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Biological Control in the Oceanic West Pacific: an Overview

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Abstract—The Pacific, largest of all oceans, contains some 25,000 islands, more than half the world's total. Because almost all of the food plants and pests are introduced, biological control of pests is highly appropriate for oceanic islands, particularly those with small human populations and extreme shortage of foreign exchange for purchasing pesticides. Indeed pest surveys in the south Pacific have shown that 85% or more of the major insect pests are introduced, particularly from Southeast Asia. Furthermore about 95% of the major weeds are introduced, most from Central or South America. In most instances these insect and weed pests are of much less importance in their area of origin because of attack by natural enemies. Classical biological control consists of introducing and establishing selected natural enemies when careful tests indicate that it is safe to do so.

Success rate in islands (Hawaii, in particular) or ecological islands (Australia, California) is the highest in the world, but has been very variable in most Pacific islands. For a decade after the late 1920's there was, however, a notable sequence of successes in Fiji, unmatched elsewhere in the South Pacific. It is very encouraging to report that, since the mid 1980's, a steadily growing and well supported momentum has been generated for biological control and this has already led to several significant successes, with more in prospect.

Nevertheless, the need for biological control programs in the Pacific is likely to increase greatly in the future as air travel and tourism expand. In Hawaii, for example, an average of 3.5 pests per year become established and in Guam about 2.5 pests per year, most nowadays coming from the Americas. In an effort to reduce the number of pest invasions the XIX International Congress of Entomology resolved to recommend to all Pacific Nations that they take urgent action to ensure (i) effective inspection of all incoming packages, including first class mail and (ii) effective insecticide treatment of all aircraft flying to and between Pacific countries.

Introduction

Biological control is the action of natural enemies in maintaining an organism at a lower average density than it attains in their absence. The concept of biological control arises from the observed differences in abundance of many animals and plants when they are examined in their native range and in areas to which they have spread and where, in general, they are far more abundant. Their substantially lower abundance in their native range is associated with an effective attack on them there by natural enemies that have not accompanied the species into new regions. Classical biological control consists of transferring some or all of these natural enemies to the new region, now occupied by what has become a pest—leading to a lower abundance of the pest: hopefully, sufficiently low that it is no longer of economic significance.

For almost all species in their native range (in fact, probably well over 99%), nature has already established a satisfactory level of biological control, so that few are regarded as pests. Indeed, it is only when we interfere with the balance of nature that many organisms become pests. Interference can take many forms. One common form is the establishment of a monoculture of a plant that was formerly widely dispersed throughout other vegetation: its pests often increase in abundance. Another is the application of a non-selective pesticide that kills many or all of the natural enemies of a particular species or group of species. Released thus from a long-established level of control, one or more species may then increase to damaging numbers, necessitating further applications of the pesticide, often at progressively shorter intervals. Although biological control will not provide a solution for all pest problems, it has proved extremely successful in a very wide range of situations. There have been major successes in both temperate and tropical climates; on both islands and continents; in northern and southern hemispheres; against pests of wide taxonomic diversity; in conjunction with pesticides; and also where pesticides could not be sensibly used.

Biological control is particularly appropriate to problems in the Oceanic Pacific, in that it offers the prospect of pest and weed control by methods that are environmentally safe and available to low-income farmers not able to afford pesticides. It does not depend for its success on an organised and effective extension service and, once established by agricultural authorities, no action is required of farmers other than to avoid, as far as possible, the disruptive use of pesticides. Biological control is a major component in the concept of Pest Management. There are, of course, other important components, including the use of resistant varieties, cultural controls and, where unavoidable (as is often the case), the intelligent use of pesticides.

Narrowing our attention now to the Pacific, this is the largest single geographic entity of the world, extending over nearly one third of the earth's surface. It is about one half of the area covered by water and one fifth more than all the land area put together. It contains some 25,000 islands. Over the past few million years, the insects and plants that have managed to establish themselves have been changing steadily due to evolutionary forces. Rarely, additional species would be transported in upper air currents, by birds, or on floating materials. In Hawaii until about 1500 AD an average of about 1 new species had become established every 20,000 years or so. All this was changed in the Pacific, first by the arrival 3 or 4 thousand years or so ago of Polynesians, Melanesians and

Micronesians and then, even more strikingly, by the steadily increasing entry in the last 200 years or less of Europeans bringing an ever increasing range of plants and animals, many of them with insects and weeds as fellow travellers. Most Pacific islands have never had continental connections, but instead were elevated from the ocean bottom. Thus, animals requiring land connection for dispersal were excluded from ever reaching them. Until humans first appeared in the Pacific, vertebrates were very poorly represented: mammals only by fruit bats; birds largely by wide-ranging sea birds; and reptiles by a few lizards. Amphibia and fresh-water fish were absent.

