# Biological Control: A Positive Point of View[1]

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## I. INTRODUCTION

In his presidential address at the December 1980 meeting of the Hawaiian Entomological Society, Francis G. Howarth presented a critical view of classical biological control. To clarify the issues, I wish to take this opportunity to present a different view of the same subject and to comment on some of the statements made by Howarth (1983) and others.

Since 1890, classical biological control (biocontrol) has been practiced in Hawaii with varying degrees of success in controlling insect and weed pests. Throughout the history of biocontrol in Hawaii much effort has been made by practitioners to search for and select effective biocontrol agents for ultimate field releases. This effort has been well documented in the Proceedings of the Hawaiian Entomological Society and other scientific journals.

Hawaii has enjoyed an enviable record of success with biocontrol. However, much of the earlier work was carried out by a number of dedicated entomologists under conditions relatively free of outside influence. In fact, at times the work was done under such obscurity that some people may have considered biocontrol to be a lonely, unrewarding field. Naturally, it failed to attract much public attention, let alone support. However, these entomologists carried out their tasks not only with great interest, but also with strong convictions toward the success and safety of biocontrol. I am sure that such entomologists as Perkins, Koebele, Muir and Swezey are no strangers to us.

## II. APPLIED BIOCONTROL

Biocontrol did not enter the spotlight until recent years when conventional pest control weapons, particularly pesticides, were faulted for contaminating food, feed and water. As a result, undesirable side effects to human health and the environment due to misuse of pesticides have been documented. Moreover, while the advent of modern technology has drastically increased the capability of detecting traces of pesticides, the knowledge to assess the risks associated with these traces of pesticides has been lagging farther and farther behind. This has created considerable concern not only to the general public, but to researchers as well.

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[1]Presidential address presented at the December 1986 meeting of the Hawaiian Entomological Society.

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This concern has prompted researchers to develop alternative methods of pest control which would be safer and more environmentally sound than conventional pesticides. Despite all the relentless efforts, there has not been one suitable method developed to totally replace pesticides in combatting every pest species. In some cases, however, biocontrol and other pest control measures have been used individually or in combination to effectively control pest populations.

In Hawaii, biocontrol alone has been effective in achieving complete control of 38 species of insect pests and 7 species of weeds (Tables 1 and 2). Also, working in conjunction with other control measures, such as pesticides, it has been judged to have substantially controlled 13 species of insect pests and 3 species of weeds (Tables 3 and 4). The concept of combining biocontrol with other pest control strategies has evolved to the present day discipline of integrated control or integrated pest management. This discipline has been successfully applied to a number of crops. In Hawaii, for example, integrated control measures have been implemented on watercress to control the diamondback moth, *Plutella xylostella* (L.) (Nakahara et al. 1986), and a pest management program has been developed on watermelon to control leafminers, *Liriomyza* spp. (Johnson 1987). The common ingredients in these two programs were a timely use of pesticides, effective biocontrol agents, adjustment of cultural practices, and accurate assessment of pest populations. Even though the use of some pesticides was still necessary, their compatibility with natural enemies was carefully balanced and tested to prevent detrimental impacts.

TABLE 1. Plant Pests Under Complete Biological Control.

| Plant Pests | Major Controlling Agents |
|---|---|
| 1. *Acyrthosiphon pisum* (Harris) (pea aphid) | P - *Aphidius smithi* Sharma & Rao |
| 2. *Agonoxena argaula* Meyrick (coconut leafminer) | I - *Trathala flavo-orbitalis* (Cameron)<br>P - *Brachymeria agonoxenae* Fullaway<br>I - *Brachymeria polynesialis* (Cameron) |
| 3. *Agrius cingulatus* (F.) (sweetpotato hornworm) | P - *Trichogramma chilonis* Ishii |
| 4. *Aleurocanthus spiniferus* (Quaintance) (orange spiny whitefly) | P - *Prospaltella smithi* (Silvestri)<br>I - *Encarsia variegata* Howard<br>I - *Encarsia* spp. |
| 5. *Aleurodicus dispersus* Russell (spiraling whitefly) | P - *Encarsia ?haitiensis* (Dozier)<br>P - *Encarsia* sp.<br>P - *Nephaspis amnicola* Wingo<br>P - *Delphastus pusillus* (LeConte) |
| 6. *Aleurothrixus floccosus* (Maskell) (woolly whitefly) | P - *Amitus ?spiniferus* (Brethes)<br>P - *Cales noacki* DeSantis |
| 7. *Anomala orientalis* (Waterhouse) (oriental beetle) | P - *Campsomeris marginella modesta* (Smith)<br>P - *Tiphia segregata* Crawford |
| 8. *Antonina graminis* (Maskell) (Rhodesgrass mealybug) | I - *Anagyrus antoninae* Timberlake<br>I - *Neodusmetia sangwani* Rao |

