is off the south end of Guam (J. Beardsley pers. comm. 1990). Adult coccinellids are known to be hosts to hymenopterous parasitoids of the widespread genus *Perilitus* (Anderson et al. 1986, Krombein et al. 1979, Shaw 1985) and also to parasitic nematodes and Microsporida (Anderson et al. 1986). These undesirable fellow travellers should not be given a chance of transferring to new countries. *Rodolia* larvae are parasitised in India by the wasp *Homalotylus flaminius* (Subramaniam 1950), for which a watch should be kept.

Adult *R. breviuscula* have a dark undersurface. Females lay an average of 200 scarlet eggs which hatch after about 5 days. The duration of larval life is about 11.3 days, the pupal period about 10.6 days, giving an egg-adult life cycle of 26.9 days. A larva is capable of consuming about 500 eggs of *I. purchasi*, a larger number of this species than claimed for any of the other five native Indian species of *Rodolia* (Subramaniam 1954).

***Cryptochetum* spp.**

The dipteran parasitoid *Cryptochetum iceryae* is an important parasitoid of *I. purchasi* and an even more effective biological control agent than *R. cardinalis* in coastal areas of California (Quezada and DeBach 1973). In Chile it, alone, is reported to keep *I. purchasi* under control (Gonzalez and Rojas 1966, Quezada and DeBach 1973). *C. iceryae* produces about 50 offspring per female and has some nine generations a year. It can develop in the early instars of its host, which provide enough nutrients for a single parasitoid, and at all stages up to fully mature females, which can support a maximum of 11 parasitoids. It has excellent powers of dispersal and host location which enables it to exploit its host even at very low host population levels and it has been suggested that it is more efficient than *R. cardinalis* under these conditions (Caltagirone and Doutt 1989, Quezada and DeBach 1973). The related *C. grandicorne*, which is reported to cause up to 90% mortality to *I. aegyptiaca* in Pakistan and India (Muzaffar 1980, Subramaniam 1954), must therefore be seriously considered as a potential biological control agent. When mealybugs are scarce, a single individual is all that *C. grandicorne* requires for development, whereas *Rodolia* will starve if it does not have access to many.

All of the 200 or so species of the family Cryptochetidae whose biology is known are parasitoids of the scale family Margarodidae and at least some species parasitise more than one host species (Ferrar 1987). *C. grandicorne* has a very widespread distribution, ranging from the Mediterranean (Italy, Algeria) to Asia (Menon 1949), but has not been

recorded from Australia. According to Thorpe (1934), it is readily reared in small cages in the laboratory, in distinction to *C. iceryae*, which requires very large cages for effective rearing (Subramaniam 1949, Thorpe 1930, 1934).

The tiny, metallic-coloured adult *C. grandicorne* mate readily in sunshine, but rarely otherwise. Eggs are inserted into first instar scales after they have settled upon their host plant. Only one larva develops per host. Young larvae absorb nutrients through the cuticle, but later instars consume fat body and eventually other tissues (Ferrar 1987, Menon 1949, Thorpe 1934).

Parasitoids and predators of *Cryptochetum* are known (Mendel and Blumberg 1991, Prasad 1989, Quezada and DeBach 1973, Rosen and Kfir 1983, Subramaniam 1954, Thorpe 1930) and care should be taken to eliminate them during preliminaries to biological control introductions. It is possible that this would increase the efficiency of *Cryptochetum* spp. as biological control agents.

Comment

Of the natural enemies present or so far introduced into the oceanic Pacific, only *Rodolia pumila* has proved to be effective enough to maintain *I. aegyptiaca* populations at a sub-economic level, although *R. cardinalis* may have done so when it was temporarily established some years ago in Guam. In spite, therefore, of the growing tendency to avoid choosing predators in favour of more highly selective parasitoids, *R. pumila* would appear to be the species of choice for the biological control of *I. aegyptiaca* in the Pacific. In any case, like the majority of parasitoids, species of *Rodolia* appear to be far more host specific than many other coccinellids. It is strongly recommended, however, if *R. pumila* is to be collected in the field in one country that it should be held in quarantine either in the donor or the receiving country, at least until the next life history stage, before field liberation. Such action would reduce the chances of introducing with it damaging parasitoids or diseases.

It would be most valuable if observations on abundance of both predators and hosts could be made at regular intervals after liberation, particularly in atolls. The information obtained would establish whether, following a reduction of *I. aegyptiaca* to extremely low numbers, self-elimination of the predator occurs. The course of such events in atolls in Kiribati would be of particular relevance, since severe typhoons, postulated on one occasion to contribute to eliminating *R. pumila* from an atoll (Schreiner 1989) rarely occur so close to the equator.

Whatever the sequence of population fluctuations in *Rodolia* spp. proves to be, the fact remains that mealybug numbers on high islands are maintained continuously at non-damaging levels, whereas on atolls there is a boom and bust cycle with predatory beetles disappearing long enough in some locations for mealybug populations to build up to highly damaging populations for several years at a time. It would thus be well worthwhile considering the introduction of parasitoids that could perhaps co-exist with *I.aegyptiaca* at very low densities (Waterhouse 1991a). Possible candidates are the hymenopteran *Tetrastichus* sp., recorded in Pakistan, *Tetrastichus purpureus* from Bangladesh and, especially, the dipteran *Cryptochetum grandicorne* recorded on *I. aegyptiaca* from Pakistan and from India where it produced up to 90% parasitisation. Other promising parasitoids might be revealed by more detailed study in India or further westwards, and thus possibly closer to the presumed centre of origin of *I. aegyptiaca.*

It may be of value at this juncture to summarise some of the attributes of *Rodolia cardinalis* and *Cryptochetum iceryae* which lead to their great effectiveness against the

cottony cushion scale. Of course, the corresponding characteristics of *Rodolia pumila* and *Cryptochetum grandicorne* are, in some respects, somewhat different. The relevant attributes of *R. cardinalis* are (Quezada and DeBach 1973, Thorpe 1930):

1. it is largely independent of climatic conditions;
2. it is restricted to *Icerya* and related scales;
3. each individual destroys several to many prey;
4. it attacks all stages of the scale from egg to adult;
5. it is very active and disperses rapidly, whereas the prey is sedentary;
6. it has about three generations to one of *I. purchasi*;
7. *I. purchasi* cannot easily conceal itself in crevices and is easily preyed upon.

With relation to *C. iceryae* (Quezada and DeBach 1973):

1. this fly is able to locate isolated colonies of *I. purchasi* more readily than *R. cardinalis;*
2. scales parasitised by mature larvae or pupae of the fly are not eaten by *R. cardinalis*;
3. the fly will attack scales on certain plants which *R. cardinalis* avoids;
4. immature stages of the fly apparently tolerate cold temperatures;
5. it requires only one host to complete its development.

4 *Neotermes rainbowi* (Hill)

Isoptera: Kalotermitidae
coconut termite, rainbow termite

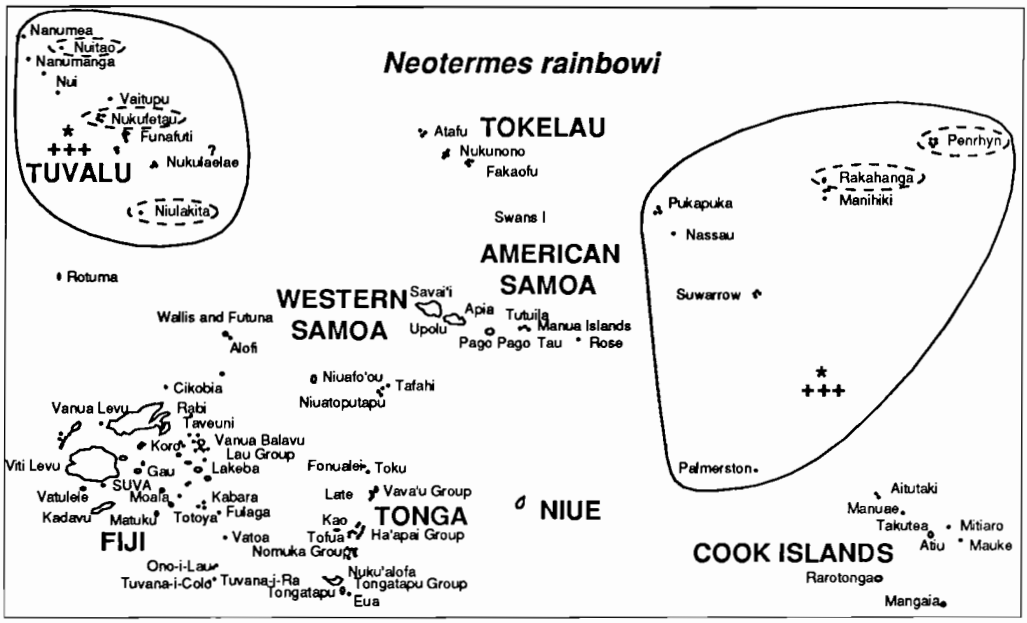

Figure 4.1 Distribution of *Neotermes rainbowi*

The coconut termite is known for certain only from two groups of small atolls in the central Pacific. The hollowing out that workers produce in the trunk of the living coconut palm leads, eventually, to the top snapping off in even mild wind.

It appears that destruction of infested coconut palms and stumps (which are all characteristically surface-marked by the termite) combined with, or perhaps replaced by individual treatment with appropriate entomopathogenic strains of fungi or nematodes, would greatly reduce losses and perhaps even lead to eradication.

There do not appear to be any suitable natural enemies that might be introduced for classical biological control.

Origin

N. rainbowi is known only from the central Pacific and presumably evolved there.

Distribution

The coconut termite has been recorded (Figure 4.1) from 5 (and possibly 6) of the 9 atolls comprising Tuvalu (Funafuti, Nanumanga, Nanumea, Nui, Vaitupu and ?Nukulaelae) (Hill 1926, Hopkins 1927, Lenz and Runko 1992). No information is available about the situation on the remaining 3 atolls (Nintao, Nukufetau and Niulakita) but it would be surprising (and most interesting) if *N. rainbowi* was not present, because these atolls are dispersed among infested ones. *N. rainbowi* is present on 4 and suspected on another 2 of the 6 atolls of the northern Cook Is (Manihiki, Nassau, Pukapuka, Suwarrow and ?Penrhyn, ?Rakahanga); and it is also present on Palmerston atoll, the most northerly of the southern Cook Is (Hoy 1978, Kelsey 1945). It is not recorded from the remaining 8 southern Cook Is, only two of which (Manuae, Takutea) are coral atolls. In 1988 *N. rainbowi* was observed in many palms on Pukapuka and Suwarow, but only in one very limited area of Nassau and not in palms elsewhere on the island, suggesting that it may have become established on the latter atoll in comparatively recent times (M. Lenz pers. comm. 1992).

The coconut termite has also been reported from Rotuma, the main (high) island of the 9-island Rotuma group (Fiji) (Maddison 1987, quoting from Swaine (1971)), but the facts that this termite attacks cocoa and citrus as well as coconuts and that the characteristic channels in the bark (see later) have not been recorded, raises doubts about the identity of the species involved and the situation is currently under investigation (M. Lenz pers. comm. 1992).

The genus *Neotermes* is in need of taxonomic revision. It is widely distributed in the south Pacific, with several described and undescribed species, but *N. rainbowi* is the only one known to attack the living wood of the coconut tree (Hopkins 1927, Thomson 1969). The most closely related species are said to be *N. samoanus* from Western Samoa, Solomon Is and Vanuatu; and *N. sarasini* from New Caledonia (Hill 1942). The report of *N. rainbowi* from Western Samoa (Maddison 1987) has proved to be a misidentification of *N. samoanus* (Gay in Lenz 1980).

The coconut termite was reported in Tuvalu in 1896 (Rainbow 1896-97) and in Cook Is about 1904 (Given 1964). Suwarrow (Cook Is) supported a copra estate in the 1920's and 1930s 'until the island became infested with termites and the export of copra was prohibited' (Stanley 1986) or until 'the ravages of termites made it necessary to prohibit the export of copra' (Douglas and Douglas 1989). It is certainly not at all clear that the atoll was uninfested before the estate was established.

Although it has not previously been reported from the three atolls comprising Tokelau, it was recorded as present but unimportant in the 1992 SPC survey (K. Kirifi, June 1992). The identity of the termite requires confirmation, since blown off tops do not occur, and the termites are normally observed in fallen or dead coconut trunks and the damage done is very minimal (K. Kirifi pers. comm. 1992).

Life Cycle

The Kalotermitidae, to which *Neotermes rainbowi* belongs, are primitive termites, many of which attack living trees and are termed live-wood termites. Hollows, where wood has been eaten out, are filled with faecal material which is earth-like in appearance and tunnels are constructed of carton-like material.

After a nuptial flight, founding pairs shed their wings and enter suitable wood through tree wounds or cracks; or they may chew a tunnel into soft wood. There mating

occurs and the female (still accompanied by the male) lays a batch of eggs to produce workers and a small proportion of soldiers. When the first progeny mature they feed and tend the king and queen and, with further egg laying, the colony starts to grow in size. Kalotermitid termites are able to replace injured kings and queens with supplementary reproductives to maintain the colony. Average colony life is probably more than 20 years.

Pest status

Although there is little evidence that the presence of the coconut termite affects the nut yield of mature trees, structural damage to the palm trunks makes them subject to windthrow (Plate 1, Figs 7, 8), even at the low velocities of the steady tradewinds. On the other hand, the yield of young palms is reduced, or they may be destroyed before reaching bearing age (Given 1964). Nuts and fronds, whether fallen or on the tree, are not infested. Although it was reported to Given (1964) by an island inhabitant that *N. rainbowi* attacks all woody trees on Suwarrow (Cook Is) except *Cordia subcordata*, it is highly probable that the termite mainly concerned was a species other than *N. rainbowi*. Twice only in detailed searches on Vaitupu (Tuvalu) was *N. rainbowi* found in other than living coconut palms or stumps. These occasions were when *N. rainbowi* was found some 40cm below ground level in a few palm fence posts and in a woody shrub which had parts of its stems and roots hollowed out. In each case the termites had constructed tunnels into the soil. By contrast, colonies in living palms were never found to have tunnels leading to the soil (Lenz and Runko 1992).

In 1941 a hurricane caused 90% loss of palms on Suwarrow and damage must also have been extensive on Pukapuka since, in 1978, there was 'little evidence of any palms older than approximately 40 years' (Hoy 1978). Around the villages on Pukapuka where the ground is clear of other vegetation relatively few infested palms were found in 1978, whereas further away where ground cover was denser, and especially where pandanus was plentiful, levels of infestation were higher — often somewhat less than one palm in fifteen but occasionally rising to one palm in three (Hoy 1978). However, almost all healthy looking 9 year old palms receiving fertiliser at the time of planting were infested (Lenz 1988).

Attacked palms are readily recognised from the very early stages of infestation, a situation apparently unique amongst termites. At first, a few holes and grooves filled with chips of bark appear on the surface of the trunk. Later, a net-like pattern of grooves and channels is produced to the full depth of the bark (Plate 1, Fig. 9) and these are covered with chips of wood and bark mixed with faecal material. In the northern Cook Is this network commences near the base of the tree, close to where the bark forms a collar over the uppermost roots, and eventually extends upwards one or two metres with the expansion of the termite colony (Lenz 1988). In Tuvalu, the attack on the bark characteristically occurs at levels of 1 to 3 m and extends upwards as the colony expands, so that many square metres of bark become marked (Plate 1, Figs 7, 8) (Hopkins 1927, M. Lenz pers. comm. 1992, Rainbow 1896-97). The function of the channels is unknown but may possibly be related to moisture control, temperature regulation or, perhaps, conditioning of the underlying woody tissues. Whatever its function it is a striking tell-tale sign of the presence of a termite colony (Plate 1, Fig. 9). Very different channels, presumably caused by some other insect are occasionally seen higher up the trunk (M. Lenz pers. comm. 1992). As attack proceeds, large cavities are eaten out of the trunk, often extending to the surface of the palm. Portion of this space is filled with a soft moist honeycomb of faeces and debris. It is at this level that the top snaps off. The stilt roots or branches of nearby *Pandanus* are sometimes hollowed out without invasion of the main trunk (Hoy 1978) and, on Suwarrow, a few eaten out palm roots were observed (Lenz

1988). In Cook Is (Suwarrow, Pukapuka), but not in Tuvalu, it was evident that colonies were able to move from their original infestation through roots and soil to neighbouring palms (Given 1964, Lenz and Runko 1992).

The inhabitants of the atoll islands infested with *N. rainbowi* are very heavily dependent on nut production, not only as a major component of human and domestic animal diet, but as a principal source of income from copra production. The coconut termite is thus of crucial economic and social importance.