Most immigration of arthropods to oceanic islands was by aerial dispersal. This was mainly in westerly storm winds contrary to the direction of the prevailing easterly, good-weather winds, but sometimes probably by sea birds. There is, indeed, a fairly good correlation between the types of insects collected from ships at sea and those that have populated the most isolated islands. It seems that relatively few insects have been able to colonise islands by surviving on floating materials. Crucial to the establishment of insects that depend upon plants is, of course, the prior establishment of appropriate plants to provide breeding sites. In the case of insects dispersing in moving air masses, a serious hazard is that of reaching an island, seeing that only a minute amount of the Pacific is above water. Other serious obstacles include damage in strong winds, desiccation in clear weather and adverse effects from salt spray.

Insects derived from the Oriental and Southeast Asian regions dominate the fauna of the mid Pacific as well as the islands of the western Pacific. The influence of the Americas is minor west of the Galapagos Is. Even in Hawaii, which is nearest to North America, American elements (except for land birds) are not dominant. Hawaiian native plants also display a predominantly Oriental and Southeast Asian influence. By contrast, Australian influence on the oceanic fauna and flora of a few hundred years ago was weak beyond New Zealand, New Caledonia and Papua New Guinea.

When the early Polynesians sailed eastwards into the Pacific some 4,000 years (or less) ago in their long out-rigger canoes they brought into the oceanic south Pacific for the first time coconuts, bananas, taro, yams, breadfruit, a few other plants and a handful of insects.

Of the 30 insect pests rated in 1985 to be most important in the western Pacific, only 4 (3 on coconut and 1 on taro) occur nowhere else and presumably evolved there (table 1). A further 15 are native to the Oriental/Southeast Asian

Table 1. Origin of major pests in the Southwest Pacific. (Waterhouse & Norris 1987)

	Total	Native to region	S.E. Asia	Americas	Europe or Africa
insects	30	4	15	3	8
weeds	17	—	3	13	1

region. Only 3 come from the Americas and most of the remainder are pests of vegetables, introduced with them in recent times from Europe. By contrast, only 3 of the 17 most important weeds are native to the Oriental region, whereas 13 originated in Central or South America—a situation so different that it points to a different means of dispersal—probably by ships in the last couple of hundred years.

Biological Control in the Oceanic Pacific

Focussing now on biological control, Hawaii probably holds the world record for biological control successes. As shown in table 2, 679 species of natural enemies have been released between 1890 and 1985 for the biological control of 114 arthropod pests and 17 weeds. Of these 679 natural enemies, 243 have become established and now provide complete control of 38 insects and 10 weeds and partial control of a further 13 insects and 3 weeds. This amounts to a partial or complete success rate of 45% for insects and 59% for weeds.

Although it would be tempting to deal with some of these successes, projects are chosen from other places in the oceanic Pacific to demonstrate that the method is equally applicable elsewhere, although certainly not yet utilised sufficiently. Indeed, it is probable that at least half (and possibly as many as two thirds) of the major insect and weed pests in the oceanic Pacific could be rendered significantly less damaging to agriculture if biological control measures were rigorously researched and introduced.

To illustrate this statement, examples were chosen, involving 7 insect pests and 2 weeds. However, to conserve space in this Supplement, the accounts have been omitted of four projects dealt with in greater detail by other contributors. These concerned the fruit piercing moth, *Othreis fullonia* (Clerck) (Muniappan et al., Sands and Liebregts) the banana skipper *Erionota thrax* (L.) (Sands et al.), the green vegetable bug, *Nezara viridula* (L.) (Esguerra et al.) and salvinia, *Salvinia molesta* Mitchell (Room).

(i) Levuana moth, *Levuana iridescens* Bethune Baker

One of several spectacular biological control projects in the mid to late 1920's in Fiji was the complete control of a small purple zygaenid moth, *Levuana iri-*

Table 2. Biological Control in Hawaii (1890–1985). (Funasaki et al. 1988, Lai 1988)

