4 *Neotermes rainbowi* (Hill)

Isoptera: Kalotermitidae
coconut termite, rainbow termite

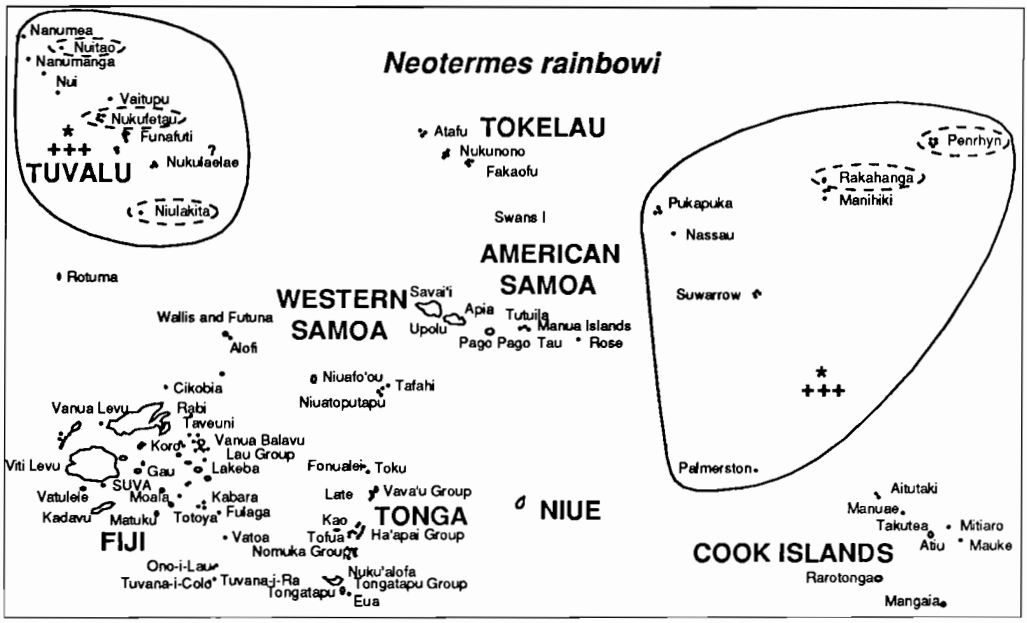

Figure 4.1 Distribution of *Neotermes rainbowi*

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.