In Tuvalu, but not in Cook Is, there is a relatively abundant undescribed species of *Nasutitermes*, which builds dark-coloured galleries on the surface of palm trunks and other vegetation, often reaching the crown. This species is unable to penetrate the hard outer wood of coconut palm, unless this is damaged, such as by the deep access steps cut into palms to facilitate climbing for toddy collection. Tunnels made by *N. rainbowi* may also provide entry. There is no evidence that *Nasutitermes* n. sp. is of economic importance (Lenz and Runko 1992).

Control Measures

These have involved the removal and burning of infested palm wood and the use of chemicals. However, chemicals such as arsenic, lindane, dieldrin and phostoxin (Hoy 1978), which are effective if properly applied, are no longer recommended on residue, cost and environmental grounds (Lenz 1988). The destruction of infested material requires considerable physical effort and, unless carried out systematically, probably does little more than depress the steady increase in the number of trees infested. On the other hand, results can be striking if destruction of infested palms is carried out effectively. Thus, clear felling in a palm regeneration program on Vaitupu carried out in the late 1970s and early 1980s reduced infestations to very low levels. Only 4 of 1155 re-planted palms inspected in 1992 were infested with *N. rainbowi* although infestations were common in some other untreated areas. By comparison, 190 had surface infestations by the economically harmless *Nasutitermes* n. sp. (Lenz and Runko 1992). Recently, experiments in Tuvalu involving injection into the termite colonies of specially selected strains of the fungus *Metarhizium anisopliae* or of an entomopathogenic nematode, *Heterorhabditis* sp. have given very promising results (Lenz and Runko 1992).

Attempts at biological control

There have been no attempts at classical biological control of *N. rainbowi*, nor apparently any against other termite species.

Natural enemies

The most important natural enemies of termites are non-specific invertebrate and vertebrate predators and entomopathogenic fungi. A few ectoparasitic mites and endoparasitic flies (belonging to the families Calliphoridae, Conopidae or Phoridae) are occasionally referred to in the extensive literature on termites; also nematodes, mermithid worms, gregarines, microsporidia, protozoa and fungi (Ernst et al. 1986, Snyder 1956, 1961, 1968). They appear to produce important mortality only in weak colonies, whose decline is thereby accelerated. None of these organisms normally appear to cause sufficiently high or widespread mortality to show promise for classical biological control.

Winged reproductives on their colonising flight are eaten in large numbers not only by ants, dragonflies and other predatory insects, but also by birds, lizards, snakes and frogs. In Australia, workers and soldiers are preyed upon by ants, several marsupials (including the echidna) and many lizards (Watson and Gay 1991). Ants are almost certainly the major predators. Indeed, about one third of the world-wide references

assembled on termite predators by Ernst et al. (1986) and Snyder (1956, 1961, 1968) refer to ants.

Termite colonies often harbour a specialised fauna of arthropods, known as termitophiles. Some of these are predators on eggs and young termites, others are scavengers feeding on nest debris and many provide secretions in return for being fed by worker termites. Nothing is known of termitophiles of *N. rainbowi*, but there is little likelihood that any could be exploited.

The only published report of natural enemies of *N. rainbowi* is the attack on young termites on Suwarrow (Cook Is) by meat ants (Given 1964). However, M. Lenz (pers. comm. 1992) has also observed ant attack on both Cook Is and Tuvalu when tunnels were broken open.

Comment

It is probable that many reports of the presence of *N. rainbowi* are due to its being confused with other termite species. On Vaitupu, of the other four termite species present, this would mainly be with *Nasutitermes* n. sp., but also possibly with *Prorhinotermes inopinatus* (Lenz and Runko 1992). Unless the characteristic channels in the bark are evident and unless hollowed out stumps containing termites are present, considerable doubts must be held until there is a positive identification by a termite specialist.

It is postulated that the presence of *N. rainbowi* galleries in the soil in the Cook Is, but their absence in Tuvalu is due to the presence in the latter group of atolls (but not in the former) of an effective subterranean competitor in the form of *Nasutitermes* n. sp.. This species is smaller in size, but more agile, agressive and numerous and, in encounters, is more likely to be victorious. It prefers to found its colonies at the base of palms and extend its feeding territory by means of subterranean galleries connecting several palm trees. From its position on the outside of the trunk it is able to invade exposed *N. rainbowi* galleries when the top of the palm is blown off. The older such stumps are, the more restricted become the portions occupied by *Neotermes* and the more extensive those by *Nasutitermes* (Lenz and Runko 1992).

There are a number of interesting unresolved problems concerning the origin and distribution of *Neotermes rainbowi*. The answers, if available, might have a direct bearing upon possible long term measures to reduce its abundance. If the currently held view is valid that the Polynesians brought the coconut with them when they migrated into the Pacific some 4000 years or so ago, the voyagers may also have had termites as fellow travellers — either *N. rainbowi* or a species that must have rapidly evolved into it. Alternatively, pairs of as yet unmated reproductives may have been carried to the atolls in storm winds from afar (but from where?). Of course, such pairs would only have been able to initiate colonies once coconut palms had been established. Further, no specific external area of origin for *N. rainbowi* appears credible at the moment. Another difficulty with this means of dispersal is that recorded distances flown by reproductives of most species is no more than a few kilometres (Nutting 1969). Nevertheless 19 alates of *Reticulitermes virginicus* were trapped by aeroplane over Louisiana at altitudes from 20 to 30,000 feet (Glick 1939), so longer distance dispersal cannot be entirely ruled out. It is relevant that nuts and palm fronds are not infested so that, if carried by canoe, colonies must have been in substantial (and thus heavy) portions of coconut trunk. It seems unlikely that termites could survive the long periods of immersion in salt water required for floating logs containing exposed termite colonies to be carried from one atoll to another far away. Of course, it is possible that *N. rainbowi* evolved as a species associated with other woody vegetation, including *Pandanus* roots and stems prior to the introduction

of the coconut into the Pacific, and that it then transferred its main attention to the latter (M. Lenz pers. comm. 1992). Infested *Pandanus* roots would be more readily transported by canoe than colonies in coconut logs and there is some evidence that roots were transported as planting material. The ease with which Kalotermitidae (and presumably *N. rainbowi*) can produce supplementary reproductives from immature termites means that new colonies could be established from a small group of workers and immatures.

Another question is what are the features of the widely dispersed atolls (none of which has ever had a land connection with its neighbours) which permit *N. rainbowi* to survive there, but apparently not on other atolls or on high islands no further away (see Figure 4.1). Is it *N. rainbowi's* ability to survive (or even require) such factors as salt spray or, more likely, could it be the lack of competition on atolls with their very limited diversity of other animals? However, there appears to be little competition for space once access has been gained to the woody stem of the living palms.

It is considered that the atolls where *N. rainbowi* occurs did not have a native ant fauna (R.W. Taylor pers. comm. 1992), although it is probable that the majority now have a range of exotic tramp species. The distribution of such species is unlikely to be uniform and it is to be expected that the larger, high islands will have more such species than atolls. The only published record for those atolls infested with *N. rainbowi* appears to be for Palmerston (Cook Is), where five species are listed (Taylor 1967) so, at the moment there is no basis for comparison. There is, however, a record from Fakaofo (Tokelau) from 1924 of the presence of 12 species of introduced ants belonging to 9 genera (Wilson and Taylor 1967) and, doubtless, additional species would have arrived since then. However, there is no indication that the higher number there than in Palmerston has any significance in relation to the occurrence of *N. rainbowi*.

If it is postulated that ants could be a major factor in preventing the spread of *N. rainbowi* to additional islands, which species are likely to be involved and could these be introduced to infested islands to reduce, or possibly even eliminate, the coconut termite? The main attack by ants on termites appears to be on reproductives after colonising flights, on workers foraging away from their nests, or when nests or galleries are broken open. If ants were effective in eliminating established colonies, their great abundance and diversity in Australia would surely ensure that termites would have difficulty in surviving, whereas this is certainly not so. It must, thus, be concluded that termites, at least in established colonies, can generally defend themselves effectively against attack by ants.

Even if ants were believed to be effective in destroying termite colonies, in recent years the attitude of those concerned with the conservation of native fauna has firmed strongly against the introduction of non-specific predators, such as ants, that have the capacity to attack, and perhaps eliminate, non-target fauna: most, perhaps all, tramp ants fall into this category. Furthermore, the tramp ants now in the Pacific are, themselves, almost all pests or potential pests. This is because many bite or sting, invade dwellings and foodstuffs and foster outbreaks of aphids and scales for the honeydew they produce. The appearance of additional tramp species is generally regarded as a disaster, for example the unintentional introduction of *Wasmania auropunctata* into New Caledonia (Fabres and Brown 1978).

To pursue this argument further and to investigate whether there could, indeed, be any merit in the introduction of one or more ant species, it would be essential to evaluate the situation on atolls where the species in question either did, or did not, occur and also to include atolls where *N. rainbowi* did, or did not, occur. Very significant logistic problems and costs would be involved.

With the present state of knowledge, there seems little doubt that further development of environmentally safe control methods, such as the use of entomopathogenic fungi or nematodes is the best use of available resources. Also, in view of the tell-tale channels on the trunk surface, the option would appear to exist of eradicating *N. rainbowi* by a well-planned colony treatment operation, supplemented with, or if appropriate replaced by, destruction of infested palms and palm stumps.

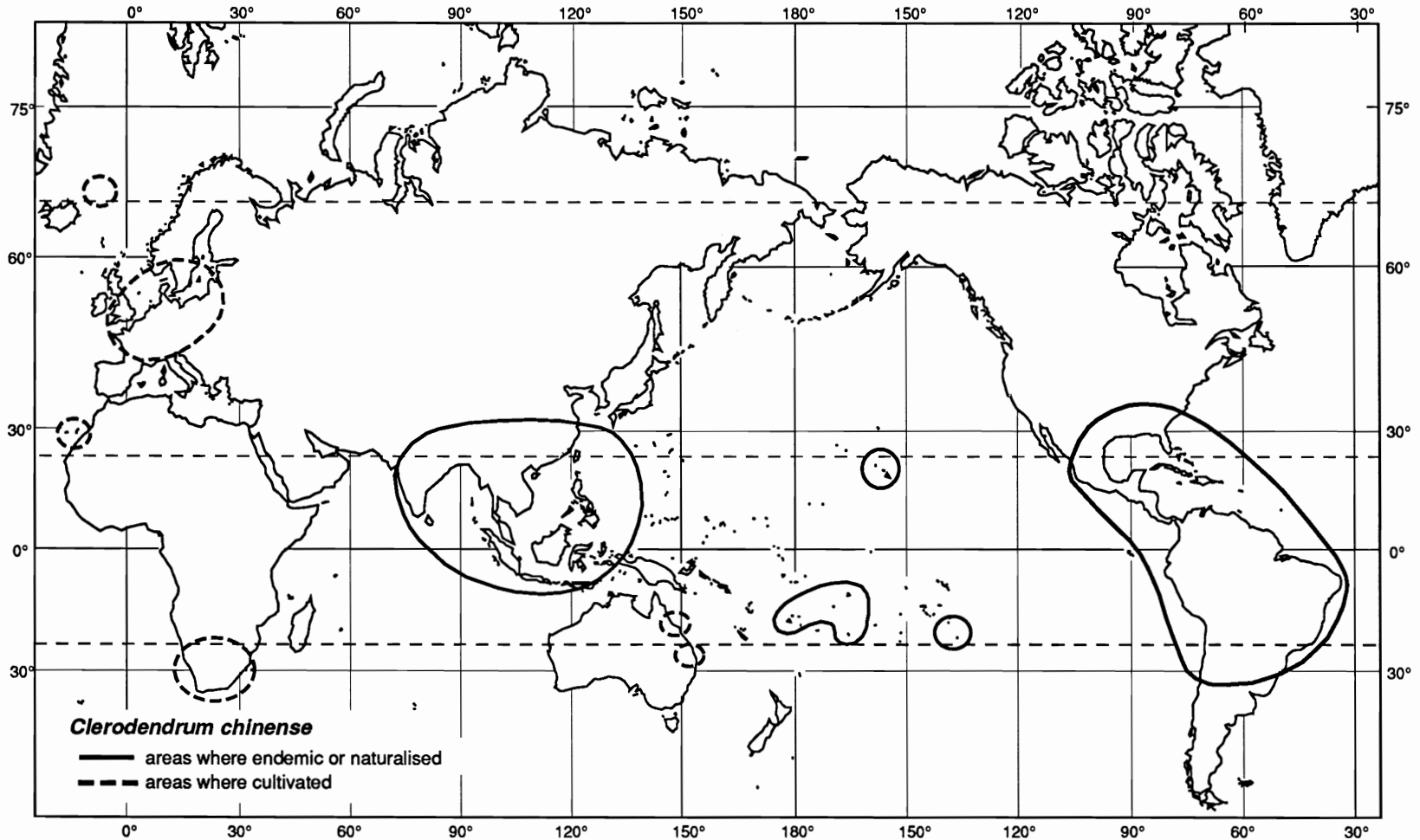

Figure 5.1 World distribution of *Clerodendrum chinense*

5 *Clerodendrum chinense*

(Osbeck) Mabberley
(formerly *C. philippinum*)
Honolulu rose

VERBENACEAE
fragrant clerodendrum, Honolulu rose, losa honolulu (Samoa), pelegrina (Tagalog, Philippines), hijantong (Bisaye, Philippines), Sabuka (Igorot, Philippines), pitate mama (Rarotonga), pikake hohono, pikake wauke (Hawaii)

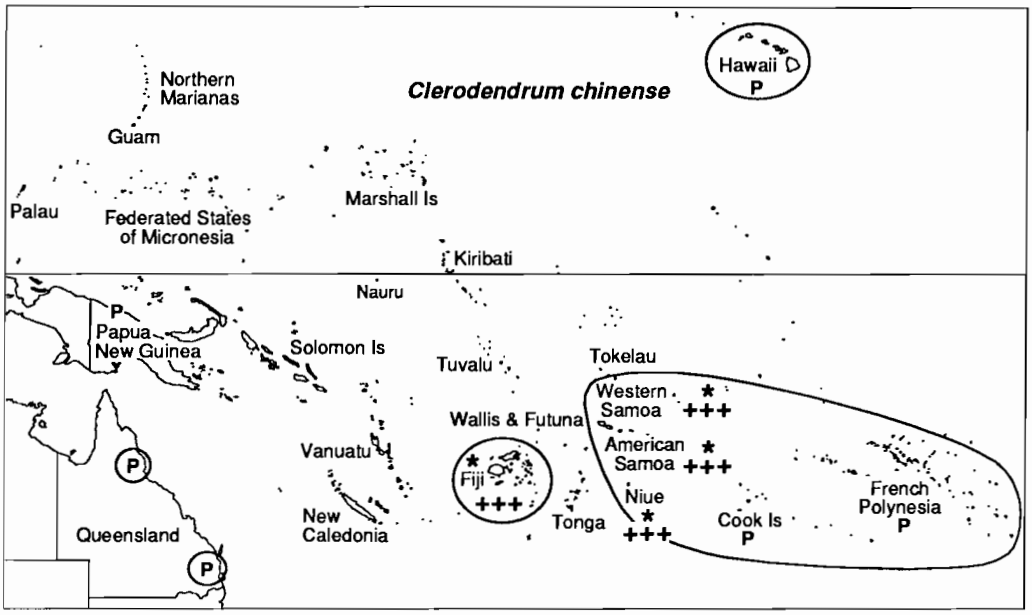

Figure 5.2 Pacific distribution of *Clerodendrum chinense*

Clerodendrum chinense is native to the region embracing southern China and northern Vietnam.

It has attractive pink to white, fragrant flower heads and is grown in many parts of the world as an ornamental. It has been naturalised for some 150 years in Central and South America, but is regarded there as, at most, a minor weed. It has been naturalised for almost as long in the eastern Pacific, without becoming an important weed but, following its more recent introduction to the southwest Pacific, it is already a serious weed in Western and American Samoa and is rapidly becoming so in Niue and Fiji. In the southwest Pacific it grows vigorously to about 2.5 m in rich moist soils, both in sunshine and in shade, outcompeting and smothering all underlying vegetation.

Only very minor damage is caused to *C. chinense* in the Pacific by the few, widely polyphagous insects that attack it there. However, several of the many species of leaf-eating beetles which cause significant damage to it in southern China and northern Vietnam are clearly candidate biological control agents. Of these, the chrysomelid *Phyllocharis undulata* is particularly promising, especially if tests confirm it to be adequately host specific.

Honolulu rose appears to be a promising target for a biological control project in the southwest Pacific.

Identity

The scientific name applied to Honolulu rose has undergone several changes over the years and, even now, there are some problems which require modern taxonomic methods for their resolution. The relevance of this in the present context is that access to relevant information in the literature can only be had if the plant names are known under which the information has been published. Furthermore, host specific natural enemies can best be sought by examining the correct plant species in its area of origin and this can only be established when means for distinguishing it are available.