Agents released	679			
established	243			
Arthropod pests	114			
		complete control	38	
		partial control	13	51 → 45% success
Weeds	17			
		complete control	7	
		partial control	3	10 → 59% success

descens, whose larvae chew the lower surface of the leaves of coconut palms. This damage not only greatly reduced the production of nuts and hence copra, but often caused the palms to die. This striking moth was unusual in that it was not known to occur anywhere in the world except on the main Fiji island of Viti Levu and on a few of its tiny offshore islands. Even in Fiji, it had only been known for about 50 years. Its very limited distribution, and also the fact that it was not attacked by any parasites, suggested that it was an introduced species and thus a candidate for classical biological control. Searches in the Solomon Is, Papua New Guinea and Malaysia disclosed no *Levuana*, but some 10 related moths, all of which were attacked by a range of parasites. One of the common parasites was a tachinid fly, *Bessa remota* (Ald.), which was brought from Malaysia to Suva on a lengthy sea voyage, bred up and released in 1926. Its numbers increased rapidly, the parasite attacking not only *Levuana* but a range of other lepidopterous larvae as well—including those of the diamondback moth, *Plutella xylostella* (L.). Nine months after release of the fly, *Levuana* had already become scarce and, after 3 years, extremely rare. By contrast, *Bessa* remained common, its abundance evidently being maintained on hosts other than *Levuana* larvae. Not long after, *Levuana* could no longer be found anywhere (Tothill et al. 1930); and it is now concluded that it is extinct in Fiji and presumably from the world.

This appears to be a unique example of an insect pest being eliminated in a biological control campaign—admittedly, however, from a rather small area. In classical biological control the pest normally continues to exist, but at a very much lower level than previously. The probable explanation is that *Levuana* is a highly preferred host of *Bessa remota* and this parasitoid was able to maintain high populations on other hosts and so able to continue a high level of attack as *Levuana* numbers dwindled, eventually to zero.

(ii) Rhinoceros beetle, *Oryctes rhinoceros* (L.)

Advancing now from the 1920's to the 1960's and to the largest project undertaken in the southern Pacific in the last 50 years, the second example refers to the rhinoceros beetle, *Oryctes rhinoceros*, which is thought to be native to the region extending from India to Indonesia. In the last 50 years or so, it has spread eastwards into the Pacific to colonize many countries including Papua New Guinea, Fiji, American and Western Samoa, Tokelau and Tonga. The adult beetles fly up into the crown of coconut and other palms, where they bore into the succulent growing point to feed on the sap that emerges from the lacerated tissues. Even limited damage to the unfurled leaves later produces large, V-shaped cuts in the open fronds. These cuts reduce the leaf area and affected coconut palms yield fewer nuts, in proportion to the amount of damage. Heavy attack may kill even mature coconut palms. Fallen palm trunks or accumulations of rotting vegetation are breeding sites where females lay their eggs. Any factors (such as hurricanes, lightning strikes, or diseases) that cause extensive death of palms provide excellent breeding grounds and are likely to lead to large *Oryctes* populations and hence to serious attacks on surviving palms. Research on methods for the control of the rhinoceros beetle had been going on elsewhere for many years, but increased greatly when *O. rhinoceros* invaded the Pacific. It was soon confirmed that meticulous sanitation inside coconut plantations and around habitations reduced beetle abundance, and hence damage, but unfortunately not to an acceptably low level. Searches in Asia and Africa revealed more than 100 parasites, predators and diseases attacking the rhinoceros beetle and related species with similar habits. Few of these natural enemies were specific and most proved difficult to establish in other countries. Initially, high hopes were held for the wasp *Scolia ruficornis* F., a parasitoid of *Oryctes* larvae, from Zanzibar, which was successfully established in several countries. The fungus, *Metarhizium anisopliae* (Metchnikoff), was found to attack larvae, pupae and adults, and to produce valuable mortality under favourable circumstances. However, even when the action of these agents was combined, economic control was still not achieved. Work on other organisms virtually ceased when a baculovirus of *Oryctes* was discovered in Malaysia. The virus multiplies in the fatbody of larvae and in the midgut cells of adult beetles. It is passed out in the feces and infection occurs during mating. It can also be passed from adult beetle to beetle while feeding in the coconut crowns and adults can become infested when visiting breeding sites containing larvae recently killed by the virus. The introduction of *Oryctes* baculovirus to the Pacific has led to a major reduction in the pest status of *O. rhinoceros*, although there are still occasional local outbreaks particularly after hurricane damage to coconut palms (Bedford 1981, 1986, Waterhouse & Norris 1987). This project must be rated a substantial, but not a complete success.

(iii) Spiraling whitefly, *Aleurodicus dispersus* Russell

A pest that in the 1980's steadily extended its distribution westwards across the Pacific is the spiraling whitefly, *Aleurodicus dispersus* which is native to Central America and the Caribbean region. It first gained a toehold in southern Florida in 1957 then a bridgehead in Hawaii in 1978. In the 1980's it invaded most of the Pacific, many countries in Southeast Asia and more recently became established as far west as the Maldive Is.

