SUCCESSFUL EXAMPLES OF BIOLOGICAL CONTROL OF PEST INSECTS AND PLANTS.

By Dr. HARVEY L. SWEETMAN,*
Massachusetts State College, Amherst, Mass.

The selection of examples where the biological control method has been successful depends somewhat upon the individual viewpoint.† A casual perusal of the literature would lead one to believe that predators and parasites had been unusually successful against many pests. In a recent communication from H. S. Smith it was stated: "If you go over the old literature on this subject in California, you will find that the black scale problem was solved by the introduction of *Rhizobius* in 1890. It was solved again in 1900 by the introduction of *Scutellista*. But we still spend in excess of a million dollars a year in southern California on spraying and fumigation for this pest. The same was true in Hawaii. For many years it was stated that one of the greatest examples of successful biological control was that of the sugar-cane leafhopper by the egg parasites, *Paranagrus* and *Ootetrastichus*. Later *Cyrtorhinus* was introduced with success, and it was admitted that control by the two egg parasites was not satisfactory. No doubt all these introductions were valuable and represent different degrees of control, each succeeding introduction resulting in a greater degree of control than previously existed. The difficulty lies in the absence of a satisfactory criterion by which to measure and record the relative effects of the introductions." A critical analysis of the data submitted to support the contentions for the early examples mentioned above is far from convincing. However, it should be recalled that the standards for measuring the success of biological control have undergone considerable change during the intervening period.

Undoubtedly, the decline in the ravages of a number of insect pests has been attributed wrongly to the artificial manipulation of parasites and predators, when this decline really was due to other factors. Frequently high percentages of parasitism and numerous specimens of beneficial insects have been observed and from such observations and data the conclusion drawn that the pest would have destroyed the crop from a commercial viewpoint if a particular enemy of the pest had not been introduced or liberated. Such evidence will not withstand critical analysis, but frequently no better data are available. It is very common during insect outbreaks to find high percentages of parasitism and predatism, but if the outbreak is very extensive no apparent good results. When the pests are scarce, previous high percentages of parasitism are often suggested as the reason for the absence. However, unless accurate data, usually for several years, in terms of real mortality and not apparent mortality are available, such conclusions are not warranted. In fact, it is very dubious if percentage alone can ever be considered critical. Having determined the real mortality produced by a given parasite or predator, and knowing the effective reproductive capacity of the organisms concerned, one is in a position to determine whether the reduction in a host population can be correlated with the prevalence of the beneficial species or not. By securing data of a similar nature regarding other destructive agencies, physical as well as biotic, it is possible to reach a rather definite conclusion regarding the effectiveness and importance of the various controlling factors. Apparently many workers have overlooked the fact that a number

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† Correspondence is encouraged from workers who may wish to delete or add examples to the list as prepared.

of destructive agents may be present in an environment, any one of which in the absence of the others, would have reduced the ravages of a particular pest. Thus it is possible in some instances, that certain parasites and predators under observation, although actually killing a high percentage of the host have merely replaced other resistances of the environment, and actually no particular benefit has been accomplished by the introduction.

An attempt has been made to select the most successful cases of control produced through parasitism and predatism. Only those cases which are unusually successful or decidedly beneficial are included. Probably most workers acquainted with the subject will agree with the examples offered, but some would wish to add many more instances as successful. Examples only temporarily or slightly successful as the reduction or near eradication of white grubs from a field by birds during cultivation are not included, since the results may be vastly different in fields near by or the following season. However, the exclusion of such temporary or local examples of control should not overshadow their importance, as it is possible that such instances of control in the aggregate are of greater importance than that of the examples given.

The table is divided into two parts ; the first including examples wherein the beneficial species have eliminated the necessity of other control measures ; the second, examples wherein the parasites or predators, or both, are usually, or largely, adequate, but some damage and even local outbreaks may occur.

It is evident that all of the examples occur on islands or insular-like regions. The pests in the adequate control group, with two exceptions, belong to the order Homoptera and are either scale-insects, mealybugs, aphids, or leafhoppers. These pests have certain characteristics in common, as being sedentary, slow in dispersal, gregarious, limited number of hosts attacked, etc., that seem to render them especially susceptible to the attacks of parasites and predators. However, among the highly beneficial group, some of the pests live in relatively inaccessible places and have habits that would seem less favourable to the attacks of enemy insects, yet the attacks of the beneficial forms seem to be almost as effective. This is especially encouraging since it demonstrates the feasibility of attempting parasite and predator control among pests living in quite varied, hidden, and even unusual habitats.

The beneficial insects belong to four orders, although more belong to the Hymenoptera than to the Hemiptera, Diptera, and Coleoptera combined. About one-fourth of the beneficial species listed are predators, thus showing the importance of predatory species in the biological control complex, a fact not generally recognised by entomologists.