TABLE 1. Plant Pests Under Complete Biological Control. *(Continued)*

| Plant Pests | Major Controlling Agents |
|---|---|
| 9. Aphids - various species | P - *Lysiphlebius testaceipes* (Cresson)<br>I - *Aphelinus gossypii* Timberlake<br>I & P - Other parasites & coccinellids |
| 10. *Amorbia emigratella* Busck (Mexican leafroller) | P - *Bracon omiodivorum* (Terry)<br>P - *Brachymeria obscurata* (Walker)<br>N - *Echthromorpha fuscator* (F.) |
| 11. *Bedellia orchilella* Walsingham (sweetpotato leafminer) | P - *Pholetesor bedelliae* (Viereck) |
| 12. *Ceroplastes cirripediformis* Comstock (barnacle scale) | P - *Coccidoxenus mexicanus* (Girault) |
| 13. *Coptosoma xanthogramma* (White) (black stink bug) | I - *Trissolcus* sp. |
| 14. *Gryllotalpa africana* Palisot de Beauvois (mole cricket) | P - *Larra luzonensis* Rohwer |
| 15. *Gynaikothrips ficorum* (Marchal) (Cuban laurel thrips) | P - *Montandoniola moraguesi* (Puton) |
| 16. *Hedylepta accepta* (Butler) (sugarcane leafroller) | I - *Trathala flavo-orbitalis* (Cameron)<br>P - *Bracon omiodivorum* (Terry)<br>N - *Diadegma blackburni* (Cameron)<br>I - *Casinaria infesta* (Cresson) |
| 17. *Icerya purchasi* (Maskell) (cottony cushion scale) | P - *Rodolia cardinalis* (Mulsant)<br>I - *Cryptochaetum iceryae* (Williston) |
| 18. *Ithome concolorella* (Chambers) (kiawe flower moth) | P - *Agathis ?cincta* Cresson |
| 19. *Melanaphis sacchari* (Zehntner) (sugarcane aphid) | I - *Aphelinus maidis* Timberlake<br>P - *Coelophora inaequalis* F. |
| 20. *Melipotis indomita* (Walker) (monkeypod-kiawe caterpillar) | P - *Eucelatoria* sp. |
| 21. *Murgantia histrionica* (Hahn) (harlequin bug) | P - *Ooencyrtus johnsoni* (Howard)<br>P - *Trissolcus murgantiae* Ashmead |
| 22. *Nezara viridula* (L.) (southern green stink bug) | P - *Trissolcus basalis* (Wollaston)<br>P - *Trichopoda pilipes* (F.)<br>P - *Trichopoda pennipes* F. |
| 23. *Nipaecoccus nipae* (Maskell) (coconut mealybug) | P - *Pseudaphycus utilis* Timberlake<br>P - *Hyperaspis silvestrii* Weise |
| 24. *Oxya japonica* (Thunberg) (Japanese grasshopper) | P - *Scelio pembertoni* Timberlake |
| 25. *Papilio xuthus* L. (citrus swallowtail) | P - *Trichogramma chilonis* Ishii<br>P - *Pteromalus luzonensis* Gahan |
| 26. *Perkinsiella saccharicida* Kirkaldy (sugarcane delphacid) | P - *Tytthus mundulus* (Breddin) |
| 27. *Pelopidas thrax* (L.) (banana skipper) | P - *Ooencyrtus erionotae* Ferriere<br>P - *Cotesia erionotae* (Wilkinson) |
| 28. *Pineus pini* (Macquart) (Eurasian pine adelgid) | P - *Leucopis obscura* Haliday<br>P - *Leucopis nigraluna* McAlpine |