All stages suck sap from their host plants and secrete copious amounts of honeydew and waxy white flocculent material. A dense growth of sooty moulds appears everywhere these secretions land—and on plants this interferes seriously with photosynthesis. The spiraling whitefly adult superficially resembles a tiny white moth and the pest derives its common name from the irregularly spiraling deposits of waxy white material which the female deposits when laying eggs.

The spiraling whitefly is an important pest of vegetables, fruit trees, ornamentals and shade trees, including coconut, banana, papaya, mango, guava, citrus and capsicum. Fortunately it was brought under effective biological control in Hawaii in the early 1980's by the introduction of natural enemies from the Caribbean. Two parasitic wasps of the genus *Encarsia* have now been introduced from Hawaii to a number of countries, including Fiji, Cook Is, Tonga, Western and American Samoa and Kiribati and the spiraling whitefly is now regarded as no more than a minor pest (Waterhouse 1991, Waterhouse & Norris 1989).

(iv) The passionfruit scale, *Pseudaulacaspis pentagona* (Targioni-Tozzetti)

Pseudaulacaspis pentagona is probably native to China and Japan, but has spread widely throughout the world. It damages a very wide range of plants and heavy infestations may kill them. There are strains attacking different hosts in different geographical areas. Thus, in Europe about 1900, the scale became such a severe pest of mulberry that it threatened the then-important silk industry. On the other hand, in Australia and USA, it attacks peach trees, but seldom mulberries. Important in the present context is its lethal attack on passionfruit vines in Western Samoa. In the early 1980's, the scale halted in its tracks a rapidly developing and highly profitable export trade of frozen passionfruit pulp.

The aphelinid wasp *Encarsia berlesi* (Howard) had been recorded as a valuable agent for the biological control of *Pseudaulacaspis* and its introduction to Europe about 1900 resulted in the scale losing economic significance there. On the other hand, a closely related scale *E. diaspidicola* (Silvestri) had not been recorded as an effective agent. Cultures of a species of *Encarsia*, presumed to be *E. berlesi*, were introduced in 1986 into Western Samoa from France, Tonga and USA. The species from France and Tonga, later identified as *E. diaspidicola*, rapidly became established and living scales soon became difficult to find, a situation that continues to apply. The project must now be rated a complete success, once again opening the way for the development of an economically important passionfruit industry (Sands et al. 1991, Waterhouse & Norris 1987).

It is interesting that *E. berlesi* from USA failed to become established. Had this species alone been introduced it is quite possible that control would not have been achieved. Indeed, it now seems possible that successful control of the scale on mulberry in Europe may have been due to *E. diaspidicola* and not, as presently credited, to *E. berlesi*.

(v) Siam weed, *Chromolaena odorata* (L.) King & Robinson

Siam weed is a widely distributed perennial shrub of Central American origin that has become widely distributed in tropical and subtropical areas in Africa, Asia and Micronesia. It has allelopathic properties, that is to say it suppresses the growth of nearby plants. It has spread widely and rapidly in Micronesia since it was first discovered in Guam in the early 1960's and now occurs throughout the Northern Marianas and the Federated States of Micronesia, causing important suppression of plantation crops.

Of over 200 insects and mites found attacking *Chromolaena* in Trinidad, a number are potentially effective natural enemies. One is an arctiid moth, *Pareuchaetes pseudoinsulata* Rego Barros, whose larvae defoliate the weed. This species was introduced into the Pacific in 1985 where it became established on Guam, the Northern Marianas and the Federated States of Micronesia. It has bred up to very large numbers in these islands, causing widespread defoliation and death of many well established stands of the weed. Earlier introductions to Africa and Asia were less successful, however: where the moth established it failed to increase in numbers to a level at which it was an effective defoliator, perhaps because of local natural enemies (Muniappan & Marutani 1991).

Discussion

Sufficient examples have already been provided and there are a number more that could have been chosen, to demonstrate that the introduction of appropriate natural enemies can, without any doubt, be a very successful approach to the control of many Pacific pests. Indeed, it is worth recording that about 20 pests or groups of pests are currently targets for biological control projects in the west and south Pacific. It is probably not too optimistic to hope that there will be at least one success every 2 years, particularly as some projects are based on successes elsewhere. One might well ask then, how soon will most of the major pests in the oceanic Pacific be effectively controlled? Unfortunately, the answer is probably 'never' at the present level of input of resources, unless means are found to reduce the rate at which new pests are being unintentionally introduced to the region.