Honolulu rose was widely referred to as *Clerodendrum fragrans* (Ventenat 1804) until Howard and Powell (1968) pointed out that, under the rules of botanical nomenclature, the specific name *fragrans* was unavailable for *Clerodendrum*. They then selected what they believed to be the first valid name to be applied to this plant, namely *C. philippinum* by Schauer (1847), whose specimens came from the Philippines. Until 1968 many workers treated *C. fragrans* and *C. philippinum* as separate species, and sometimes the latter was cited as a synonym of the former. Plants of *C. philippinum* produce one of three flower types (i) double, without functional anthers or stigma, (ii) double, with many, most, or all flowers fertile or (iii) single, with fertile flowers. Between 1968 and 1989, when Mabberley (1989) introduced another change (see below), (i) was known as *C. philippinum* (Schauer), (ii) as *C. philippinum* var. *subfertile* (Moldenke 1973) and (iii) as *C. philippinum* var. *simplex* Moldenke (1971). Other forms or varieties are *multiplex*, *pleniflorum* (both synonyms of *C. philippinum*) and *corymbosum* (Lam. and Bakk.) Moldenke from Sulawesi. However, even during this period the picture was far from clear because, as Howard and Powell (1968) point out, Schauer's 1847 description was probably not entirely accurate. Their examination of his isotype material in the Gray Herbarium shows that, whereas many of the flowers in the tight infloresence are single and show stamens and a style, others are semi- to fully double with multiple numbers of petals and staminodes. Of course, whether or not these differences in flower type are significant for biological control will depend upon whether the different forms are differently attacked by natural enemies.

Next, Mabberley (1987) pointed out that the first valid name was actually *Clerodendrum chinense*, a name established in 1757 by Osbeck. However the plant had been placed incorrectly in the bromeliad genus *Cryptanthus*, where it has remained unrecognised for almost 250 years. The type specimen was collected on Dane's island near Whampoa, southern China on 11 September 1751 and described (in Swedish) thus:

(Merrill 1916). 'In the direction of the city there grew a kind of small bush, about as high as gooseberry bushes, with double white flowers. The leaves are as large as those of the rose mallow, cordate, blunt-serrate, the margins with unequal lobes, pubescent on the upper surface, smooth beneath and with at least eight primary nerves, the flowers in terminal racemes.'

In the present account the double flowered plant (Plate 2, Fig. 1) will be referred to as *C. chinense* and the single flowered plant as *C. chinense* var. *simplex*. However, in referring to a number of publications where no distinction of floral type has been made the name *C. chinense* has been used.

The genus *Clerodendrum* contains some 500 species of shrubs, trees and vines, most of which are native to the vast region extending from Africa to eastern Asia, with a few only from the Americas. Many are grown for their odd and beautiful flowers. *C. chinense* is an important horticultural plant in many tropical and subtropical areas of the world. It is one of the most commonly cultivated, garden-escaped, and naturalised species of *Clerodendrum*.

Origin

C. chinense is native to southern China and probably to nearby countries, although further surveys are required to establish its likely native distribution in Vietnam and, perhaps, in Laos.

Distribution

The world distribution of native and naturalised *C. chinense* is given in Table 5.1 and shown in Figure 5.1. The regions enclosed by a solid line in Figure 5.1 include those (i) where it is native and also, in some areas, perhaps, naturalised (southern China to Vietnam and Laos) and (ii) where it is naturalised but not native (elsewhere in Southeast Asia; southern USA to South America; certain Pacific islands). Table 5.2 lists areas where, in 1971, it was growing as an ornamental, but not known to have become naturalised. It is probably now grown rather more widely than indicated, although it may not be present even yet in tropical Africa. Most records are from Moldenke (1971), with the addition of data relating to Western and American Samoa, Malaysia and Singapore. Data from the last two areas are derived from an examination of specimens in their respective herbaria (M.H. Julien pers. comm. 1989 and searches by the author).

Table 5.1 World distribution of endemic and naturalised *Clerodendrum chinense* (Mainly after Moldenke 1971).

USA (Florida, Arkansas)	Peru	Philippines (Jolo,
Mexico	Brazil	Luzon*, Mindanao,
Guatemala	Bolivia	Negros and Sulu)
British Honduras	Paraguay	Indonesia (Bakong,
Honduras	Chile	Bali, Banka, Batu,
El Salvador	Argentina	Bintang, Celebes,
Nicaragua	Ascension	Java, Karimata,
Costa Rica	*Pakistan (East Bengal	Singkep, Sumatra)
Panama	and West Punjab)	(*Borneo, Celebes, Java,
Bermuda	*Nepal	Lombok, Sumatra)
Bahamas	*India	[Celebes (var.
*Cuba	Sri Lanka	*corymbosum*)]
Isla de Pinos	Burma (Upper Burma)	Borneo (* only)
Jamaica	*China	Sarawak
Dominican Republic	[Fukien, Guangdong,	Moluccas (Tornate)
Haiti	Yunnan, Lantau]	Fiji
Puerto Rico	[*Fukien, Guangsi,	*Hawaii
Virgin Islands	Guangdong, Kweichow,	American Samoa
Leeward Islands	Yunnan, Hainan]	Western Samoa
Windward Islands	Hong Kong	Niue
Trinidad	*Thailand	Cook Islands
Colombia	Indochina	Society Islands
Venezuela	(Annam * only)	Tuamotu
Guyana	Malaysia	Ecuador
Surinam	Singapore	*Taiwan
French Guiana	Japan (* only)	

* var. *simplex* also

The earliest known specimens of *C. chinense* are those collected in 1751 and 1790 in China (Osbeck 1757, Sweet 1827). It is still to be found in natural habitats in southern China, but less commonly than *C. chinense* var. *simplex*, which is abundant in northern

Vietnam and common in northern Thailand (M.H. Julien pers. comm. 1992). Ventenat (1804) states that his material came from plants in Paris provided by Lahaye which the latter had obtained from Java on La Pérouse's (1787) expedition. La Pérouse visited the Philippines, but not Java and, since Lahaye was on d'Entrecasteaux's expedition which did visit Java (in 1792), it is probable that the plants originated there. At all events, *C. chinense* was certainly present in the islands of the region well before the turn of that century. Probably because of its showy flower heads and jasmine-like fragrance at night it was dispersed widely. Walker (1834) records it as a greenhouse plant in England in 1834 and Schauer (1847) its cultivation in China and its occurrence in Central and South America (Guyana, Martinique, Brazil). It was reported as early as 1864 to be naturalised and usually double-flowered in Antigua and from Cuba to Brazil (Griseback 1864) and in Hawaii before 1888 (Hillebrand 1888).

Table 5.2 Countries where, in 1971, *C. chinense* was known to be cultivated (Moldenke 1971).

Antigua	Florida	Nigeria
Argentina	Germany	Philippines
Australia	Ghana	Puerto Rico
Austria	Guatemala	Romania
Bahamas	Guyana	Sarawak
Belgium	India	Sierra Leone
Brazil	Japan	South Africa
California	Java	Soviet Union
Canary Islands	Malaysia	Sweden
China	Mauritius	Switzerland
Colombia	Mexico	Texas
Cuba	Netherlands	Venezuela
Dominica	New York	
Ecuador	New Zealand	

* Note: *C. chinense* var. *simplex* is known to be grown in Indochina, Java and Sabah

In the Pacific (Figure 5.2) it is naturalised in Cook Is, Fiji, French Polynesia, Niue, Hawaii and American and Western Samoa (Swarbrick 1989, Whistler 1983). It has not been recorded from Micronesia (Moldenke 1971) and its absence from there is confirmed for Guam (Moore and Krizman 1981, R. Muniappan pers. comm. 1989, Stone 1970) and the Northern Marianas (Fosberg et al. 1975). It is not known in New Caledonia (R. Amice pers. comm. 1989). It is growing as an ornamental in New Zealand (Moldenke 1971) and in Australia (Cairns and Brisbane botanic gardens).

Further details follow of its introduction to, and distribution in, the Pacific:

COOK IS

C. chinense occurs in both Rarotonga and Aitutaki (P. Samuel pers. comm. 1989). It was first collected in 1929 (Whistler pers. comm. 1989), grows to 0.9 to 1.5 m and is common in lowlands and moist places away from the sea (Wilder 1931), but is not a major pest in agricultural lands (P. Samuel pers. comm. 1989).

FIJI

C. chinense was first collected as a roadside shrub by Degener and Ordonez during their 1940-1941 expedition (Smith 1942). It was probably introduced as an ornamental but, by 1958, had already become naturalised and common, forming large roadside patches in the wet zones of Viti Levu, Vanua Levu and Taveuni (Parham 1959, 1972). It also occurs now

on Rotuma Is (M. Nagatalevu, pers. comm. 1989). It is spreading steadily along roads in the wetter areas, rapidly becoming a serious weed and is now numbered high amongst the top 10 weeds.

FRENCH POLYNESIA

C. chinense was introduced in 1845 (Pancher in Cuzent 1860, according to Setchell 1926) and now occurs at low altitudes in Tahiti, Moorea and Raiatea; also in Makatea (in the Tuamoto Is) (P. Birnbaum pers. comm. 1989). It was recorded in May 1922 as an extensive thicket of low roadside bushes (Setchell 1926). There is a specimen in the Bishop Museum collected in Tahiti in 1922 (A. Whistler pers. comm. 1989) and another collected in 1927 on Raiatea is listed in the Flora of the Society Is (Papy 1951-1954). A specimen collected in 1927 on Raiatea is in the herbarium of the University of Malaysia.

HAWAII

C. chinense was first collected in Hawaii in 1864-1865. It was listed as present by Drake del Castillo (1886) and by Hillebrand (1888) as a naturalised plant. 'Along roadsides (Nuuanu) and near abandoned habitations, as on the hill back of Punahou where it covers several acres of ground to the exclusion of everything else' (Hillebrand 1888). Plants up to about 2 m high now occur in moist places on all islands of the group except Kaho'olawe and Ni'ihau and there are numerous references to its presence (e.g. Haselwood and Motter 1966, Kuch and Tongg 1960, Neal 1929, 1965, Pope 1968, St John 1973, Wagner et al. 1990). 'A clerodendron growing wild on the outskirts of Honolulu as a roadside weed and around deserted homes ... On roadsides, upper Manoa Valley' (Neal 1929). 'Naturalised on open, wet, partly shaded, disturbed areas at the edges of mesic and wet forest, taro paddies, or streams' at elevations from 50 to 670 m' (Wagner et al. 1990). Although in the above situation it is described as ornamental and usually doubled flowered, like weedy forms elsewhere, *C chinense* in Hawaii is more generally considered as a minor weed there (Pope 1968), and it is obviously not important enough to have attracted the attention of those involved with biological control problems. Neal (1929) stated that 'New plants develop from underground stems', and although Wagner et al. (1990) state that fruit are unknown, seed production was recorded by Haselwood and Motter (1966) and Neal (1929). Thus the low weed status of the plant in Hawaii is not obviously connected with peculiarities in the mode of reproduction, and the situation might well repay study.

NIUE

C. chinense was first collected in 1965, having been introduced from American Samoa some time after 1950 to a village on the southern side of Niue. It is now well established and grows to a height of about 1.5 m on fertile soils (Sykes 1970). Its weed status is steadily increasing (T.G. Mautama pers. comm. 1989) and it is now rated number 5 amongst the island's worst weeds (A. Hill pers. comm. 1992).

PAPUA NEW GUINEA

Clerodendrum chinense var. *simplex* is present in Rabaul. It is troublesome when preparing ground for planting cocoa, but is not regarded as an important weed. It is fertile, but also spreads by root suckers (P.D. Turner, pers. comm. 1989).

AMERICAN SAMOA

It is not known when *C. chinense* was brought to American Samoa but it is rapidly becoming a major weed. Until recently it was common along roadsides and on the borders of plantations. Now, on Tutuila, it has started penetrating into coconut and banana

plantations and into taro (*Alocasia*) fields. On the Manua islands it still occurs only along roadsides (A. Vargo pers. comm. 1989).

WESTERN SAMOA

Whistler (1983) records the first collection of *C. chinense* in 1955. It was not mentioned in lists of plants of Western and American Samoa published in the thirties (Christopherson 1935, Lloyd and Aiken 1934). It is present on Upolu and Savaii, but not on Apolima or Manono (A. Peters pers. comm. 1989). Stems are said to have been used as pegs during a survey of some of the roads leading out of Apia, which may account for its widespread distribution along roadsides. Since it is such a conspicuous plant, absence of records earlier than 1955 suggests that, if present much before then, it must have been uncommon or perhaps still only a garden plant. In 1992 it was rated number 2 amongst the country's worst weeds (A. Hill pers. comm. 1992).

SOUTHEAST ASIA

It is not known how far the native range of *C. chinense* extends into Southeast Asia, but available information is summarised.

MALAYSIA

The earliest specimens in the herbaria in Malaysia and Singapore were collected in 1885 and have double or semi-double flowers. Plants growing in 1989 in the Kuala Lumpur Botanic Gardens have semi-double flowers and are surrounded by young seedlings; hence the flowers are fertile (M.H. Julien pers. comm. 1989).

INDONESIA

In addition to the early double-flowered plants referred to by Ventenat (1804), double flowered *C. chinense* was recorded in Java both by Miquel (1856) and Backer and van den Brink (1965). The latter authors record 'Erect shrub, with numerous root-suckers. Up to now found wild only on Idjèn plateau; elsewhere occasionally as a garden ornamental ... flowers double ... stamens and ovary absent ... Naturalised in shaded localities near houses'. The form *subfertile* of *C. chinense* (i.e. double, fertile flowers) was described by Moldenke (1973) from specimens collected in 1935 in marshland and swamp forest in Sarawak.

PHILIPPINES

Most authors tend to regard *C. chinense* as a naturalised, rather than a native plant, but not a weed. Thus Quisumbing (1951) writes 'Pelegrina is found in cultivation (although it is occasional also as an escape plant) in and near towns throughout the Philippines. It is a native of southeastern Asia and is now pantropic in cultivation'. Merrill (1912) states that he had seen only the double-flowered form in the Philippines where it is 'frequently cultivated for ornamental purposes' and (1923) 'throughout the Philippines in cultivation, occasional also as an escape in and near towns'. Schauer's (1847) material came from the Philippines and the plant was recorded by Soler (1886) from Luzon. Recently an experienced Philippine weed scientist J.V. Pancho (pers. comm. 1989) expressed doubt that it is native and pointed out that, although widely distributed, it is sporadic in distribution. It is occasionally cultivated as an ornamental shrub, individual plants of which may have either single, semi-double or double flowers.

VIETNAM

C. chinense has been reported growing in natural habitats only in Quang Ngai Province, central coastal Vietnam (M.H. Julien pers. comm. 1992).

On the other hand, *C. chinense* var. *simplex* is relatively common along roadsides and in forest clearings, where it grows to a height of 1 to 1.5 m. *C. chinense* is recorded in Vietnam in 14th century herbals (T. T. Gian pers. comm. 1989), suggesting that it may be native to the region.

Characteristics

C. chinense is an erect, soft, perennial shrub, 1 to 3 m in height, bearing fine hairs on stems that are generally sub-rectangular in cross section. Its finely pubescent leaves are simple, opposite and heart-shaped, 6 to 20 cm long, and with an acute tip. Leaf margins tend to be wavy and may be toothed and leaf stalks are about half as long as the leaves. The pale-pink to white flowers are borne in a dense, terminal, hydrangea-like mass 4 to 12 cm in diameter between the leaves at the top of each stem (Plate 2, Fig. 3). The calyx is divided into 5 to 8 elongate lobes, bearing sunken glands. The corolla is fused, funnel-shaped and divided into many lobes. In the weedy form in the Pacific the flowers are double, and there are no stamens or ovaries: hence the plant is sterile. It spreads by root suckers which extend below the soil surface and at intervals produce buds, each of which develops into a new stem. The flowers are delicately scented at night, although scarcely so by day: when crushed the leaves are ill-scented.

C. chinense has extra-floral nectaries in four locations (i) on the undersides of the calyx; (ii) on the undersides of the bracts; (iii) at the base of the petioles; and (iv) on the undersides of the leaves. These nectaries attract a large number of ant species, but do not provide ant dwellings or domatia. Some nectar-seeking beetles are also attracted (Jolivet 1983).