TABLE 1. Plant Pests Under Complete Biological Control. *(Continued)*

| Plant Pests | Major Controlling Agents |
|---|---|
| 29. *Polydesma umbricola* Boisduval (monkeypod moth) | I - *Eucelatoria armigera* (Coquillett)<br>P - *Brachymeria obscurata* (Walker)<br>I - *Hyposoter exiguae* (Viereck)<br>I - *Coccygomimus punicipes* (Cresson) |
| 30. *Pseudaletia unipuncta* (Haworth) (armyworm) | P - *Glyptapanteles militaris* (Walsh)<br>P - *Cotesia marginiventris* (Cresson)<br>I - *Chaetogaedia monticola* (Bigot)<br>P - *Euplectrus plathypenae* Howard |
| 31. *Pseudococcus affinis* (Maskell) (obscure mealybug) | P - *Cryptolaemus montrouzieri* Mulsant |
| 32. *Psylla uncatoides* (Ferris & Klyver) (acacia psyllid) | P - *Harmonia conformis* (Boisduval) |
| 33. *Scotorythra paludicola* (Butler) (koa moth) | N - *Enicospilus* sp.<br>I - *Hyposoter exiguae* (Viereck)<br>I - *Pristomerus hawaiiensis* Perkins<br>P - *Lespesia archippivora* (Riley) |
| 34. *Siphanta acuta* (Walker) (torpedo bug) | P - *Aphanomerus pusillus* Perkins |
| 35. *Spodoptera exempta* (Walker) (nutgrass armyworm) | P - *Cotesia marginiventris* (Cresson)<br>P - *Meteorus laphygmae* (Viereck)<br>I - *Eucelatoria armigera* (Coquillett) |
| 36. *Syagrius fulvitarsis* Pascoe (Australian fern weevil) | P - *Doryctes syagrii* (Fullaway) |
| 37. *Tarophagus proserpina* (Kirkaldy) (taro delphacid) | P - *Cyrtorhinus fulvus* Knight<br>P - *Ootetrastichus megameli* Fullaway |
| 38. *Therioaphis maculata* (Buckton) (spotted alfalfa aphid) | P - *Trioxys complanatus* Quilis |

P - purposely introduced species
I - immigrant species
N - native species

TABLE 2. Weeds Under Complete Biological Control.

| Noxious Weeds | Major Controlling Agents |
|---|---|
| 1. *Ageratina adenophora* (Spreng.) K. & R. (Maui pamakani) | P - *Procecidochares utilis* Stone |
| 2. *Ageratina riparia* (Regel) K. & R. (Hamakua pamakani) | P - *Procecidochares alani* Steyskal<br>P - *Oidaematophorus beneficus* Yano & Heppner<br>P - *Cercosporella* sp. |
| 3. *Emex australis* Steinh. *Emex spinosa* (L.) Campdera (emex) | P - *Apion antiquum* Gyllenhal |
| 4. *Hypericum perforatum* L. (Klamath weed) | P - *Zeuxidiplosis giardi* (Kieffer)<br>P - *Chrysolina quadrigemina* (Suffrain)<br>P - *Chrysolina hyperici* (Foster) |
| 5. *Tribulus terrestris* L. *Tribulus cistoides* L. (puncture vine) | P - *Microlarinus lypriformis* (Wollaston)<br>P - *Microlarinus lareynii* (Jacquelin du Val) |

P - purposely introduced species

TABLE 3. Plant Pests Under Substantial Biological Control.