New introductions have been far better documented for Hawaii and Guam than for elsewhere in the Pacific. More than 95% of the arthropod pests in Hawaii have been accidentally introduced in the last 200 years. During the last 50 years, new species have become established at the rate of nearly 20 per year and, on average, 3.5 of these each year have proved to be of economic importance. It is even more worrying that, in the 5 years between 1984 and 1989, the annual addition of new pest species has increased to more than 7 per year. The steadily increasing air traffic over the past 25 years has been a major factor in the increasing rate of new pest introductions. Most new pests in Hawaii nowadays are native to North, Central or South America, with a far lesser number native to Asia or Southeast Asia (Beardsley 1991, 1993).

In Guam, an average of at least 2.5 new insect pests were introduced each year in the decade of the 1980's, at least a third from the Americas via Hawaii. Other pests have arrived in Guam from Asia or other Micronesian islands. Although the mode of introduction of most pests generally cannot be determined, in 3 recent cases in Guam, one almost certainly arrived via an Air Force flight and two with commercial shipments of ornamentals from Hawaii (Schreiner 1991).

This very worrying situation led a Workshop on 'Exotic Pests in the Pacific' held under the auspices of the Pacific Science Association in Guam in 1990 to adopt a resolution which, slightly modified to the form below, was passed at the final Plenary session of the XIX International Congress of Entomology in Beijing in July 1992.

Whereas the Pacific ocean is a major and valuable barrier in limiting the spread of exotic arthropod and weed pests both to island and to continental nations; and

Whereas well over 90 per cent of the major pests in the oceanic Pacific are exotic introductions; and

Whereas there is a steady increase in the frequency of introductions, which is correlated with increased air traffic and associated with unscreened first class mail and horticultural imports; and

Whereas island ecosystems are fragile, easily damaged and their biota subject to competition from, and extermination by, introduced exotics.

Be it resolved that

The XIX International Congress of Entomology strongly recommends to all Pacific Nations they take urgent action to ensure:

1. effective inspection of all incoming packages, including 1st class mail, and
2. effective insecticide treatment of all aircraft flying to and between Pacific countries.

References

Beardsley, J. W. 1991. Introduction of Arthropod Pests into the Hawaiian Islands. Micronesica, Suppl. 3: 1–4.

Beardsley, J. W. 1993. Exotic Terrestrial Arthropods in the Hawaiian Islands: Origins and Impacts. Micronesica, Suppl. 4: 11–15.

Bedford, G. O. 1981. Control of the rhinoceros beetle by baculovirus. *in* Burgess, H. D. (ed) 1981. Microbial Control of Pests and Plant Diseases 1970–1980, pp 409–426. Academic Press, London, UK, 949 pp.

Bedford, G. O. 1986. Biological control of the rhinoceros beetle in the south Pacific by baculovirus. Agriculture, Ecosystems and Environment 15: 141–147.

Funasaki, G. Y., P. Y. Lai, L. M. Nakahara, J. W. Beardsley & A. K. Ota 1988. A review of biological control introductions in Hawaii: 1890–1985. Proc. Hawaii. Entomol. Soc. 28: 105–160.

Lai, P. Y. 1988. Biological control : a positive point of view. Proc. Hawaii. Entomol. Soc. 28: 179–190.

Muniappan, R. & M. Marutani. 1991. Distribution and control of *Chromolaena odorata* (Asteraceae). Micronesica, Suppl. 3: 103–107.

Sands, D. P. A., R. Broe & W. J. M. M. Liebregts. 1990. Identity of *Encarsia* spp. (Hymenoptera: Aphelinidae) introduced into Western Samoa for biological control of *Pseudaulcaspis pentagona* (Targioni-Tozzetti) (Hemiptera: Diaspididae. Proc. Entomol. Soc. Wash. 92: 135–138.

Tothill, J. D., T. H. C. Taylor & R. W. Paine. 1930. The Coconut Moth in Fiji. A History of its Control by Means of Parasites. Imperial Bureau of Entomology, London. 269 pp.

Schreiner, I. H. 1991. Sources of new insects established on Guam in the post World War II period. Micronesica, Suppl. 3: 5–13.

Waterhouse, D. F. 1991. Biological control: mutual advantages of interaction between Australia and the Oceanic Pacific. Micronesica, Suppl. 3: 83–92.

Waterhouse, D. F. & K. R. Norris. 1987. Biological Control: Pacific Prospects. Inkata Press Melbourne, 454 pp.

Waterhouse, D. F. & K. R. Norris. 1989. Biological Control: Pacific Prospects, Supplement 1. Australian Centre for International Agricultural Research, Canberra, 123 pp.