Weed status

The weed status of *C. chinense* is greatest in Western Samoa, where it is a major weed of roadsides and village gardens (Plate 2, Fig. 1). It also invades pastures, plantations and national parks and dominates all but tall vegetation. Surveys in Upolo recorded *C. chinense* in 7% and 2% of taro fields with an average cover of 22.9% and 6.6% respectively (Kürschner 1986, Sauerborn 1982), figures that are probably not significantly different. It spreads rapidly by root suckers which emerge to form such dense thickets that all underlying plants are smothered (Plate 2, Fig. 2). By 1989 Honolulu rose was growing in dense clumps of up to several hundred metres in diameter. In one such clump, having 11 stems per m^2 in shaded areas and up to 30 in newly infested open areas, the stem height ranged from 1 to 3 m and the ground cover up to 90%. In open areas the rate of outward clump expansion was 6 to 8 m per annum, but less than 2 m in forested areas. Although about 90% of the ground was under cultivation in a sampling area of 24.5 ha, *C. chinense* covered some 50% of the area, with an average stem height of 1.5 m. Even in areas of intensive cropping, such as in taro or bananas under coconuts, patches of *C. chinense* were present. Indeed, 20 to 40% (and up to 70%) cover occurred in banana plantations and up to 80% ground cover in areas temporarily left uncropped (Iosefa 1989). It is little wonder that Honolulu rose is regarded as an extremely serious weed in Western Samoa.

Suckers have been recorded to penetrate under a bitumen road to emerge and form thickets on the other side. The plant thrives best where the soil is fertile and moist and where there is plenty of sunlight. However, it can tolerate shade. In particular, the rich, moist soils of geologically-recent volcanic islands favour it.

Honolulu rose is also regarded as a major weed in American Samoa, Fiji (Plate 2, Fig. 2) and Niue. In Fiji it is naturalised and common, forming large patches on roadsides and waste spaces in the wet zone of Viti Levu, Taveuni and Rotuma (Parham 1959, 1972). It is of less importance in crops, although it is now spreading aggressively (M. Nagatalevu pers. comm. 1989). In Niue its status has changed rapidly over the past five years from relatively unimportant to being one of the major weeds and rated fifth in importance in 1992. It is believed to have been spread by tractor-mounted slashers and by suckers in rubbish thrown into the bush. It is a problem particularly in bush gardens on fertile soils (T.G. Mautama pers. comm. 1989).

By contrast, there are other Pacific countries into which Honolulu rose has been introduced where it is regarded at most as a minor weed. Thus, in Hawaii it has shown relatively few weedy traits and is not common either as a garden plant or in the wild. Neither is it regarded as a weed in Tahiti, where it has been present since 1845 and fairly common, at least since 1922.

In the Botanic Gardens in Cairns (Australia) it has increased from a small plant to a clump many metres across, with plantlets coming up all around the main clump (J. Swarbrick pers. comm. 1989, D. Warmington pers. comm. 1989).

There are some reports from Central America and the Caribbean of *C. chinense* exhibiting a degree of weediness, for example references to it in Haiti as 'a large-leaved weed growing in thick stands in coffee glades' (Dozier 1931).

In the Philippines, it is occasionally grown as an ornamental and in other situations it is not considered as a weed (R.T. Lubigan pers. comm. 1989). *C. chinense* is not known to be abundant or aggressive in what is believed to be its native range in southern China and northern Vietnam.

Except in the oceanic southwest Pacific, the undesirable attributes of *C. chinense* are probably more than counterbalanced by its value as an ornamental plant and the pleasing fragrance of its flowers. It is reported to be used in leis but, in this respect, it is clearly far less popular than the ivory, bell-like flowers of its relative, pikake (*Clerodendrum indicum*).

Many species of *Clerodendrum* contain chemicals that have toxic, antifeedant (Kato et al. 1972) or other pharmacological effects, but extracts that have been tested in various ways for insecticidal properties have displayed only moderate activity. A chemical examination of the aerial parts of *C. chinense* was reported by Nair et al. (1974) and two very rare steroids were identified in the leaves and stems by Akihisa et al. (1988). The antifeeding effects of extracts of six species of *Clerodendrum*, including *C. chinense*, for larvae of the cluster caterpillar *Spodoptera litura* were examined by Hosozawa et al. (1974) who reported the presence of the antifeeding diterpenes, clerodendrin A and B.

In Malaysia, some species of *Clerodendrum* are associated with sorcery or are used medicinally because of their supposed or actual curative powers (Neal 1965). Thus *C. chinense* is reported to be used topically, either in a fomentation for rheumatism and ague or, with other substances, for skin diseases (Burkill 1935, Quisumbing 1951). It is still used for medicinal purposes in Vietnam, alone or mixed with other herbs for the control of diseases including dysentery and venereal diseases (Jolivet 1983, T.T. Gian pers. comm. 1989).

In India, partially clarified aqueous extracts of *C. chinense*, applied as a 4% foliar spray every three to four days from seedling stage, reduced infection of *Vigna radiata* and *V. mungo* plants by mung bean yellow mosaic virus by about 60% and enhanced their yield (Verma *et al.* 1985). Antiviral activity was also shown by aqueous leaf extracts of *C. aculeatum* against tobacco mosaic virus in tobacco (Prasad 1986).

Control measures

Control of *C. chinense* is mainly by hand weeding, particularly in crops (taro, vegetables). In Hawaii, it is recommended that the plants be dug out (Pope 1968). No detailed screening of herbicides has been carried out, although 2,4,5-T, or the more expensive Tordon 520 Brushkiller, are suggested as possible herbicides for Western Samoa (Reynolds 1978). More recently a mixture of dicamba and 2,4-D has proved effective (T.V. Bourke pers. comm. 1989). Work carried out in Western Samoa has also shown that metsulfuron methyl ester produces effective control. It has been recommended that the plants be cut and the new growth sprayed (N. Nagatalevu pers. comm. 1989).

When herbicides were applied in Western Samoa to regrowth four weeks after it had been slashed to the ground, ghyphosphate partially destroyed the foliage, but complete regrowth had occurred by 4 to 6 weeks after application. Treatment with 2,4,5-T resulted in complete kill of foliage, but 5 to 15% of the plants had regrown after 8 weeks (E. Kürschner pers. comm. 1989).

Natural enemies

The only account of the natural enemies of *C. chinense* in its native range appears to be that of Jolivet (1983), who carried out observations in northern Vietnam in the course of studying the association of ants and plants. Most of his records relate to plants growing in clearings or along paths in the forest of Cuc Phuong, some 80 km south of Hanoi. There, some 25 insect species (Table 5.3) and a small snail were observed attacking its leaves or flowers. The species varied according to the season, time of day or night and plant environment, the fauna being richest in forest clearings and poorest near habitations. A number of other insects (but rarely Lepidoptera) sought nectar from the flowers and many ants, but fewer beetles, were attracted to the extra-floral nectaries. Ants and beetles were the main pollinators.

Table 5.3 List of insects associated with *C. chinense** in Vietnam (after Jolivet 1983).

Hemiptera
- TINGIDAE
  - undetermined gall-forming species

Coleoptera
- ELATERIDAE
  - ?*Agriotes* sp.
- PHALACRIDAE
  - *Phalacrus* sp.
- CHRYSOMELIDAE
  - Chrysomelinae
    - *Phyllocharis undulata*
  - Eumolpinae
    - *Cleorina* ? *dohertyi*
    - *Colaspoides* sp. nr *polvipes*
  - Cassidinae
    - *Aspidomorpha furcata*
  - Halticinae
    - *Haltica foveicollis*
    - *Hyphasis* sp.
    - *Hyphasis* sp. nr *parvula*
    - *Luperomorpha* sp. prob. *albofasciata*
    - *Nisotra* sp.
    - *Sabaethe* 3 spp.
    - *Sabaethe fusca*
  - Galerucinae
    - *Hoplasomoides egena*
    - *Monolepta* sp.
- CURCULIONIDAE
  - Otiorhychinae
    - Genus and sp. undetermined
  - Baridinae
    - *Acythopeus* sp.
    - 3 genera and species undetermined
  - Alcidodinae
    - *Alcidodes* sp.
  - Erirhininae
    - *Imerodes* sp.
  - Rynchophorinae
    - *Aplotes* sp.
  - Tanymecinae
    - ? *Burmotragus* sp.

* It is probable that Jolivet's observations were made on *C. chinense* var. *simplex*

The almost invariable presence of ants on *C. chinense* when it is flowering is considered to deter a range of herbivores that might otherwise attack it. Herbivores that do colonise the plants invariably appear to be those that produce toxic secretions or have other defense mechanisms. Characteristically they are not nectar-seeking and tend to occupy areas away from the nectaries guarded by ants. They occur on both upper and lower surfaces of the leaves and are capable of rapidly skeletonising them. Nectar secretion (and hence visits by ants) ceases during seed formation, leaving the plant more vulnerable during this period, although still protected against some non-habituated herbivores by the foetid smell of the leaves and the various deterrent chemicals present (Jolivet 1983).

Although they occur throughout the year, the gregarious yellow larvae of the chrysomelid beetle *Phyllocharis undulata* are particularly damaging to small and medium clumps of *C. chinense* var. *simplex* in summer. This species is active only by day and seems indifferent to the presence of ants, presumably being protected by its toxic secretions. When mechanically disturbed larvae are reluctant to detach from the leaves (Jolivet 1983). *P. undulata* larvae also occur on the leaves of another verbenaceous plant *Vitex holophylla* (Dang 1981, Medvedev and Dang 1982), but in the field they do not attack the leaves of *Clerodendrum fallax* (P. Jolivet pers. comm. 1989) or *C. paniculatum*, which often grows alongside *C. chinense* in Vietnam (Jolivet 1983). *Phyllocharis undulata* has also been observed feeding actively on the leaves of *C. chinense* at Au Voa, Bavi District, west of Hanoi and in the Vinh Phu province north of Hanoi. At the same time (May) no insect damage was observed to plants at Lang Son on the Vietnam-China border, nor was damage observed, in April to plants in the Chiang Mai region of Thailand (B. Napompeth pers. comm. 1989).

The morphology of the larvae of *P. undulata* was described by Medvedev and Zaitzev (1979) and the larva figured by these authors and by Kalshoven (1981). The yellowish pupae occur in the soil and the adults are strikingly coloured, yellow and blue (Plate 2, Fig. 4). They tend to be very localised and to fly readily when disturbed, but they may also exhibit reflex immobility. The orange-yellow eggs, which are often parasitised in Java (Kalshoven 1981), are laid in clusters on the undersides of the leaves. If *Phyllocharis* is eventually selected as a biological control agent it should be cleared of its gregarine fauna (*Gregarina juengeri*) before release (Théodoridès et al. 1984).

Another damaging chrysomelid, and the only one listed in Table 5.3 that is recorded as attacking the flowers, is *Hoplasomoides egena*, whose adults fly off rapidly when disturbed. This beetle suffers high mortality in autumn from attack by *Beauveria bassiana*, but this fungus is inactive during summer. In Asia, members of the genera *Hoplasomoides* and *Hoplasoma* appear, to be restricted to the verbanaceous genera *Clerodendrum, Premna* and *Vitex* (Jolivet 1983).

Characteristically, when disturbed, adults of the halticine chrysomelids immediately jump into the air and take flight (Table 5.3). They are presumably responsible for the numerous small holes in the leaves of many herbarium specimens of *C. chinense* from Southeast Asia, but no details are provided by Jolivet (1983) of the damage that they cause in Vietnam. Most are recorded as disappearing in summer and the elaterid *Agriotes*. sp. is also absent in summer. Two of the species listed (*Haltica foveicollis* and *Nisotra* sp.) may only be casual visitors to the plant. The latter elaterid beetle probably feeds only on nectar.

The presence of unidentified mealybugs amongst the flower bracts is mentioned by Jolivet (1983). These have a mutualistic association with ants, which eagerly seek their secretions.

Large galls, probably caused by tingid bugs, are common on stems, petioles, leaves and particularly on the leaf veins of *Clerodendrum* spp., and of *C. chinense* in particular. Only one lepidopterous larva, yellow and urticating, was observed by Jolivet (1983) It occurred on a plant without attendant ants. T.T. Gian (pers. comm 1989) has recently observed a lepidopterous larva (Tortricidae) feeding on the leaves. Small mites, which

were abundant around the petiole nectaries appeared to ingest nectar and seemed to cause no damage (Jolivet 1983).

In contrast with the situation in Vietnam, there are few records of attack elsewhere on *C. chinense* (Table 5.4). The issid bug *Colpoptera clerodendri* was described by Dozier (1931) from specimens collected from *C. chinense* in Haiti. However, as this host is not native there, the bug must have transferred to it from some other plant. Its host range merits investigation since it is possible that it will not attack any plants of economic importance. Of the other species listed, the widespread aphid *Myzus ornatus* is a polyphagous pest of an extensive range of economic plants and the widely polyphagous *Phenacoccus parvus* is probably a relatively recent introduction from tropical America to the Pacific. There it is known from Fiji, New Caledonia, Vanuatu and Western Samoa. It was collected from *C. chinense* in Savaii (Western Samoa) in 1987 (Williams and Watson 1988b), and was observed to be causing damage a decade earlier in Upolu (P.A. Maddison pers. comm. 1989). The growing tips are most heavily infested during the dry season (A. Peters pers. comm. 1989). *P. parvus* is recorded as attacking the weeds *Lantana camara, Mikania micrantha* and *Sida acuta* in Vanuatu (Cock 1984) and it has recently been taken on *C. chinense* in Cairns, Queensland (D. Warmington pers. comm. 1980).

Planococcus pacificus is the most widespread mealybug in the Pacific. It is widely polyphagous and a serious pest of coffee in Papua New Guinea. It was collected on flower heads of *C. chinense* near Suva, but did not appear to be damaging them (author's observations 1989).

The soft brown scale *Coccus hesperidum*, reported from *C. chinense* in Florida, is one of the most polyphagous species in the Coccidae (Gill et al. 1977) and is cosmopolitan in glasshouses and on plants in tropical and subtropical regions. It is an important pest of citrus in many parts of the world (Talhouk 1975), if not brought under biological control, as it has now been in a number of areas (Clausen 1978a).

In the São Paulo botanic gardens, the leaves of *C. chinense* were heavily damaged in the last months of 1981 and the beginning of 1982 by the native chrysomelid beetle *Omophoita sexnotata* (Bergmann et al. 1983). No subsequent observations have been made by these authors either on the insect or its host (J.A. Winder pers. comm. 1989), but *O. sexnotata* would be of no value as a biological control agent since it is reported to attack ears of wheat in Rio Grande do Sul. Several other species of *Omophoita* are also well known pests in Brazil.

Diaphania hyalinata larvae, which were recorded on the leaves of *C. chinense* in Bermuda, also damage the leaves and fruit of cucurbits there (Ogilvie 1926).

Table 5.4 Natural enemies of *Clerodendrum chinense* in places other than Vietnam.

Natural enemy	Location	Reference
Hemiptera		
PENTATOMIDAE		
Nezara viridula	Western Samoa	Isoefa 1989
ISSIDAE		
Colpoptera clerodendri	Haiti	Dozier 1931
APHIDIDAE		
Myzus ornatus	India	Raychaudhuri 1983
Unidentified aphid	American Samoa	A. Vargo pers. comm. 1989
DIASPIDIDAE		
Chrysomphalus dictyospermi	Italy	Savastano 1930
Hemiberlesia (= *Aspidiotus*)	Italy	
Iataniae	Italy	Costantino 1950
	Cuba	Houser 1918

(continued on next page)

Natural enemy	Location	Reference
PSEUDOCOCCIDAE		
Phenacoccus parvus	Western Samoa	Isofea 1989, Williams & Watson 1988b
	Australia	Warmington pers. comm. 1989
	Thailand	author's observations 1990
Planococcus pacificus	Fiji	author's observations 1989
	Western Samoa	T.V. Bourke pers. comm. 1989
	Australia	author's observations
Pseudococcus longispinus	Ukraine	Kirichenko 1928
Unidentified	American Samoa	A. Vargo pers. comm. 1989
COCCIDAE		
Gascardia cirripediformis	Cuba	Ballou 1926
Gascardia floridensis	Bermuda	Waterston 1941
Coccus hesperidum	Florida	Hamon & Williams 1984
Protopulvinaria pyriformis	Bermuda	Waterston 1941
Pulvinaria sp. (? *urbicola*)	Cuba	D.R. Miller pers. comm. *
Saissetia hemisphaerica	Cuba	Ballou 1926
Unidentified	Sumatra	Van Leedwen-Reignvaan 1941
COREIDAE		
Pternistria bispina	Australia	author's observation
Coleoptera		
CHRYSOMELIDAE		
Omophoita sexnotata	Saõ Paulo (Brazil)	Bergmann et al. 1983
Lepidoptera		
PYRALIDAE		
Crocidolomia pavonana	Fiji	Lever 1945
SPHINGIDAE		
Acherontia styx	Thailand	Pholboon 1965
Diaphania (Margaronia) hyalinata	Bermuda	Ogilvie 1926
? Family		
(Minor larval damage to leaves)	Western Samoa	author's observations, Iosefa 1989
	Fiji	author's observations
LYCAENIDAE		
Hypolycaena erylus himavantus Fruhstorfer	Thailand	Pholboon 1965
Hypolycaena phorbas	Australia	D. Warmington pers. comm. 1989
NOCTUIDAE		
Spodoptera litura	American Samoa	A. Vargo pers. comm. 1989
Fungi		
Aecidium clerodendri	Philippines	Baker 1914, Sydow & Sydow 1913a
Cercospora volkameriae	Brazil	Speg 1908 in Singh 1972
Endophyllum superficiaie	Thailand	Black & Jonglaekha 1989
Pleosporia infectoria	India	Reddy & Rao 1975

* Information supplied by D.R. Miller, Systematic Entomology Laboratory, USDA, from a card index at Beltsville, Md.