| Plant Pests | Major Controlling Agents |
|---|---|
| 1. *Aspidiotus destructor* Signoret (coconut scale) | P - *Telsimia nitida* Chapin<br>P - *Lindorus lophanthae* Blaisdell<br>I - *Aphytis* spp. |
| 2. *Ceratitis capitata* (Wiedemann) (Mediterranean fruit fly) | P - *Biosteres tryoni* (Cameron)<br>P - *Biosteres arisanus* (Sonan) |
| 3. *Cinara atlantica* (Wilson) (Carolina conifer aphid) | P - *Hippodamia convergens* Guerin- Meneville |
| 4. *Dacus dorsalis* Hendel (oriental fruit fly) | P - *Biosteres longicaudatus* (Ashmead)<br>P - *Biosteres arisanus* (Sonan)<br>P - *Biosteres vandenboshi* (Fullaway) |
| 5. *Elimaea punctifera* (Walker) (narrow winged katydid) | I - *Anastatus koebelei* Ashmead<br>I - *Ufens elimaeae* Timberlake<br>I - *Oligosita* sp. |
| 6. *Hedylepta blackburni* (Butler) (coconut leafroller) | N - *Diadegma blackburni* (Cameron)<br>P - *Lespesia archippivora* (Riley)<br>P - *Brachymeria obscurata* (Walker)<br>N - *Echthromorpha fuscator* (F.) |
| 7. *Herpetogramma licarsisalis* (Walker) (grass webworm) | I - *Trichogramma* spp.<br>P - *Meteorus laphygmae* Viereck<br>I - *Trathala flavo-orbitalis* (Cameron)<br>I - *Eucelatoria armigera* (Coquillett) |
| 8. *Ophiomyia phaseoli* (Tryon) (bean fly) | P - *Opius importatus* Fischer<br>P - *Opius phaseoli* Fischer |
| 9. *Artogeia rapae* (L.) (imported cabbageworm) | P - *Cotesia glomeratus* (L.)<br>P - *Lespesia archippivora* (Riley) |

**TABLE 3.** Plant Pests Under Substantial Biological Control. *(Continued)*

| Plant Pests | Major Controlling Agents |
|---|---|
| 10. *Planococcus citri* (Risso) (citrus mealybug) | P - *Cryptolaemus montrouzieri* Mulsant<br>P - *Leptomastidea abnormis* (Girault) |
| 11. *Pulvinaria psidii* Maskell (green shield scale) | I - *Metaphycus flavus* (Howard)<br>P - *Cryptolaemus montrouzieri* Mulsant |
| 12. *Rhabdoscelus obscurus* (Boisduval) (New Guinea sugarcane weevil) | P - *Lixophaga sphenophori* (Villeneuve) |
| 13. *Spodoptera mauritia* (Boisduval) (lawn armyworm) | P - *Cotesia marginiventris* (Cresson)<br>P - *Chelonus insularis* (Cresson) |

P - purposely introduced species
I - immigrant species
N - native species

**TABLE 4.** Weeds Under Substantial Biological Control.

| Noxious Weeds | Major Controlling Agents |
|---|---|
| 1. *Lantana camara* L. (lantana) | P - *Eutreta xanthochaeta* Aldrich<br>P - *Hypena strigata* F.<br>P - *Octotoma scabripennis* Guerin<br>P - *Uroplata girardi* Pic<br>P - *Teleonemia scrupulosa* Stal<br>P - *Plagiohammus spinipennis* Thompson |
| 2. **Clidemia hirta* (L.) D. Don (Koster's curse) | P - *Liothrips urichi* Karny<br>P - *Blepharomastix ebulealis* Guenee |
| 3. *Opuntia megacantha* Salm-Dyck (prickly pear cactus) | P - *Cactoblastis cactorum* (Berg)<br>P - *Dactylopius opuntiae* (Cockerell)<br>P - *Archlagocheirus funestus* (Thomson) |

P - purposely introduced species
* - controlled in agricultural lands but not in forests

## III. COMMENTS

Recently Gagne and Howarth (1982) and Howarth (1983, 1985) have implied that some biocontrol agents are responsible for the demise of some elements of our native biota, especially native moths. Also, Zimmerman (1958) attributed a near or complete extermination of many Hawaiian Lepidoptera to parasites, accidentally imported or purposely introduced, for the control of various moths of economic importance. To elucidate the actual impacts of biocontrol introductions on our native biota, Funasaki et al. (1988) conducted an extensive review of available literature and found that biocontrol introductions have been recorded as having attacked relatively few species of our native biota. There are absolutely no data indicating that biocontrol introductions have caused any extinctions of native biota.