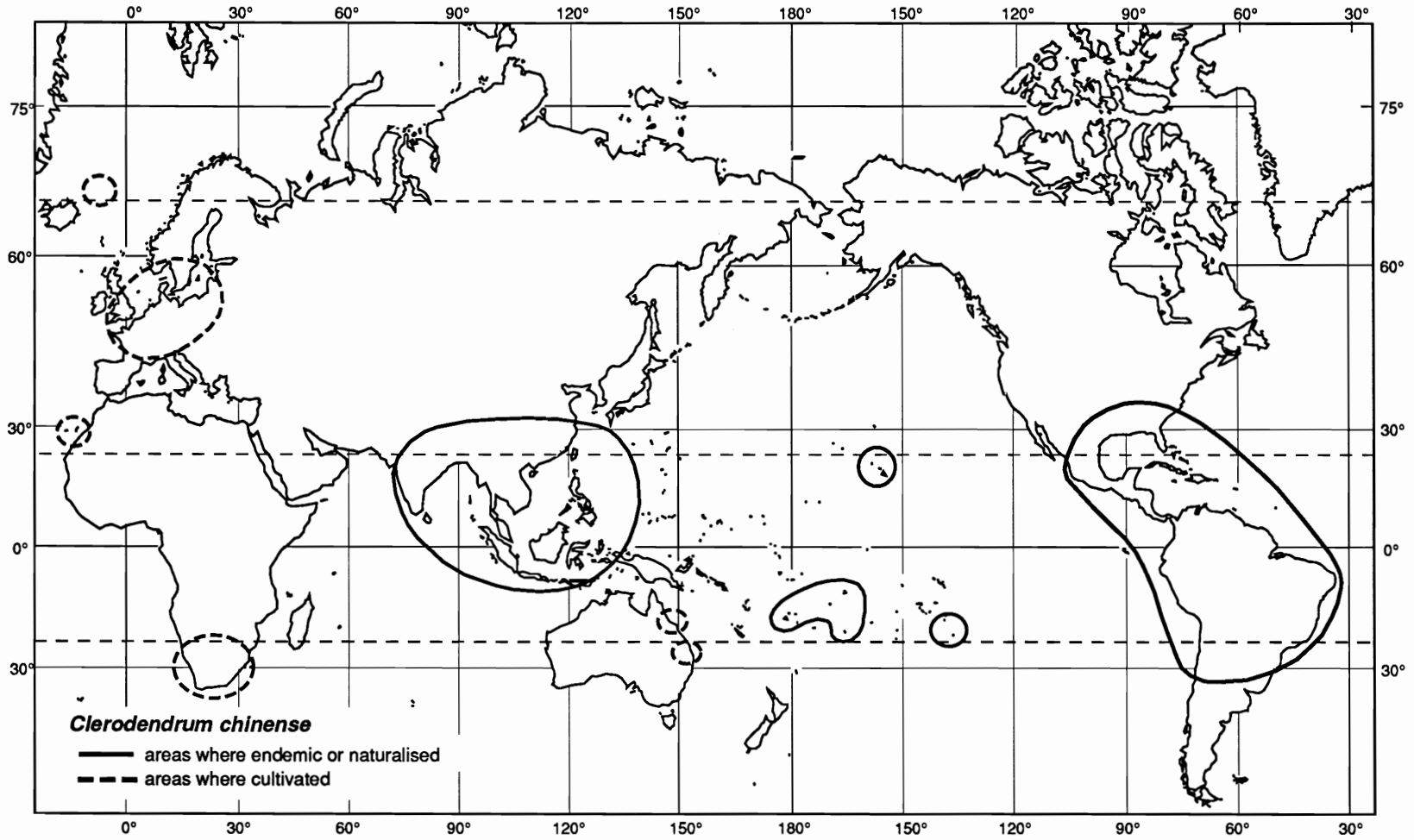

Figure 5.1 World distribution of *Clerodendrum chinense*

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)

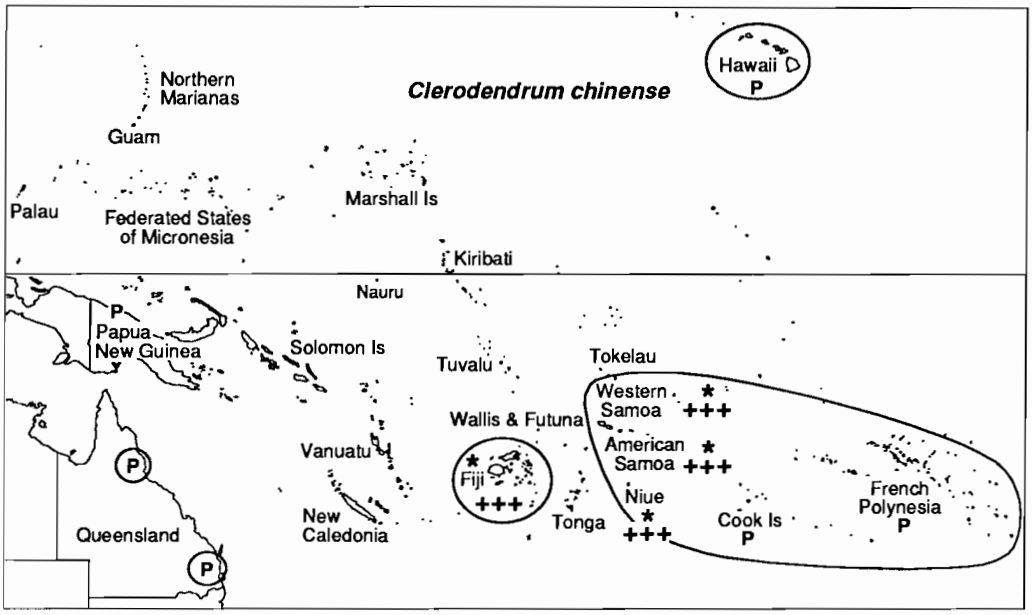

Figure 5.2 Pacific distribution of *Clerodendrum chinense*

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

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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.