The cabbage centre grub *Crocidolomia pavonana*, a serious world-wide pest, has been recorded attacking *C. chinense* in Fiji (Lever 1945).

Defoliation of *C. chinense* in Cairns by larvae of the lycaenid butterfly *Hypolycaena phorbas*, attended by the green tree ant *Oecophylla smaragdina* has been reported (D. Warmington pers. comm. 1989). Larvae of this butterfly occur also on a number of other plants (including *Cupaniopsis anacardioides* (Sapindaceae), *Faradaya splendida*, *Clerodendrum floribundum* (Verbenaceae), *Planchonia caryea* (Lecythidaceae), *Flagellaria indica* (Flagellariaceae), *Acmena* (Myrtaceae) and mistletoe (Loranthaceae) (Common and Waterhouse 1981).

In American Samoa the armyworm *Spodoptera litura* was reported to attack both taro and bordering growth of *C. chinense* (A. Vargo pers. comm. 1989). In 1988 minor damage to leaves of *C. chinense*, which appeared to be caused by a lepidopterous larva was observed by the author near Apia in October and a lepidopterous larva was observed attacking leaves in Fiji in July. The convolvulus moth *Agrius convolvuli* was reported in India to lay eggs on *C. chinense*, although no feeding damage was observed (Nagarkatti 1973). This record is paralleled by reports that newly-emerged adults of the tenthredinid turnip pest *Athalia lugens infumata* in Japan move to the leaves of *Clerodendrum trichotomum* to mate (Kitano 1988), but not to use it as a host.

Leaves of many of the specimens of *C. chinense* (as *C. fragrans*) from Malaysia or Singapore in the Singapore herbarium have holes reminiscent of flea beetle attack and photographs of plants growing in the Kuala Lumpur Botanic Gardens in April show similar damage. In the Philippines small to large (1 cm diameter) holes occur in the leaves, which might be flea beetle damage (J.V. Pancho pers. comm. 1989).

The rust *Endophyllum superficiale* occurs on *C. chinense* in Thailand and Vietnam and attacks a number of other *Clerodendrum* species in Southeast Asia and one in Australia. A *Cercospora*-like fungus was also present in Vietnam (Black and Jonglaekha 1989, M. Julien pers. comm. 1991). A fungus (the *alternaria* state of *Plesosporia infectoria*) was found on the leaves of *C. chinense* in Andra Pradesh (India), severe attack causing the drying of both young and mature leaves and occasional defoliation of plants (Reddy and Rao 1975). Also, there is an early record (February 1911) of the rust *Aecidium clerodendri* attacking *C. philippinum* in the Philippines (Laguna, Luzon) (Sydow and Sydow 1913a). This rust was also recorded attacking *Clerodendrum calamatosum*, *C. intermedium* and an unidentified species of *Clerodendrum* in January and September (Baker 1914, Sydow and Sydow 1913a,b).

In view of the extremely wide distribution of *C. chinense* and its common use as an ornamental plant, the paucity of records of natural enemies elsewhere than in Vietnam might be interpreted to mean that it is seldom attacked or, if it is, that the damage is so minor as not to arouse concern. This view, however, finds little support from Table 5.5, which lists organisms attacking other species of *Clerodendrum*, records of which have been encountered during the search for information on *C. chinense*. It would be quite exceptional if a genus with some 500 species did not have at least a similar number of associated, relatively host specific insects. A more plausible inference, therefore, is that the insects attacking this genus have been very poorly studied. Of the insects listed in Table 5.5, most are polyphagous, generally widely so, as well as widespread, and either pest or potential pest species. Hence most could not be considered as potential biological control agents, and only the three aphids *Aphis clerodendri*, *Nasonovia rostrata* and *Prociphilus clerodendri* seem to offer any prospects of being useful but, to offset this, it is quite possible that some of the fungi (in particular *Aecidium clerodendri*, may have a useful degree of specificity. *Aphis clerodendri* belongs to the *A. gossypii* group which is in taxonomic disarray. Similar aphids have been collected from *Clerodendrum* spp. in Australia, Philippines and India (V.F. Eastop pers. comm. 1989).

Table 5.5 Natural enemies of species of *Clerodendrum* other than *C. chinense*.

Natural enemy	Host	Location	Reference
Hemiptera			
RICANIIDAE			
Ricania fenestrata	*C. inerme*	India	Swaminathan & Ananthakrishnan 1984
APHIDIDAE			
Aphis clerodendri	*C. trichotomum*	Japan	Higuchi & Miyazaki 1969, Inaizumi 1970, Matsumura 1917
		Korea	Paik 1972
	C. trichotomum var. *yakushimensis*	Japan	Higuchi & Miyazaki 1969
A. clerodendri var. *amamiana*	*C. trichotomum* var. *yakushimensis*	Japan	Takahashi 1966
A. gossypii	*Clerodendrum* sp.	Hawaii	Zimmerman 1948
	Clerodendrum spp.	India	Raychaudhuri 1983
	C. ineana	India	Raychaudhuri 1983
	C. infortunatum	India	Raychaudhuri 1983
	C. intermedium	Philippines	Calilung 1969
	C. japonicum	Japan	Higuchi & Miyazaki 1969
	C. serratum	India	Raychaudhuri 1983
	C. thomsonae		Patch 1938
	C. trichotomum	Japan	Higuchi & Miyazaki 1969, Patch 1938
A. nasturtii	*Clerodendrum* spp.	India	Raychaudhuri 1983
	C. infortunatum	India	Raychaudhuri 1983
A. spiraecola (= *A. citricola*)	*Clerodendrum* spp.	India	Raychaudhuri 1983
	C. infortunatum	India	Raychaudhuri 1983
Aulacorthum magnoliae	*C. trichotomum*	Japan	Higuchi & Miyazaki 1969
Brachycaudus helichrysi	*Clerodendrum* spp.	India	Raychaudhiri 1983
Mollitrichosiphon nandii	*C. serratum*	India	Raychaudhiri 1983
Myzus ornatus	*Clerondendrum* spp.	India	Raychaudhiri 1983
	C. myricoides	California	Leonard et al. 1971
M. persicae	*C. japonicum*	Japan	Miyazaki 1971
	C. myricoides	California	Leonard et al. 1970
	C. speciosissimum	California	Leonard et al. 1970
Nasonovia rostrata	*C. infortunatum*	India	David & Hameed 1974, Raychaudhuri 1983
Prociphilus clerodendri	*C. trichotomum*	Japan	Okamoto & Takahaski 1927
		Korea	Paik 1972
Sinomegoura citricola	*Clerodendrum* spp.	India	Raychaudhuri 1983
ALEYRODIDAE			
Aleurocanthus alternans	*C. polycephalum*	West Africa	Cohic 1969
A. descarpentriesi	*C. polycephalum*	West Africa	Cohic 1969
Aleurolobus juillieni	*C. thomsonae*	Congo	Cohic 1968b
Aleuroplatus triclisiae	*C. speciosissimum*	West Africa	Cohic 1968a
Aleurotuberculatus uraianus	*Clerodendrum* sp.	Taiwan	Takahashi 1932
Bemisia tabaci	*C. infortunatum*	India	Misra & Singh 1929

(continued on next page)

Natural enemy	Host	Location	Reference
	C. splendens		Mound & Halsey 1978
	C. villosum	Malaysia	Corbett 1935
Pealius rubi	*C. trichotomum*	Japan	Takahashi 1955
Tetraleurodes russellae	*Clerodendrum* sp.		Cohic 1968b
ORTHEZIIDAE			
Orthezia insignis	*Clerodendrum* sp.	Egypt	Hall 1922
	Clerodendrum sp.	Uganda	Ghesquière 1950
	C. inerme	Egypt	Ezzat 1956
	C. macrosiphon	Ceylon	D.R. Miller pers. comm.
	C. milkii	India	D.R. Miller. pers comm.
	C. minahassae	Malaysia	Corbett & Gater 1926
	C. penduliflorum	Singapore	Morrison 1921
	C. thomsonae	India	D.R. Miller pers. comm.
ASTEROLECANIIDAE			
Asterolecanium pustulans	*Clerodendrum* sp.		Moldenke 1985a
		Florida	D.R. Miller pers. comm.
		El Salvador	D.R. Miller pers. comm.
COCCIDAE			
Coccus acuminatus	*Clerodendrum* sp.	Jamica	D.R. Miller pers. comm
C. capparidis	*C. indicum*	Florida	Hamon & Williams 1984
C. cirripediformis	*Clerodendrum* sp.	Florida	Hamon & Williams 1984
C. hesperidum	*Clerodendrum* sp.	S. Africa	Munro & Fouche 1936
	Clerodendrum sp.	USA	Pirone et al. 1960
	C. forgesii	USSR	Saakian-Baranova 1964
	C. fretidum	USSR	Saakian-Baranova 1964
	C. infortunatum	USSR	Arkhangel'skaya 1929 Porschsenius 1957
Gascardia sp.	*Clerodendrum* sp.	Uganda	Compere 1937
	C. thomsonae	Bermuda	D.R. Miller pers. comm.
G. africanus	*C. fallax*	Egypt	Hall 1923
G. cirripediformis	*Clerodendrum* sp.	Florida	Hamon & Williams 1984
G. destructor	*Clerodendrum* sp.	Uganda	Gurney 1936
G. floridensis	*Clerodendrum* sp	Egypt	Hall 1923
	C. corallita	Bermuda	Ogilvie 1928
Protopulvinaria pyriformis	*Clerodendrum* sp.	Bermuda	Ogilvie 1928
Pulvinaria sp.	*C. fallax*	Cuba	D.R. Miller pers. comm.
	C. siphonanthus	Panama	D.R. Miller pers. comm.
P. psidii	*Clerodendrum* sp.	Florida	Pirone et al. 1960
P. urbicola	*Clerodendrum* sp.	Florida	Hamon & Williams 1984
Saissetia coffeae	*Clerodendrum* sp	Florida	Hamon & Williams 1984
S. hemisphaerica	*Clerodendrum*		Moldenke 1985a
		Panama, Brazil	D.R. Miller pers. comm.
S. miranda	*C. speciossimum*	Florida	Mead 1983
S. oleae	*Clerodendrum* sp	Florida	Hamon & Williams 1984
	C. kaempferi	Florida	Hamon & Williams 1984
	C. nutans	Cuba	Ballou 1926
S. zanzibarensis	*C. glabrum*	Zanzibar Is.	Way 1954
PSEUDOCOCCIDAE			
Dysmicoccus neobrevipes	*Clerodendrum* sp.	W. Samoa	Williams & Watson 1988b

(continued on next page)

Natural enemy	Host	Location	Reference
Ferrisia virgata	*C. paniculatum*	Siera Leone	Hargreaves 1937
Nipaecoccus viridis (= *N. vastator*)	*C. capsularis*	India	Ali 1961, Ghosh & Ghosh 1985
	C. fallax	Cuba	Ballou 1926
	C. heterophyllum	Madagascar*	Mamet 1951

* This pseudococcid was wrongly identified as *Pseudococcus filamentosus* (D.J. Williams pers. comm. 1989).

	C. infortunatum	India	Ghosh & Ghosh 1985
	C. olitorius	India	Ghosh & Ghosh 1985
Phenacoccus hirsutus	*Clerodendrum* sp.	Egypt	Hall 1923
Planococcus citri	*Clerodendrum* sp.	S. Australia	Williams 1985a
		USA	Pirone et al. 1960
		Egypt	Hall 1923
	C. fallax	Fiji	Veitch & Greenwood 1924
	C. formicarum	Gold Coast	Strickland 1947
	C. paniculatum	Mauritius	Mamet 1948
P. pacificus	*Clerodendrum* sp.	W. Samoa	Williams & Watson 1988b
	C. disparifolium	W. Samoa	Williams & Watson 1988b
	C. fallax	W. Samoa	Williams & Watson 1988b
	C. paniculatum	W. Samoa	Williams & Watson 1988b
Pseudococcus filamentosus	*Clerodendrum* sp.	Hawaii	Fullaway 1925
		Malaysia	Takahashi 1950
	C. heterophyllum	Madagascar	Mamet 1951
	C. squamatum	Hawaii	Fullaway 1923
Pseudococcus longispinus	*Clerodendrum* sp.	USSR	D.R. Miller pers. comm.
P. njalensis	*Clerodendrum* sp.	Gold Coast	Hall 1945
Unidentified	*C. balfouri*	USA	Ehrhorn 1926
DIASPIDIDAE			
Abgrallaspis cyanophylli	*Clerodendrum* sp.	W. Samoa	Williams & Watson 1988a
Aonidiella aurantii	*Clerodendrum* sp.	S. Africa	Munro & Fouche 1936
		California	D.R. Miller pers. comm.
A. orientalis	*C. phlomoides*	India	Rahman & Ansari 1941
	C. inerme	India	Rahman & Ansari 1941
A. pectinatus	*Clerodendrum* sp.	S. Africa	Munro & Fouche 1936
Aspidiotus cyanophylli	*C. siphonanthus*	Panama	D.R. Miller pers. comm.
A. excisus	*C. inerme*	Florida	Dekle 1976
		Florida	Takahashi 1929, 1936a
Chrysomphalus dictyospermi	*Clorodendrum* sp	Italy	Savastano 1930
	C. glaucum	Italy	Savastano 1930
	C. roseum	Italy	Savastano 1930
	C. splendens	Italy	Savastano 1930
	C. squamatum	Italy	Savastano 1930
Hemiberlesia lataniae	*Clerodendrum* sp.	Florida	Dekle 1976
Hemichionaspis sp.	*C. glaucum*	Java	D.R. Miller pers. comm.
Pinnaspis minor	*C. thomsonae*	Malaysia	D.R. Miller pers. comm.
Pseudischnaspis alienus	*Clerodendrum* sp.	Cuba	Houser 1918
MARGARODIDAE			
Drosicha mangiferae	*C. infortunatum*	India	Tandon et al. 1978, Srivastava & Fasih 1988
Icerya seychellarum	*Clerodendrum* sp.	Solomon Is	Williams & Watson 1990

(continued on next page)

Natural enemy	Host	Location	Reference
TINGIDAE			
Paracopium sp.	*C. buchholzii*		Jaeger 1976
Paracopium sp.	*C. inerme*		Murphy 1989
P. cingalense	*C. phlomidis*	India	Mani 1973
P. (= *Eurycera*) *glabricorne*	*C. schweinfurthii*	Tanzania	Verdcourt 1962
P. hamadryas	*Clerodendrum* sp.	Belgian Congo	Drake 1925
	C. buchholzii	Gold Coast	Horvàth 1929
ALYDIDAE			
Leptocorisa varicornis	*C. infortunatum*	India	Sen 1955
Thysanoptera			
THRIPIDAE			
Frankliniella brevicaulis	*Clerodendrum* sp.	Central America	USDA 1978
F. formosae tricolor	*C. trichotomum*	Japan	Moulton 1928
Coleoptera			
MELOIDAE			
Epicuata hirticornis	*C. cyrtophyllum*	Taiwan	Maki 1920
	C. paniculatum	Taiwan	Maki 1920
CERAMBYCIDAE			
Dihammus cervinus	*Clerodendrum* sp.	Burma, India, Pakistan	Browne 1968
	C. infortunatum	India	Beeson 1925
Smermus fisheri	*C. infortunatum*	Burma	Gardner 1941
CHRYSOMELIDAE			
Alagoasa bicolor	*C. aculeatum*	Puerto Rico	Virkki & Zambrana 1980
Argopistes hargreavesi	*Clerodendrum* sp.	Kenya	Jolivet 1983
Cladocera uniformis	*Clerodendrum* sp.	Kenya	Jolivet 1983
Luperomorpha vittata	*C. inerme*	India	Lingappa & Siddappaji 1978
Oidosoma africanum	*C. capitatum*	Kenya	Jolivet 1983
Omophoita cyanipennis	*C. aculeatum*	Puerto Rico	Virkki 1980, 1982
	C. speciosissimum	Cuba	Virkki 1980
Phyllocharis cyanicornis	*C. floribundum*	Australia	D.P Sands pers. comm. 1989
P. gracilis	*C. floribundum*	Australia	D.P. Sands pers. comm. 1989
Pseudomela murrayi	*Clerodendrum* spp.	Kenya	Jolivet 1983
Unspecified Halticine	*C. aculeatum*	Puerto Rico	Virkki 1980
SCOLYTIDAE			
Xylosandrus compactus (= *Xyleborus morstatti*)	*Clerodendrum* sp.		Anon. 1941
Diptera			
AGROMYZIDAE			
Unidentified sp.	*Clerodendrum* sp.	Uganda	Spencer 1973
Lepidoptera			
HEPIALIDAE			
Sahyadrassus malabaricus	*C. viscosum*	India	Nair 1982