With all due respect to Zimmerman, Gagne, Howarth, Hadfield and other researchers, I would like to select a few key issues and offer my comments as follows:

## 1. Introduced Species vs. Immigrant Species

In reviewing the four publications by Zimmerman (1958), Gagne and Howarth (1982) and Howarth (1983, 1985), a striking similarity is apparent that the terms "introduction" and "importation" have been used interchangeably. No effort has been made to distinguish species that are purposely introduced through a biocontrol program, from those that somehow accidentally find their way into Hawaii and become established. This indiscriminate use of terminology has led to confusion resulting in some of the faulty examples cited to support their statements. As a consequence, the conclusions derived from these statements are questionable. For example, *Orthesia insignis* Browne was cited by Howarth (1983) to exemplify a statement "2 wrongs supposedly make a right." Based on this, *O. insignis* was implied to have been purposely introduced to control lantana. The fact is that *O. insignis* is an accidental immigrant (Perkins and Swezey 1924) which was first found on the island of Maui in 1899. Because of the damage inflicted by *O. insignis* on lantana, ranchers who were troubled with lantana had arbitrarily collected the insect and released it on other islands. When Koebele learned about the establishment of *O. insignis* and its spread by ranchers, he, along with the Commissioner of Agriculture, issued a special warning opposing the spread of this new pest on the basis of its potential threat to economically important plants (Perkins and Swezey 1924). Because of this threat, the purposeful introduction in 1908 of a coccinellid, *Hyperaspis jocosa* (Mulsant), from Mexico to control *O. insignis* was deemed necessary. Therefore, this is clearly not a case of "2 wrongs supposedly make a right" as indicated by Howarth (1983).

To prevent this unnecessary confusion, Funasaki et al. (1988) have offered clearer definitions to distinguish purposely introduced species from immigrant species which arrive accidentally.

## 2. Natural Enemies vs. Unnatural Enemies

It has generally been accepted by biological control workers that the term "biocontrol" is defined as "the action of parasites, predators, and pathogens in maintaining another organism's population density at a lower average than would occur in their absence" (DeBach 1964). As such, biocontrol is employed to regulate plants and animals which gain entry into a new location and become pests, through the actions of natural enemies. This encompasses both the purposeful introduction and manipulation of natural enemies which were left behind in the native habitats of the pests (Bartlett and van den Bosch 1964, van den Bosch et al. 1982).

Howarth (1983) argued that biocontrol agents, in reality, are unnatural enemies because many were not native to the homeland of the pest. However, isn't it true that the ancestors of all of the plants and animals currently considered native in Hawaii were from somewhere outside of Hawaii? Isn't it also true that the unique morphological and genetic characteristics of native species are a result of evolutionary processes which have taken place after the establishment of their ancestors? Although these are facts, no questions have ever been raised as to whether or not the native species in Hawaii are natural. Also, it is a recognized fact that natural enemies, even if they are transferred from one geographical area to another to help control immigrant pests, occur naturally. Therefore, the status of biocontrol agents being natural is indisputable.

### 3. Negative Impacts of Biocontrol?

As a biocontrol practitioner, I am particularly alarmed by the statement "... classical biological introductions to date have involved significant negative impacts on agriculture, native ecosystems, and human health" (Howarth 1983). Since the statement did not specify whether or not the "impacts" were experienced in Hawaii or elsewhere, it would be difficult to conduct a full, accurate assessment of the validity of this statement. Nonetheless, a review of Hawaii's records on biocontrol introductions should help to determine whether or not purposely introduced biocontrol agents have, in any way, caused negative impacts on agriculture, native ecosystems and human health in Hawaii.

Based on the review conducted by Funasaki et al. (1988) there is no evidence to substantiate the claim that biocontrol introductions have caused any negative consequences on agriculture or human health in Hawaii. On the contrary, agriculture and public health have benefited from successful results of Hawaii's biocontrol program. In fact, it is acknowledged by Howarth (1983) that "... the method has been used with some impressive economic successes both in Hawaii and elsewhere ..." Since the benefits and successes of the biocontrol program are indisputable, the remaining question on the impacts of biocontrol introductions on native ecosystems needs to be addressed.