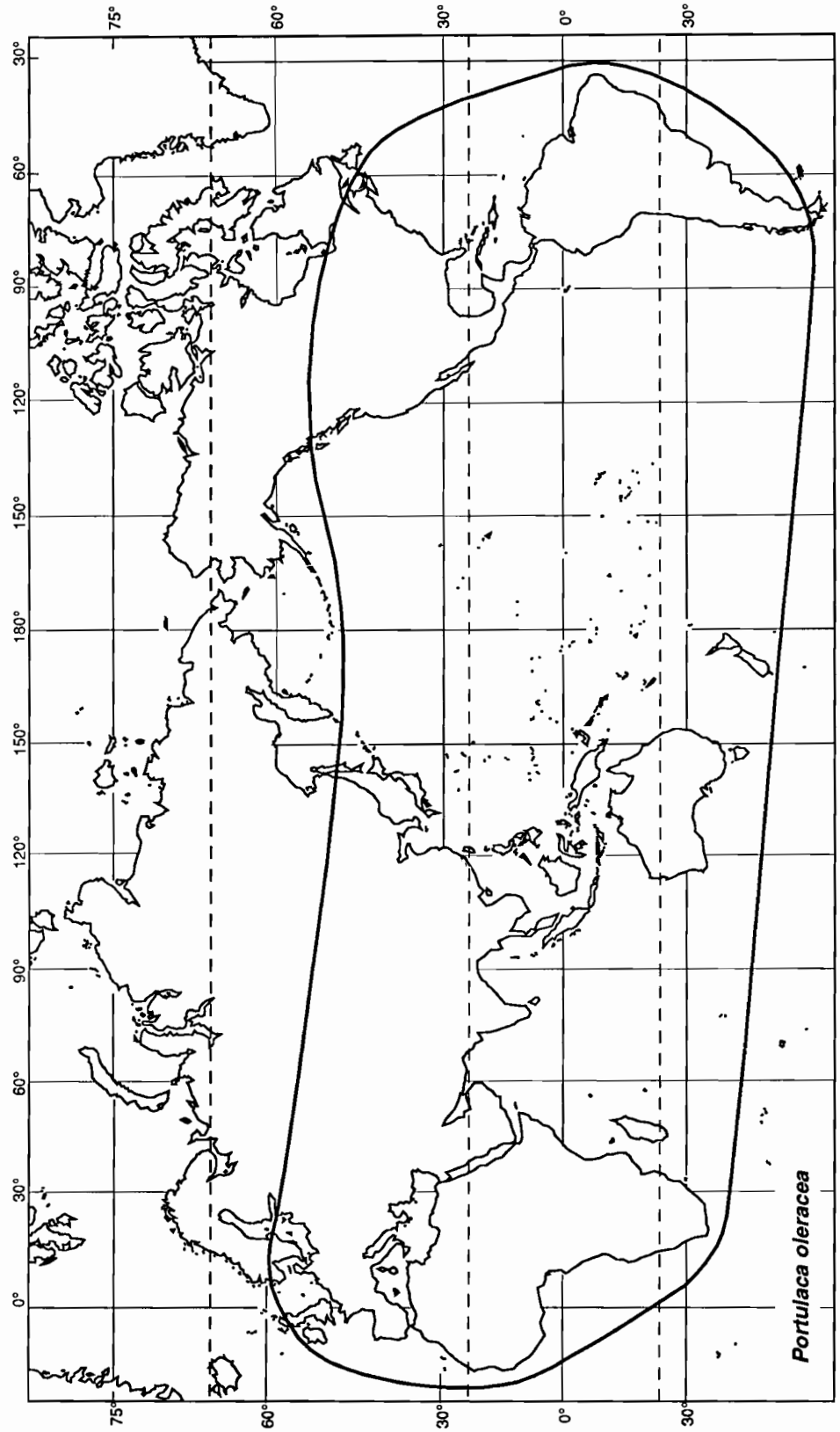

Figure 6.1 World distribution of *Portulaca oleracea*

6 *Portulaca oleracea* Linnaeus

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

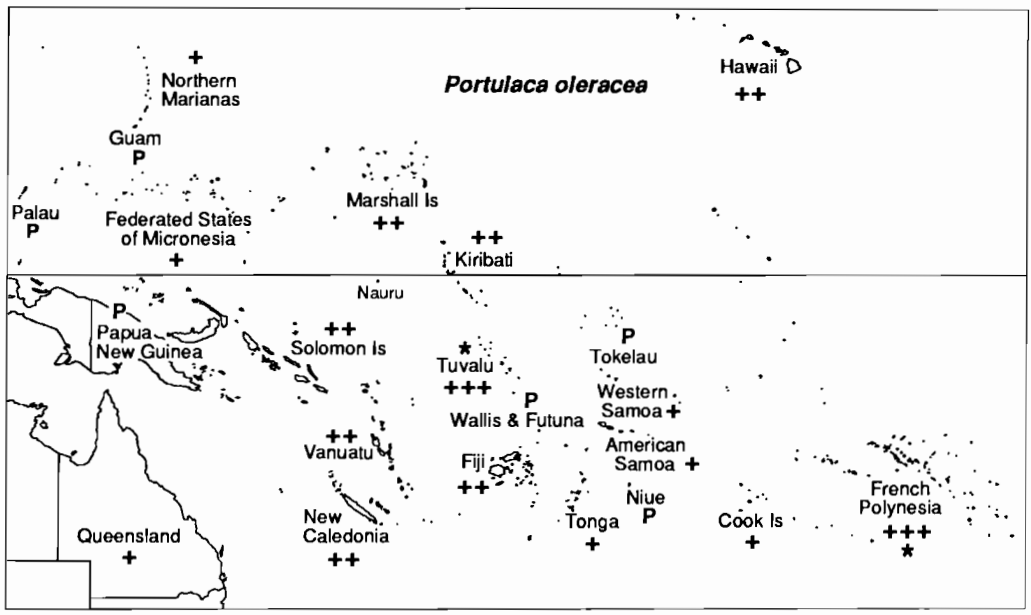

Figure 6.2 Pacific distribution of *Portulaca oleracea*

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

(continued on next page)

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

(continued on next page)

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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