(continued on next page)

Natural enemy	Host	Location	Reference
COSSIDAE			
Xyleutes ceramicus	*Clerodendrum* sp.	Burma	Atkinson 1929-31
	C. infortunatum	Burma	Garthwaite 1940
	C. infortunatum	India	Arora 1971
Zeuzera coffeae	*C. infortunatum*	India	Arora 1971
PSYCHIDAE			
Clania cramerii	*Clerodendrum* sp.	Pakistan	Hamid 1966
PYRALIDAE			
Salebria iriditis	*C. serratum*	Java	Meyrick 1933
LYCAENIDAE			
Anthene lycaenoides	*Clerodendrum* sp.	Australia	Common & Waterhouse 1981
Euchrysops cnejus	*C. inerme*	India	T. Singh 1982
Hypolycaena phorbas	*C. floribundum*	Australia	Common & Waterhouse 1981
	C. inerme	Australia	Moss 1989
Pseudodipsas eone	*C. cunninghamii*	Australia	Common & Waterhouse 1981
SPHINGIDAE			
Acherontia styx	*C. indicum*	Indonesia	Kalshoven 1981
	C. inerme	Saudi Arabia	Pittaway 1987
ARCTIDAE			
Diacrisia rhodophila var. *rhodophilodes*	*Clerodendrum* sp.	Taiwan	Sonan 1940
Spilosoma (= *Diacrisia*) *obliqua*	*Clerodendrum* sp.	India	Yadava & Singh 1977
	C. inerme	India	Singh & Gangrade 1977
		Pakistan	Hussain et al. 1987
	C. siphonanthus	India	Lal & Mukharji 1978, Lal & Verma 1980
Hymenoptera			
TENTHREDINIDAE			
Athalia rosae ruficornis	*C. trichotomum*	Japan	Nishida & Fukami 1990, Nishida et al. 1989
Acari			
Brevipalpus phoenicis	*C. siphonanthus*	Hawaii	Garett & Haramoto 1967
		India	Lal 1979, Lal & Mukharji 1979
Eotetranychus uncatus	*C. siphonanthus*	India	Lal & Mukharji 1979
Tetranychus kanzawai	*C. trichotomum*	Japan	Takafuji & Ishii 1989
Tetranychus macfarlanei	*Clerodendrum* sp.	India	Pande & Yadava 1976
	C. aculeatum	India	Pande & Yadava 1976
	C. inerme	India	Pande & Yadava 1976
Nematoda			
Heterodera marioni	*Clerodendrum* sp.		Moldenke 1985a
Meloidogyne sp.	*Clerodendrum* sp.	USA	Westcott 1971
M. incognita	*Clerodendrum* sp.	USA	Pirone et al. 1960

(continued on next page)

Natural enemy	Host	Location	Reference
Plant Kingdom			
CONVOLVULACEAE			
Cuscuta reflexa	*Clerodendrum* sp.	India	Gupta et al. 1979
		Indonesia	van Oostroom & Hoogland 1953
	C. inerme	India	Sheriar 1951
Fungi			
Aecidium clerodendri	*Clerodendrum* sp.	Java	Baker 1914, Hennings 1892, 1908
	C. calamatosum	Philippines	Sydow & Sydow 1913a,b
	C. intermedium	Philippines	Sydow & Sydow 1910, 1913a,b
	C. multidorum		Moldenke 1985a
Asternia entebbeensis	*Clerodendrum* sp.	Uganda	Hansford 1946
A. clerodendricola	*Clerodendrum* sp.		Moldenke 1985a
Alternaria citri	*C. siphonanthus*	India	I.D. Singh 1982
Ascochyta infortunata	*C. infortunatum*	India	Ramakrishnan 1951
Balladynastrum clerodendri	*Clerodendrum* sp.		Moldenke 1985a
Capnodium sp.	*C. inerme*	India	Vora & George 1978
Cercospora sp.	*C. indicum*	USA	Sobers & Martinez 1964
	C. speciosum	USA	Sobers & Martinez 1964
	C. thomsoniae	USA	Sobers & Martinez 1964
C. apii f. *clerodendri*	*Clerodendrum* spp	Florida	Sobers & Martinez 1966 Westcott 1971
C. bakeri	*C. intermedium*	Philippines	Baker 1914
C. kashotoensis	*C. inerme*	India	Ragunathan et al. 1972
C. volkameriae	*C. infortunatum*	India	Srivastava et al. 1980
	C. siphonatum	India	Singh 1972
Cercoseptoria clerodendri	*Clerodendrum* sp.		Moldenke 1985a
Cerotelium daedaloides	*Clerodendrum* sp.	India	Singh 1972
	Clerodendrum sp	Uganda	Cummins 1943
	C. buchholzii	Uganda	Cummins 1943
Colletotrichum crassipes	*C. infortunatum*	India	Mohanan & Kaveriappa 1986
C. gloeosporioides	*C. infortunatum*	India	Karunakaran et al. 1980
Coniothyrium clerodendri			Moldenke 1985a
Curvularia eragrostidis	*C. infortunatum*	India	Raju & Leelavathy 1984
Cylindrocladium quinqueseptatum	*Clerodendrum* sp.	India	Sulochana et al. 1982
Didymaria clerodendri			Moldenke 1985a
Dimeria citricola			Moldenke 1985a
Fusarium concolor	*C. indicum* (but not on *C. infortunatum*)	India	Pandey & Pant 1980
Ganoderma lucidum	*C. inerme*	India	Rajak & Rai 1984
Halposporella clerodendri			Moldenke 1985a
Kutilakesa pironii (*Nectriella pironii*)	*C. bungei*	Florida	Alfieri et al. 1979
Meliola clerodendri	*Clerodendrum* sp.	Uganda	Hansford 1961
		Congo	Hansford 1961
	C. bucholzii	Sierra Leone	Hansford 1961
		Gold Coast	Hansford 1961

(continued on next page)

Natural enemy	Host	Location	Reference
	C. capitatum	Gold Coast	Hansford 1961
	C. paniculatum	Sierra Leone	Hansford 1961
	C. scandens	Sierra Leone	Hansford 1961
M. clerodendricola	*Clerodendrum* sp.	Celebes, Congo, Penang, Philippines, Samoa, Uganda	Hansford 1961
	C. canescens	Tonkin	Hansford 1961
	C. capitatum	Gold Coast	Hansford 1961
	C. cumingianum	Philippines	Hansford 1961
	C. formicarium	Cameroons	Hansford 1961
	C. glabrum	Sierra Leone	Hansford 1961
	C. intermedium	Philippines	Hansford 1961
	C. minahassae	Philippines	Hansford 1961
	C. scandens	Cameroons	Hansford 1961
	C. speciosissimum	Amboina	Hansford 1961
	C. speciosum	San Domingo	Hansford 1961
	C. trichostomum	Japan	Hansford 1961
	C. tuberculatum	Cuba	Hansford 1961
	C. volubile	Sierra Leone	Hansford 1961
M. durantae var. *acutiseta*	*Clerodendron* sp.	Uganda	Hansford 1961
M. sakawensis	*C. intermedium*	Philippines	Baker 1914
Phyllosticta clerodendri			Moldenke 1985a
P. inermis			Moldenke 1985a
Physalospora clerodendri	*C. infortunatum*	India	Ramakrishnan 1952
Podosporium penicillium var. *clerodendri*	*C. commersonii*	Philippines	Baker 1914
Puccinia erebia			Moldenke 1985a
	C. minahassae	Philippines	Baker 1914
Septoria petrakiana			Moldenke 1985a
S. phlyctaenoides		USA	Seymour 1929, Westcott 1971
Synchytrium sp.	*C. infortunatum*	India	Srivastava 1985
Tetrachia singularis			Moldenke 1985a
Bacteria			
Xanthomonas clerodendri	*C. phlomoides*	India	Patel et al. 1952
Viruses			
cucumber mosaic virus	*C. viscosum*	India	Joshi & Prakash 1978
tobacco ringspot	*C. thomsoniae*	Wisconsin (USA)	Khan & Maxwell 1975a,b
zonate ringspot	*C. thomsoniae*	Florida (USA)	Burnett & Youtsey 1962, Westcott 1971

Comment

Plants under the name *Clerodendrum chinense* vary greatly in weediness from one region to another. This may be because (i) their genetic constitution varies, (ii) certain environmental conditions (climate, soils) favour weediness in particular regions, (iii) the intensity of effective plant competition may vary, (iv) pressure from natural enemies may vary, and (v) likewise the intensity of human intervention.

There is clear evidence that flower type of *C. chinense* and its varieties vary over its distribution, but no information is available as to the significance of this in relation to potential weediness. All that can be said at this stage is that the seriously weedy form reported only in the Pacific is one that has double, sterile flowers. Since this form only propagates vegetatively (by suckers), all may well be derived from a single clone and possibly as a mutation from *C. chinense* var. *simplex*. This clone may, however, differ in weediness from the non-seeding stocks of the species introduced last century to French Polynesia and Hawaii. Studies employing electrophoresis and molecular techniques are necessary to throw light on this aspect.

There is also clear evidence that moist, fertile soils and abundant sunlight greatly favour growth of *C. chinense*. In Fiji its occupation of the wetter rather than the drier regions of several islands, emphasises the importance of adequate moisture. Thus it is clearly favoured by the rich, moist soils of geologically-recent volcanic islands (Swarbrick 1988), but not by the coral atoll environment, despite its occurrence on Aitutake (Cook Is). It is thus puzzling that it is not an important weed in Hawaii or French Polynesia, where parts at least of the environment would appear to be very suitable, and where it has been naturalised long enough to have become a pest if it could do so.

Competition from other plants may, conceivably, be somewhat less severe in the regions where it has become weedy but, such a phenomenon would be very difficult to characterise.

Insufficient information is available on what natural enemies attack *C. chinense* in its native range. Preliminary surveys at critical seasons in Vietnam, Laos and southern China would provide information on potential biological control agents occurring there and whether it might be fruitful to mount of a major project. The chrysomelid beetles from Vietnam (in particular *Phyllocharis undulata*) and the rust *Aecidium clerodendri* from the Philippines certainly merit further investigation. Tables 5.3 to 5.5 provide some indication of the groups of organisms most likely to be encountered. In view of the comparatively large number of Hemiptera listed in Table 5.5, it would be surprising if *C. chinense* did not prove to be host to a number of species in this order in its area of origin.

The closest relative of *C. chinense* is *C. bungei*, according to an examination of 52 morphological characters of 129 species (Stenzel et al. 1988). *C. bungei* appears to have evolved in the same general region as *C. chinense* and is known from the Chinese provinces of Anhwei, Chekiang, Honan, Hunan, Hupeh, Guangsi, Guangdong, Kiangsi, Kiangsu, Kweichow, Shensi, Sikang, Szechuan and Yunnan. It is also recorded from Hainan Is, Ryukyu Is, Indochina and Sikkim (Moldenke 1971). It has been widely dispersed as an ornamental and is naturalised in many parts of the world, especially Central and South America, but also in Hawaii and Guam. In brief, *C. bungei* may be distinguished by its leaves having serrated edges, and the flowers being single and, usually red to purple-pink, but rarely white. The corolla tube of the flower is several times longer than the calyx whereas, in *C. chinense*, the corolla tube is only slightly longer than the calyx (Moldenke 1985b). Like *C. chinense* it has extra-floral nectaries (Jolivet 1983). Surveys for natural enemies of *C. chinense* in its area of origin should, whenever possible, include observations also on organisms attacking *C. bungei*, since this may give useful information on host specificity.

There is only one species of *Clerodendrum*, namely *C. inerme*, that appears to be native to the oceanic Pacific. This ranges from Pakistan eastwards to Niue, occurring in the Pacific as a littoral shrub. Except for this species, the conservation aspect could be disregarded in the Pacific in considering the suitability of natural enemies belonging to this genus. Of course, the aesthetic importance of any introduced species of *Clerodendrum* would also need to be considered if they were at risk of attack and also the possibility of its attack on teak (Verbenaceae) where this tree is likely to be grown.

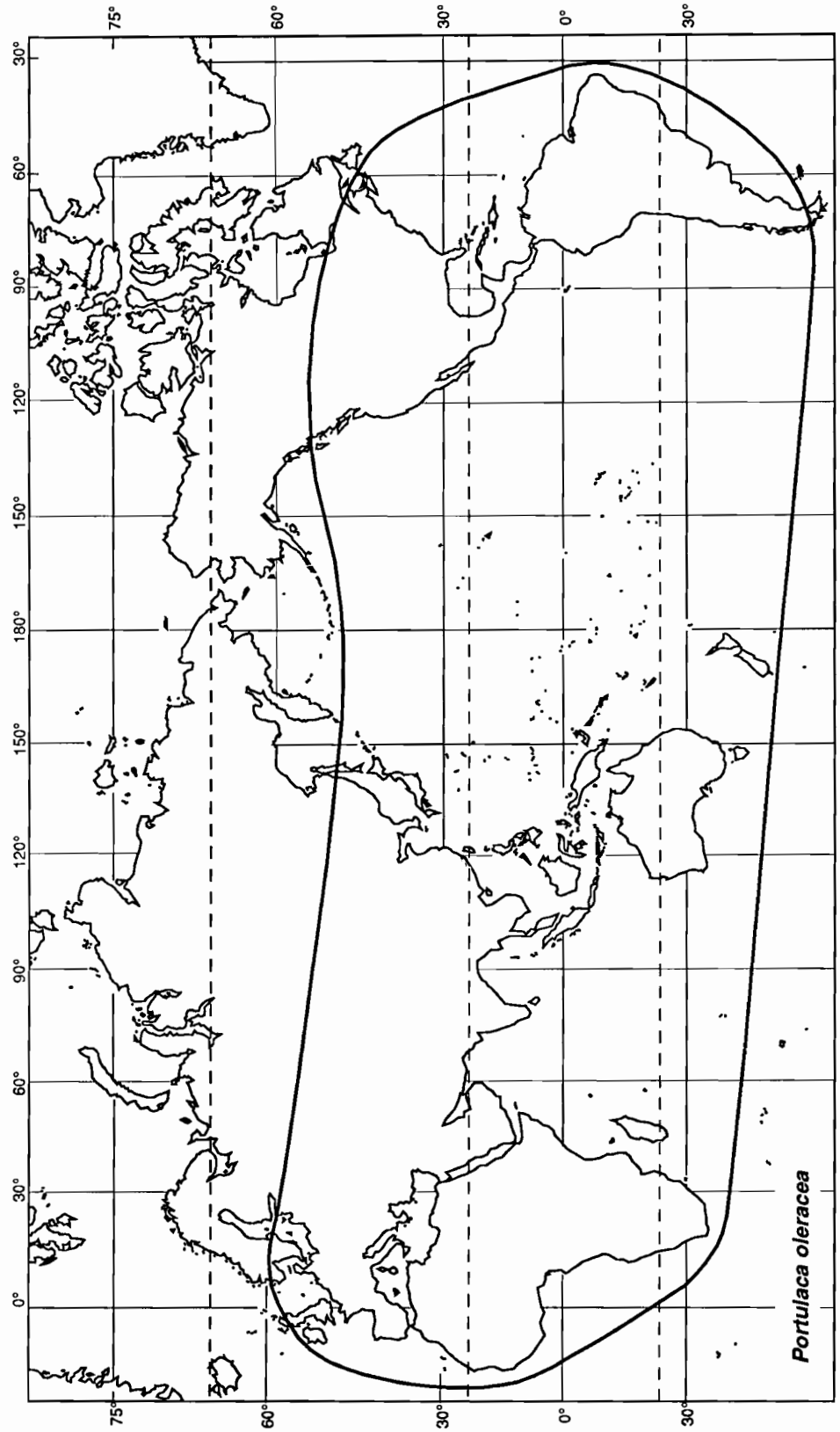

Figure 6.1 World distribution of *Portulaca oleracea*

6 *Portulaca oleracea* Linnaeus

PORTULACACEAE
pigweed, purslane; taukuku ni vuaka (Fiji); kamole (Niue); tamole (Samoa, Tonga)

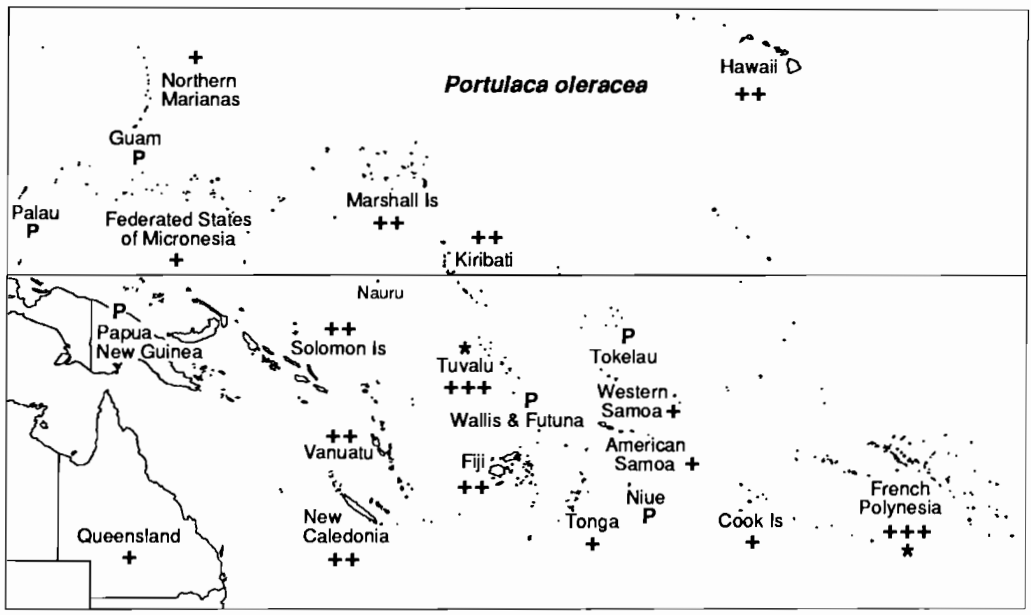

Figure 6.2 Pacific distribution of *Portulaca oleracea*

Portulaca oleracea, one of the world's very worst weeds, is widespread throughout tropical, subtropical and temperate areas.