During 1890-1985, records indicate that a total of 283 species of parasitic insects were purposely introduced into Hawaii, of which, 115 species (40.6%) eventually became established (Lai and Funasaki 1986). Among the established species, 17 species (14.8%) have been reported to attack target as well as other non-target hosts. Furthermore, of the 115 species, only 6 (5.2%) have been recorded to attack native Lepidoptera

(Funasaki et al. 1988). None of these have been proven to have caused extinction of any native Lepidoptera. In fact, several species of Lepidoptera, native and immigrant, which had been reported to be extinct were later discovered in different habitats. For example, Gagne and Howarth (1982) reported that *Manduca blackburni* (Butler) presumably became extinct due to the loss of hosts and biocontrol introductions. However, Riotte (1986) revealed that in 1984, 2 larvae of *M. blackburni* were found on Maui by Ms. B. Gagne on *Nothocestrum latifolium* Gray (Solanaceae), which was not previously known to be a host plant.

One may argue that some of those species currently considered as accidental immigrants were the result of indiscriminate introductions made in the late 19th and early 20th centuries. However, there is no direct evidence that can be found in the literature to support this argument. Swezey (1931), recognizing the need for consolidating all of the records of biocontrol introductions, published a comprehensive list of the successful introductions during 1890-1925. Again in 1938, Swezey summarized records of biocontrol introductions made during 1929-1938. In addition, the records deposited at both the Hawaiian Sugar Planters' Association (HSPA) and the Hawaii Department of Agriculture (HDOA), contain most, if not all, of the introduced species that have been released in Hawaii (Lai and Funasaki 1986).

## 4. EUGLANDINA vs. ACHATINELLA

In addition to insects and mites, other animals, such as snails, birds, fishes and amphibians, have also been introduced for biocontrol purposes (Lai and Funasaki 1986). In recent years, this group of introductions has generated considerable controversy over their possible impacts on native biota. Of these, a predaceous snail, *Euglandina rosea* (Ferussac), leads the pack.

In a field study to estimate population of *Achatinella mustelina* Mighels at a site in the Waianae mountains, Hadfield and Mountain (1980) found that based on a single visit each in 1976 and 1977, the populations of *A. mustelina* were maintained at the same level as that estimated in 1974 and 1975 when a more intensive study was conducted. However, Hadfield and Mountain (1980) concluded that *E. rosea* was responsible for the destruction of the population of *A. mustelina* on the basis of a follow-up observation made in August 1979. This conclusion was drawn by associating the absence of live *A. mustelina* with the presence of empty shells of *E. rosea* near the study site. This association is inconclusive because (1) rats have been indicated to have caused mortality on *A. mustelina* (Hadfield and Mountain 1980); and (2) the presence of empty shells of both *A. mustelina* and *E. rosea* may be attributable to the predation by a flat worm, *Geoplana septemlineata* Hyman (L.N. Nakahara pers. comm.). Obviously, Hadfield and Mountain have chosen to emphasize the possible effects of predation by *E. rosea*, without the support of quantitative data. They failed to explain why the empty shells of *E. rosea* were found in the study site, what caused the death of those *E. rosea*, and what is the correlation, if any, between the presence of *E. rosea* and the decline of *A. mustelina*. I am not arguing the role that *E. rosea* may have played as one of the mortality factors impacting on the population of *A. mustelina*. Rather, I am arguing the validity and accuracy of deriving a conclusion solely on the basis of one qualitative observation. I feel that in order to fully understand the impact of *E. rosea* on *A. mustelina*, an exclusion method must be developed to isolate each mortality factor and assess its impact. Then, and only then, can a definitive, reliable conclusion be drawn.

## 5. Biological Pollution vs. Pesticide Pollution

Howarth (1983) categorized the establishment in the wild of foreign or non-native organisms as "biological pollution". I am of the opinion that the term "biological pollution" should be applicable only to species which have gained entry into Hawaii and thrived to become pests of economic, medical, or ecological significance. However, it should not be applicable to those biocontrol introductions which restrict their feeding habits to pest species.