Some 100 species of insects are reported to attack it. Of these, 13 appear to be restricted to the genus *Portulaca* and probably several to *P. oleracea*. Where they occur naturally, three leaf-mining or gall-forming flies, one leaf-mining moth, one leaf-mining sawfly and two weevils all show high specificity to *P. oleracea* and sufficient capacity to cause damage to be seriously considered as biological control agents.

If this suite of phytophagous insects is not already present, their establishment without their own natural enemies should lead to a significant lowering in the weed status of *P. oleracea*.

Portulacea oleracea is a prime target for an attempt at biological control.

Origin

Pigweed is possibly of Central American origin, although the name 'porcilaca' used for *P. oleracea* by Pliny the Elder (23-79 AD) and the view expressed in many botanical texts suggest that it is of Mediterranean or West Asian origin. However, pollen and seeds dating back to 1350 AD have been found in sediments in Ontario; and seeds in Louisiana, Illinois and Kentucky dating between 1000 BC and 750 AD (Miyanishi and Cavers 1980). Furthermore, a larger number of host specific insects have been found in the Americas than in Europe, (see below), suggesting that it has been present longest in the Americas. Its very wide distribution may be due to the fact that seeds eaten by birds have a high viability after passage through the digestive tract (Byrne and McAndrews 1975). The evolutionary centre of the genus *Portulaca* is postulated to be Australia (Geesink 1969) and the family Portulaceae is generally agreed to be of Gondwanan origin.

Distribution

Pigweed is very widespread throughout the tropical, subtropical and temperate regions of the world, including Southeast Asia, Papua New Guinea, Australia and New Zealand. In the oceanic Pacific it occurs in Hawaii and all of the 20 countries belonging to the South Pacific Commission (table 1.1).

Characteristics

Pigweed is a C4, usually diploid annual, reproducing by seed, or by stem fragments on moist soil. In sunlight it is prostrate (Plate 2, Fig. 5) but in partly shaded positions it may grow to 0.5m. The stems are succulent, often reddish, 0.2m to 0.5m long, smooth and fleshy and form mats. The leaves are alternate, flowers are self-pollinated, yellow, sessile and single or several together in the leaf clusters at the ends of branches (Plate 2, Fig. 6). They open only on sunny mornings. The seeds are about 0.5mm in diameter.

Importance

P. oleracea is one of the 12 non-cultivated species that have been most successful in colonising new areas (Allard 1965). It is a weed of 45 crops in 81 countries and was ranked 9th of the world's worst weeds (Holm et al. 1977). It rated equal 32nd in a recent Southeast Asian survey (Waterhouse 1993), 49th in Australia (A.J. Wapshere pers. comm. 1992) and 6th in the Pacific in 1992 (A. Hill pers. comm. 1992). In the tropics it is particularly important in many upland crops, including groundnuts, maize, rice, sorghum, sugar cane and vegetables. Although drought resistant, it thrives in moist fertile soils in cultivated fields and gardens, bare driveways and waste places. There are many ecological types which have enabled it to adapt to most agricultural areas of the world. In the Philippines up to 10,000 and in North America up to 243,000 seeds are produced per plant. The tiny seeds, which survive burial for long periods, are spread by wind, water and with the seeds of crops; and some birds feed on them. They germinate best above 30°C and poorly below 24°C.

Pigweed does not compete well with other weeds. However, it establishes rapidly after soil disturbance and may flower and seed before being outcompeted by taller plants.

The succulent leaves and stems are rich in oxalates and nitrates, which may cause death of livestock. It was one of mankind's early vegetables and improved varieties (hexaploids) with larger leaves are still eaten. It has been used as an emergency human food in Kiribati in periods of extreme drought, but it has recently become a problem in vegetable gardens where pig or poultry manure is used (G.S. Sandhu, pers. comm. 1992). It is used as food for pigs.

P. oleracea is an alternative host of the nematodes *Meloidogyne* sp., *M. incognita*, *Paratylenchus minutus*, *Rotylenchus reniformis* and *Heterodera marioni* and of the viruses causing tobacco mosaic, groundnut rosette, anemone brown ring, aster yellow, beet curly top, chili veinbanding, clover big vein, tobacco broad ring spot, tobacco etch and tobacco streak (Holm et al. 1977).

Natural enemies

In view of its very widespread distribution it is perhaps not surprising that pigweed is attacked by a wide range of insects. Thus Bennett and Cruttwell (1972) list 60 species, mainly from the Caribbean and South America, and Romm (1937) 83 mainly from USA, resulting in a total of about 120. Table 6.1 lists 13 insects that, so far as is known, are restricted to *P. oleracea*, or at least to the genus *Portulaca* and table 6.2 additional species most of which are known to be (or suspected of being) polyphagous. It might be thought, perhaps, that most polyphagous insects that encounter pigweed can develop on it, but this is not necessarily so. For example, nymphs of the grasshopper *Heteracris littoralis* that fed on it showed a 70 to 80% mortality and adults were short-lived (Ibrahim 1980).

Table 6.1 Insects restricted to *P. oleracea* or at least to the genus *Portulaca*.

Species	Distribution	Reference
Diptera		
ANTHOMYIIDAE		
Pegomya dolosa	Trinidad	Bennett & Cruttwell 1972 Cruttwell & Bennett 1972a
CECIDOMYIIDAE		
Asphondylia portulacae	El Salvador, Argentina, Colombia, Bolivia, Leeward Is, St Kitts Nevis, Montserrat, Jamaica	Gagné 1968, Bennett & Cruttwell 1972
Neolasioptera portulacae	Cuba, Florida, St Vincent Trinidad, St Kitts Nevis, Montserrat, Jamaica, Colombia	Gagné 1968 Bennett & Cruttwell 1972
Lepidoptera		
HELIODINIDAE		
Heliodine quinqueguttata	Trinidad Montserrat Puerto Rico	Bennett & Cruttwell 1972, Cruttwell & Bennett 1972b Wolcott 1948
Hymenoptera		
TENTHREDINIDAE		
Schizocerella pilicornis	California, Mexico USA, Australia Argentina to USA	Bennett & Cruttwell 1972 Krombein & Burks 1967 Muesebeck et al. 1951
Coleoptera		
CURCULIONIDAE		
Apion sp.	Brazil	D'Araujo et al. 1968
Baris arctithorax	Egypt	Tawfik et al. 1976
Baris lorata	Sudan	Marshall 1911
Baris portulacae	India	Marshall 1916
Centrinaspis perscitus	Colombia, Trinidad, USA	Bennett & Cruttwell 1972, Romm 1937
Ceutorhynchus oleracae	Java	Marshall 1935
Ceutorhynchus portulacae	India	Marshall 1916
Hypurus bertrandi	Puerto Rico France Egypt USA, Hawaii	Wolcott 1948 Tempère 1943 Tawfik et al. 1976 Clement & Norris 1982

Table 6.2 Additional insects attacking *Portulaca oleracea*.

Species	Reported from	Part attacked	Reference
Orthoptera			
ACRIDIDAE			
Melanoplus spretus	USA	leaves	Romm 1937
Microcentrum retinerve	USA	leaves	Romm 1937
Thysanoptera			
PHLAEOTHRIPIDAE			
Haplothrips gowdeyi	Hawaii	leaves	Sakimura 1936
Haplothrips robustus	Hawaii		Bianchi 1985
THRIPIDAE			
Chirothrips manicatus	USA	leaves	Romm 1937
Frankliniella tritici	USA	flowers	Romm 1937
Scirtothrips citri	USA	flowers and buds	Romm 1937
Thrips tabaci	Hawaii	terminals	Romm 1937
Hemiptera			
ALEYRODIDAE			
Bemisia tabaci	Egypt		Tawfik et al. 1976
APHIDIDAE			
Aphis sp.	Venezuela		Bennett & Cruttwell 1972
Aphis craccivora	Australia	leaves	ANIC
Aphis cytisorum (= A. laburni)	Trinidad, Asia	young stems	Romm 1937
Aphis euphorbiae (= *Macrosiphum solanifolii*)	Hawaii	terminals	Romm 1937
Aphis fabae	Asia	leaves	Romm 1937
Aphis gossypii	USA, St Kitts Australia	under leaves	Bennett & Cruttwell 1972 Romm 1937, ANIC
Aphis medicaginis	Hawaii	shoots	Romm 1937
Aphis middletoni (= *A. maidiradicis*)	USA	roots	Romm 1937
Aphis nasturtii			Patch 1938
Aphis persicae			Patch 1938
Aphis plantaginis	USA	roots, leaves	Romm 1937
Aphis pomi	USA	buds, shoots	Romm 1937
Aphis rhamni	USA	under leaves	Romm 1937
Aphis rumicis			Patch 1938
Aphis spiraecola (= *A. citricola*)	USA, UK	leaves	Romm 1937
Aulacorthum solani			Patch 1938
Brachyunguis (= *Xerophilaphis*) *plotnikovi*	Asia	leaves	Romm 1937
Myzus persicae	USA, Indonesia	stems	Bennett & Cruttwell 1972 Romm 1937
Myzus pseudosolani	USA	leaves	Romm 1937
Pemphigus brevicornis	USA	roots	Romm 1937
Toxoptera aurantii	Australia	leaves	ANIC
CICADELLIDAE			
Agallia albidula	Brazil		Bennett & Cruttwell 1972
Agallia configurata	Trinidad		Bennett & Cruttwell 1972

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Species	Reported from	Part attacked	Reference
Agallia sanguinolenta	USA	leaves	Romm 1937
Empoasca sp.	USA	leaves	Romm 1937
Eutettix tenellus	USA	leaves	Romm 1937
COCCIDAE			
Coccus hesperidum	Venezuela	stems	Bennett & Cruttwell 1972
Saissetia coffeae	Brazil	stems	Bennett & Cruttwell 1972
PSEUDOCOCCIDAE			
Ferrisia virgata	Brazil	leaves & stems	Bennett & Cruttwell 1972
	Hawaii	roots	Swezey 1935
Phenacoccus solani	Hawaii,		Bennett & Cruttwell 1972
	California		Romm 1937
Pseudococcus brevipes	Hawaii		Romm 1937
Pseudococcus solani	USA		Romm 1937
Pseudococcus virgatus	USA		Romm 1937
Rhizoecus kondonis	Japan		Bennett & Cruttwell 1972
MARGARODIDAE			
Icerya purchasi			Romm 1937
LYGAEIDAE			
Geocoris bullatus	USA	leaves	Romm 1937
Nysius coenosulus	Hawaii	leaves	Beardsley 1977
Nysius cymoides	Egypt		Tawfik et al. 1976
Nysius delectus	Hawaii	leaves	Romm 1937
Nysius ericae	Bermuda	leaves	Bennett & Cruttwell 1972
			Romm 1937
Nysius terrestris	Hawaii	leaves	Beardsley 1977
Nysius sp. nr *vinitor*	Hawaii	leaves	Beardsley 1979
Nysius sp.	Australia		Bennett & Cruttwell 1972
	Hawaii	leaves	Beardsley 1971
Sphragisticus nebulosus	USA	leaves	Romm 1937
MIRIDAE			
Psallus seriatus	USA	terminals	Romm 1937
Pycnoderes quadrimaculatus	Hawaii	leaves	Illingworth 1930
PENTATOMIDAE			
Scaptocerus castanea	Brazil		Bennett & Cruttwell 1972
Coleoptera			
CHRYSOMELIDAE			
Bruchus orventatus	USA	seeds	Bennett & Cruttwell 1972
Diabrotica duodecimpunctata	USA	leaves	Romm 1937
Diabrotica longicornis	USA	roots	Romm 1937
Diabrotica vittata	USA	leaves	Romm 1937
Disonycha caroliniana	USA	leaves	Romm 1937
Disonycha crenicollis	USA	leaves	Romm 1937
Disonycha mellicollis	USA	leaves	Romm 1937
Graphops pubescens	USA	roots	Romm 1937
Monolepta sp. nr *morio*	Rhodesia	leaves	Bennett & Cruttwell 1972
Systena s-littera	Venezuela		Bennett & Cruttwell 1972
Systena taeniata	USA	leaves	Romm 1937
CURCULIONIDAE			
Faustinus apicalis	Venezuela		Bennett & Cruttwell 1972
Faustinus cubae	Venezuela		Bennett & Cruttwell 1972

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Species	Reported from	Part attacked	Reference
Hyperodes echinatus	USA	leaves	Romm 1937
Microlarinus lypyriformis	Hawaii	leaves & stems	Davis & Krauss 1966
Sitona hispidulus	USA	leaves	Romm 1937
Sitona lepidus (= *S. flavescens*)	USA	roots	Romm 1937
MELOIDAE			
Pseudomeloe pustulata	Argentina		Bennett & Cruttwell 1972
MELOLONTHIDAE			
Holotrichia leucophthalma	Malaysia		Bennett & Cruttwell 1972
Diptera			
AGROMYZIDAE			
Phytomyza palliata	USA	leaf miner	Romm 1937
ANTHOMYIIDAE			
Delia platura (= *Hylemya cilicrura*)	USA	sprouting seeds	Romm 1937
CECIDOMYIIDAE			
Campylomyza sp.	USA	roots	Romm 1937
Joannisia sp.	USA	roots	Romm 1937
EMPIDIDAE			
Platypalpus crassifemoris	USA	roots	Romm 1937
SYRPHIDAE			
Paragus tibialis	USA	tunnels stems	Romm 1937
Sphaerophoria cylindrica	USA	leaves	Romm 1937
Lepidoptera			
COLEOPHORIDAE			
Coleophora sp.	Trinidad	leaves	Bennett & Cruttwell 1972 Romm 1937
LYCAENIDAE			
Callicista bubastus	Trinidad	leaves & stems	Bennett & Cruttwell 1972
NOCTUIDAE			
Agrotis crinigera	Hawaii	stems	Romm 1937
Agrotis (= *Euxoa*) *radians*	Australia	leaves	Bennett & Cruttwell 1972 Romm 1937
Agrotis repleta	Venezuela	stems	Bennett & Cruttwell 1972
Agrotis ipsilon	Hawaii	stems	Romm 1937
Discestra (= *Mamestra*) *trifolii*	USA	stems	Romm 1937
Elaphria nucicolora	Hawaii	leaves	Swezey 1951
Euxoa kerri	Hawaii	leaves	Romm 1937
Euxoa messoria	USA	leaves	Romm 1937
Euxoa tessellata	USA	leaves	Romm 1937
Feltia malefida	USA	leaves	Romm 1937
Feltia subterranea	Venezuela	stems	Bennett & Cruttwell 1972
Lycophotia infecta	USA	leaves & stems	Romm 1937
Lycophotia margaritosa	USA, Hawaii	stems	Romm 1937
Lycophotia saucia	USA	buds	Romm 1937
Mythimna (= *Cirphis*) *loreyi*	Philippines		Bennett & Cruttwell 1972
Peridroma incivis	USA	leaves	Romm 1937
Spodoptera (= *Prodenia*) *eridania*	Venezuela	leaves & stems	Bennett & Cruttwell 1972
Spodoptera frugiperda	Brazil, USA	leaves & stems	Bennett & Cruttwell 1972 Romm 1937