Also, Howarth (1983) expounded 6 areas of concern from his comparison of the environmental considerations of chemical and biological pest control. Of these areas of concern, the issues relating to area covered, research of efficacy and impacts, economics, and biosystemics are quite broad and subject to personal interpretation. Whereas, the issue on specificity of biocontrol introductions has been well studied by Funasaki et al. (in press). Therefore, I will restrict my comments on the relative irreversibility of pesticides and on a comparison between pesticides and biocontrol introductions in relation to their potential risks on public health and the environment.

Unlike pesticides, biocontrol introductions have never been indicated as carcinogens, oncogens, mutagens, or teratogens. Also, unlike pesticides, biocontrol introductions have never been found contaminating food, feed, air, soil, or groundwater. I agree that there are methods available to detect the presence of traces of pesticides in our food, feed, or water. However, knowledge of the potential risks from these traces of pesticides on human health and the environment is seriously lacking.

Pesticide contamination on food and feed may be easier to deal with simply by condemnation and proper disposition. However, pesticide contamination of groundwater is an entirely different situation in that the appearance of contaminants in groundwater often follows their release to the subsurface of soil by years, if not decades (MacKay et al. 1985). When such contaminants manage to leach into groundwater, they will remain in the groundwater for years because of the following two reasons: 1) such pesticides have escaped their loss pathways including volatilization, biological and chemical degradation, and retention by the soil; and 2) the residence time of most basal groundwater is at least several years (F.L. Peterson pers. comm.). Also, because of the inaccessibility and vastness of

Hawaii's basal groundwater, it would be difficult, if not impossible, to clean up pesticides from a contaminated groundwater (F.L. Peterson pers. comm.). Installation of an expensive filtering system has been used to remove traces of pesticides, such as the one installed in the Mililani drinking water well on Oahu in 1986 to rid residues of 1,2-dibromo-3-chloropropane (DBCP) and 1,2,3-trichloropropane (TCP) (K. Hayashida pers. comm.). The persistent natures of pesticides in groundwater are, therefore, indicative of a relatively irreversible characteristic of chemical pollution.

## IV. CONCLUSIONS

It is a recognized fact that there are benefits and risks in all insect control methods and no method alone can solve all pest problems. However, because of the continued influx of new immigrant species and the favorable climatic conditions in Hawaii, we have often experienced sudden population build-ups, particularly the species considered as pests of desirable plants or animals found in the lowland urban and suburban areas, and on agricultural and disturbed forest lands. During 1962-1976, 52 species that are pests or known to be pests elsewhere were reported to have become established in Hawaii (Beardsley 1979). Since these newly established pests are usually free from the limiting effects of their indigenous natural enemies, which have been left behind in their native homeland, a sensible solution to the problems caused by such newly established pests in Hawaii is to introduce natural enemies from their native homeland for field releases. Prior to the release of any biocontrol introductions, extensive research effort is invested in reviewing available literature, searching for suitable natural enemies for introduction, screening and studying the proposed species for introduction in a quarantine laboratory, consulting two advisory committees, and then submitting requests to the Board of Agriculture for final disposition. This check-and-balance system was adopted by the HDOA in 1944 and has proven to be highly effective in regulating the biocontrol introduction program to ensure that the species released pose no harm to desirable plants or animals, human health, or native ecosystems. The staff of the HDOA involved in this program has worked very closely with scientists at the University of Hawaii, Bishop Museum, HSPA and other institutions in an attempt to eliminate or minimize unnecessary risks which may be associated with biocontrol and to improve the rate of success.

Although some purposeful introductions of biocontrol agents have been reported to prey on or attack some desirable species of plants and animals, the biocontrol introductions undertaken in the past 96 years have generally been effective and safe to the environment. It is, therefore, clear that as long as a strict screening and reviewing process is undertaken, biocontrol can be an effective alternative to pesticides. Biocontrol is definitely neither a panacea nor a Pandora's box.

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