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Species	Reported from	Part attacked	Reference
Spodoptera (= *Prodenia*) *latifascia*	Venezuela	leaves & stems	Bennett & Cruttwell 1972
Spodoptera littoralis	Egypt		Tawfik et al. 1976
NYMPHALIDAE			
Euptoieta claudia	Brazil, USA	leaves	Bennett & Cruttwell 1972, Romm 1937
Hypolimnas bolina	Java	leaves	Kalshoven 1981
Hypolimnas misippus	Australia, Brazil, Puerto Rico	leaves	Bennett & Cruttwell 1972, Common & Waterhouse 1981, Romm 1937
Junonia villida	Australia	leaves	Common & Waterhouse 1981
OECOPHORIDAE			
Theama argyrophorum	Argentina		Bennett & Cruttwell 1972
PYRALIDAE			
Epipagis cambogialis	Brazil	leaves & stems	Bennett & Cruttwell 1972
Hellula undalis	USA	leaves	Romm 1937
Hymenia fascialis	Bermuda	leaves	Romm 1937
Hymenia recurvalis	Trinidad Hawaii	leaves	Bennett & Cruttwell 1972 Swezey 1935
Loxostege bifidalis	Brazil	leaves	Bennett & Cruttwell 1972
Loxostege similalis	USA	leaves	Romm 1937
Nomophila noctuella	USA	tunnel stems	Bennett & Cruttwell 1972 Romm 1937
Ostrinia (= *Pyrausta*) *nubilalis*	USA	tunnel stems	Romm 1937
Psara bipunctalis	Trinidad	leaves	Bennett & Cruttwell 1972
SPHINGIDAE			
Agrius (= *Herse*) *convolvuli*	India		
Copidryas gloveri	USA	leaves	Romm 1937
Hyles euphorbiarum	Brazil	leaves & stems	Bennett & Cruttwell 1972
Hyles (= *Celerio*) *lineata*	Argentina, Venezuela, USA, Hawaii	stems and leaves	Bennett & Cruttwell 1972 Romm 1937 Swezey 1935
Hymenoptera			
BRACONIDAE			
Diospilus sp.		roots	Romm 1937
EULOPHIDAE			
Ceratoneura sp.	Trinidad	flower buds	Bennett & Cruttwell 1972
Ceratoneura petiolata	Puerto Rico	flower buds	Bennett & Cruttwell 1972

It is of interest that 7 of the restricted species listed in Table 6.1 appear to have originated in the Americas, 2 each in Africa and India, but only 1 each in France and Southeast Asia. With the exception of the weevil *Ceutorhynchus portulacae*, described from *P. oleracea* in Java, no reports have been found of insects possibly restricted to pigweed in Southeast Asia or the Pacific. However, the host specificity of only two (*Baris arctithorax* and *Hypurus bertrandi*) of the eight weevils listed is at all well known. Host specificity has, however, been investigated by Bennett and Cruttwell (1972) or Cruttwell and Bennett (1972a, b) for the 5 species of Diptera, Lepidoptera and Hymenoptera listed in Table 6.1. In Hawaii *Hypurus bertrandi* (originally misidentified by G.K. Marshall as *Ceutorhynchus* sp.) was reported in 1958 to be numerous enough to defoliate the plant in many cases and to cause it to collapse as if sprayed with some herbicide (Bianchi 1955).

Although listed by Holm et al. (1977) as 9th of the world's worst weeds, it is interesting that, as of 1979, it was not (or no longer) listed as a noxious weed in Hawaii, although it had a high hazard status for each island (Tagawa 1979). Nevertheless, in 1992, Hawaiian weed scientists considered it as one of their worst weeds (W.C. Mitchell pers. comm. 1992). It is thus unclear what degree of control *Hypurus bertrandi* and the range of non-specific insects attacking pigweed (Table 6.2) are now exercising.

P. oleracea is attacked in Hawaii, California, Jamaica, Venezuela, Europe and Sudan by the fungus *Dichotomophthora portulacae*, by *D. lutea* (= *D. indica*) in India and Ontario (Klisiewicz et al. 1983, Mehrlich and Fitzpatrick 1935, Rao 1966) and also in Europe and the West Indies (IMI 1992). It is attacked in USA by *Bipolaris* (= *Helminthosporium*) *portulacae* (Rader 1948). *B. portulacae* also occurs on *Portulaca grandiflora* in Canada (IMI 1992). The white rust *Albugo portulacae* occurs in Europe, Africa, Asia, North, Central and South America (IMI 1992). In Canada it is common on *P. oleracea* and sometimes locally destructive under favourable conditions, but is probably not an important controlling factor (Miyanishi and Cavers 1980). On the other hand, *Dichotomophthora lutea* was lethal during the winter in India (Rao 1966) and *Bipolaris portulacae* was found killing pigweed in widely separated areas in New York State, although it was concluded that, under dry summer conditions, the fungus was of little value in controlling the weed (Rader 1948). In California *Dichotomophthora portulacae* caused dark discoloration and constriction of the stems, and roots were invaded later, damage which, when combined with attack by the insects, *Hypurus bertrandi* and *Schizocerella pilicornis*, resulted in plant death. Suspensions of the fungus grown on potoato-dextrose agar successfully infected young plants under conditions of high but not of low humidity (Klisiewicz et al. 1983). Unfortunately, *D. portulacae* is reported to occur on other plants, including *Basella rubra*, cactus, *Capsicum annuum*, *Glycine max* and even in a human corneal ulcer (IMI 1992). Unless, therefore, there are strains specific to *Portulaca oleracea*, it could not be used as a mycoherbicide.

Other pathogens reported to be specific to *P. oleracea* are *Albugo portulacearum* (Poland), *Ascochyta portulacae* (USSR), *Cercospora portulacae* (India), *Cercosporella dominicana* (Dominica) and *Dendrographium lucknowense* (India). The non-specific *Bipolaris indica* occurs on *P. oleracea*, and also on a wide range of agriculturally important and other plants (IMI 1992).

If any of these fungi prove to be adequately specific, it is possible that it (they) might be introduced to assist in the biological control of pigweed in situations where the humidity remains high over long periods.

Attempts at biological control

No attempts have been made to introduce natural enemies for the biological control of *P. oleracea*. However, the weevil *Hypurus bertrandi* has made its way, unaided, from France to USA and the sawfly *Schizocerella pilicornis* from the Americas to eastern Australia. There are no reports of any attack by either species in their new regions on plants other than *P. oleracea*.

Biology of the major natural enemies

Pegomya dolosa (Anthomyiidae: Diptera)

Eggs of this fly are laid singly on the underside of the pigweed leaf and hatch after about 3 days. The larvae are leaf miners and devour the contents of the leaf, then emerge to enter another. Two or more leaves are commonly destroyed. After about 7 days, the 6 to 7mm long larvae leave the plant to pupate in the soil, leading to 3 to 4mm long adults. Two wasps were occasionally found attacking *Pegomya* in Trinidad, a solitary egg parasitoid and a solitary larval-pupal pteromalid.

Of a large number of economic and other plants tested, including *Portulaca grandiflora*, *P. pilosa* and *P. quadrifida*, all except *Portulaca grandiflora* were rejected by *Pegomya* larvae. Larvae on *P. grandiflora* readily mined and fed in the leaves, but all died within 3 days, possibly due to some toxic substance or deficiency in nutrition. It is possible that *Pegomya* is monophagous.

With one exception, all species in the genus *Pegomya* whose host plants are known, attack plants in only one family. Thus, although it is conceivable that *Pegomya* might attack plants of other genera in the Portulacaceae, it is quite unlikely that plants in other families would be attacked. Cruttwell & Bennett (1972a) conclude that *Pegomya* sp. could be safely introduced for the biological control of *P. oleracea.*

***Asphondylia portulacae* (Cecidomyiidae: Diptera)**

Eggs of this flower gall midge are inserted into the very small buds of pigweed which then develop abnormally. Usually only one larva develops per bud, occupying a chamber in the swollen receptacle. Prior to pupating in the bud the larva forms a window, leaving only the outer cuticle through which the adult escapes. Attacked flowers do not produce seed. *A. portulacae* is heavily attacked by parasitoids (Bennett and Cruttwell 1972).

The species of *Asphondylia* are considered to be highly host specific. Fifty two of the 54 species in this group are known only from a single host and each of the two exceptions only attacks two plants of the same genus. It was postulated that host specificity testing is unnecessary (Bennett and Cruttwell 1972).

***Neolasioptera portulacae* (Cecidomyiidae: Diptera)**

Females of the midge cause elongate to globular stem galls up to 1.5cm in diameter. Each gall contains several (up to 10) larvae. Galls retard, or prevent, flower and seed production. In open, less fertile sites every pigweed stem may be infested, but in lush growth or shaded sites the level of attack is usually very low. Larvae pupate within the gall after creating a window of plant cuticle through which the adult escapes. *N. portulacae* is attacked heavily by parasitoids.

With the exception of one species, which attacks two plant genera, each of the 51 species of the subgenus *Neolasioptera* is restricted to one plant genus. Bennett and Cruttwell (1972) believe that *N. portulacae* is sufficiently host specific to be employed for biological control without further testing.

***Heliodine quinqueguttata* (Heliodinidae: Lepidoptera)**

This moth lays its eggs singly or in groups of up to 6. They hatch in 5 to 6 days and larvae wander some distance over the leaf before mining into it or into the stem or a seed capsule. As plant tissues collapse or decay, the larva leaves the mine to enter the plant elsewhere. After 7 to 8 days the fifth instar larva leaves the mine and pupates within a flimsy silk cocoon attached to the stems or leaves of the plant.

No natural enemies of the eggs or pupae are known, but larvae are attacked by a solitary endoparasitoid, *Pholetesor* = (*Apanteles*) sp. (*cicumscriptus* group).

Host specificity tests were carried out on a wide variety of economic and non-economic plants, but development was completed only on *Portulaca oleracea*, *P. pilosa* and *P. grandiflora.* However, in the field in Trinidad neither *P. pilosa* nor the weedy *P. quadrifida* were ever attacked and *P. grandiflora* was not grown. Available records indicate that no *Heliodine* species attacks crops and that each species is restricted to a single plant family. It was considered that *H. quinquegutta* was sufficiently specific to be used for biological control (Cruttwell and Bennett 1972b).

***Schizocerella pilicornis* (Tenthredinidae: Hymenoptera)**
This leaf mining sawfly occurs naturally from Argentina (and Brazil) to USA (Muesebeck et al. 1951) and was accidentally introduced from USA to Australia (Queensland and New South Wales) (Benson 1962, Krombein & Burks 1967). There are two biotypes, each of which breeds true. The larvae of one, which is widespread, mines the leaves, whereas the larvae of the other (from Mississippi northwards in USA) feeds externally on the leaves (Gorske and Sell 1976). Eggs are normally laid singly in the edges of the leaves, each female laying up to 40 eggs soon after emergence and mating. The mining larvae damage the leaves extensively, moving from one to another when a leaf collapses. At least two leaves are destroyed by each larva. The fully fed larvae enter the soil and spin cocoons. There are at least two generations a year and certainly many more in warmer areas, since the life cycle can be completed in 13 days (Clement and Norris 1982). Prepupae in diapause overwinter in the soil in California. (Force 1965, Garlick 1922, Gómes de Lima 1968, Gorske et al. 1977, Webster and Mally 1900).

In California 58 to 84% of *P. oleracea* leaves harboured eggs or larvae of *S. pilicornis* and such severe damage may be caused that plants are defoliated and somtimes killed. Adults live for a day and do not feed.

S. pilicornis has not been recorded from any plant other than *P. oleracea* and is believed to be monophagous, although no laboratory tests have been done for host specificity. A transovarially transmitted microsporidian, *Nosema pilicornis*, causes high mortality in infected *S. pilicornis* larvae in USA and should be eliminated in any transfer of the sawfly to new areas (Gorske and Maddox 1978).

An 80% loss of sugarbeet yield was recorded in California when *S. pilicornis* was prevented by insecticide application from attacking *P. oleracea* plants which were occurring at a density of 20 or more per m of crop row. Insecticide-protected weeds produced about 4 times as much seed as unprotected plants, although the latter still produced enough (4000 to 5000/m^2/day) to maintain a high seed bank in the soil (Norris, 1985).

***Apion* sp. (Curculionidae: Coleoptera)**
In Brazil, *Apion* sp. causes gall formation in the flower buds of *P. oleracea* (D'Araujo et al. 1968) and *Apion* larvae causing similar and significant damage were encountered in north Argentina (Bennett and Cruttwell 1972, Bennett pers. comm. 1992).

***Baris arctithorax* (Curculionidae: Coleoptera)**
This weevil causes gall formation on pigweed in Egypt, but does not attack any economic plant. Eggs are laid singly in stem cavities gnawed by the female. The plant tissue then develops abnormally to produce single closed galls, but the most serious damage is caused by larvae feeding inside the stems. Young infested plants produce weak vegetative growth and few seeds and may be killed. Adult weevils feed on the leaf surface. Egg development takes 4 days at 29.5°C, larval development 28 days at 24.6°C, the prepupal stage (in the soil) lasts 2.5 days at 29.9°C and the pupal stage 6.9 days at 29.5°C. The pre-oviposition, oviposition and post-oviposition periods are 8.5, 33.1 and 5.8 days respectively at 28.1°C. After 74% infestation of plants in summer a peak of 95% occurred in autumn. (Awadallah et al. 1976, Tawfik et al. 1976).

***Hypurus bertrandi* (Curculionidae: Coleoptera)**
The portulaca leaf-mining weevil has spread from France to Hawaii (1950) (Davis 1955, Maehler 1954), and California (1980). Eggs are deposited singly in the parenchyma and larvae mine the leaves. Infested leaves wilt and fall and the larvae then migrate to fresh leaves, often destroying four or five. However, if no undamaged leaves are available, they

attack the outer tissues of the stems. Pupation occurs in a cell formed by soil particles cemented by fecal secretion. In France adults overwinter under the bark of trees. They feed on leaf margins, stems and developing seed capsules. *H. bertrandi* develops from egg to adult in 10 days at 32.2°C and 16 hrs light and, in France, there are at least 3 overlapping generations a year. It is heavily parasitised there by a number of wasps. *P. oleracea* is its only reported host plant (Tawfik et al. 1976, Clement and Norris 1982, Hoffmann and Tempère 1944, Norris 1985, Tempère 1943, 1944, 1950).

Comment

The family Portulacaceae is relatively small with 20 genera and about 250 species worldwide. Of these, the genus *Portulaca* contains some 100 to 125 species (West 1990) (or 'no more than 15 good species': Geesink 1969), all tropical, subtropical or temperate. Of the Portulacaceae, relatively few are cultivated: *Portulaca grandiflora* as a brightly flowering ornamental, *Talinum triangulare* and *T. paniculatum* as pot herbs (but they may also be agricultural weeds), *Montia fontana* for salads, *Lewisia* spp. (mostly alpine herbs) as ornamental rock plants, and the African *Anacampseros* as a succulent, but these are not of great economic importance (Cruttwell and Bennett 1972a). Other species, such as *Portulaca pilosa* and *P. quadrifida* are weeds. This situation simplifies, particularly for the Pacific, the range of tests necessary to determine whether natural enemies have adequate host specificity. Although the specificity of the seven major natural enemies dealt with above appears to be adequate in their countries of origin, consideration still needs to be given to plants of importance that have not been tested, or not exposed to natural infestation by the agents in the field.

Each of these natural enemies is capable of causing significant damage to *P. oleracea* and some of them even death. If a group of them is assembled in a country, they should be capable of stressing pigweed sufficiently to reduce greatly its competitiveness and seed production, particularly if their own natural enemies are rigorously excluded during transfers.

As the first step in any biological control program, it will be necessary to carry out a survey of the organisms already attacking *P. oleracea* throughout the Pacific and particularly in the countries reporting most concern with this weed (Table 1.1).

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8.	*Nezara viridula*, green vegetable bug	Hemiptera
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34.	*Cassia tora* and *C. obtusifolia*, foetid cassia	Caesalpiniaceae
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45.	*Solanum torvum*, prickly solanum	Solanaceae
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2.	*Frankliniella occidentalis*, western flower thrips	Thysanoptera
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4.	*Hypothenemus hampei*, coffee berry borer	Coleoptera
5.	*Hellula* spp., cabbage centre grubs	Lepidoptera
6.	*Erionota thrax*, banana skipper	Lepidoptera

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