In nearly all of the examples given, species other than those listed attack the hosts, but the principal parasites and predators are shown and in most examples are not appreciably aided by the species omitted. The predator, *Cryptolaemus montrouzieri*, until recently, was commercially controlling *Pseudococcus gahani*, although the beetles were unable to maintain themselves and were liberated as needed. About two years ago the Chalcid, *Coccophagus gurneyi*, completely replaced *Cryptolaemus* as the controlling agency, being more efficient as well as maintaining itself. The two cutworms, *Cirphis unipuncta* and *Spodoptera mauritia* are still troublesome at times, but the prevalence and frequency of outbreaks are enormously reduced by several parasites, of which the two most important are given.

It is worth noting that the most successful examples have been brought about by one parasite or predator in most instances. Among the pests listed, the cutworms, *Cirphis* and *Spodoptera*, come the nearest to indicating the partial success of a group of parasitic enemies, but this is the poorest example listed.

Attempts to control pest plants by the biological method have yielded some very interesting results, although not equal to those obtained against insects. However, a number of examples seem to fit into the highly beneficial group.

Highly Beneficial Control.

Pest Species	Order	Beneficial Species	Order	Family	Parasite or Predator	Countries
Anomala orientalis, Waterh. ...	Coleoptera	*Scolia manilae*, Ash.	Hymenoptera	Scoliidae	Parasite	Hawaiian Islands
Oryctes tarandus, Oliv.	Coleoptera	*Scolia oryctophaga*, Coq.... ...	Hymenoptera	Scoliidae	Parasite	Mauritius
Syagrius fulvitarsis, Pasc.... ...	Coleoptera	*Ischiogonus syagrii*, Ful. ...	Hymenoptera	Braconidae	Parasite	Hawaiian Islands
Diaspis pentagona, Targ.... ...	Homoptera	*Prospaltella berlesei*, How. ...	Hymenoptera	Aphelinidae	Parasite	Italy
Perrisia pyri, Bch.	Diptera	*Misocyclops ornatus*, Kieff. ...	Hymenoptera	Scelionidae	Parasite	New Zealand
Cirphis unipuncta, Haw.	Lepidoptera	*Euplectrus platyhypenae*, How....	Hymenoptera	Elachertidae	Parasite	Hawaiian Islands
Spodoptera mauritia, Boisd. ...	Lepidoptera	*Archytas cirphis*, Cur. etc. ...	Diptera	Tachinidae	Parasite	
Rhabdocnemis obscura, Boisd. ...	Coleoptera	*Ceromasia sphenophori*, Vill. ...	Diptera	Tachinidae	Parasite	Hawaiian Islands
Pseudococcus citri, Risso	Homoptera	*Cryptolaemus montrouzieri*, Muls.	Coleoptera	Coccinellidae	Predator	California
Eriococcus coriaceus, Mask. ...	Homoptera	*Rhizobius ventralis*, Erich. ...	Coleoptera	Coccinellidae	Predator	New Zealand

EXAMPLES OF SUCCESSFUL CASES OF CONTROL BY BIOLOGICAL METHODS.
Adequate Control.

Pest Species	Order	Beneficial Species	Order	Family	Parasite or Predator	Countries
Pseudococcus nipae, Mask. ...	Homoptera	*Pseudaphycus utilis*, Timb. ...	Hymenoptera	Encyrtidae	Parasite	Hawaiian Islands
Eulecanium coryli, L.	Homoptera	*Blastothrix sericea*, Dalm. ...	Hymenoptera	Encyrtidae	Parasite	British Columbia
Asterolecanium variolosum, Ratz....	Homoptera	*Habrolepis dalmani*, West. ...	Hymenoptera	Encyrtidae	Parasite	New Zealand
Pseudococcus filamentosus, Ckll. ...	Homoptera	*Anagyrus dactylopii*, Haw. ...	Hymenoptera	Chalcididae	Parasite	Hawaiian Islands
Eriosoma lanigerum, Haus. ...	Homoptera	*Aphelinus mali*, Hald.	Hymenoptera	Aphelinidae	Parasite	New Zealand, etc.
Aleurocanthus spiniferus, Quaint.	Homoptera	*Prospaltella smithi*, Silv. ...	Hymenoptera	Aphelinidae	Parasite	Japan
Aleurocanthus woglumi, Ash. ...	Homoptera	*Eretmocerus serius*, Silv. ...	Hymenoptera	Aphelinidae	Parasite	Cuba
Pseudococcus gahani, Green ...	Homoptera	*Coccophagus gurneyi*, Comp. ...	Hymenoptera	Aphelinidae	Parasite	California
Gonipterus scutellatus, Gyll. ...	Coleoptera	*Anaphoidea nitens*, Gir.	Hymenoptera	Myrmaridae	Parasite	New Zealand
Levuana iridescens, B.-Bak. ...	Lepidoptera	*Ptychomyia remota*, Ald. ...	Diptera	Tachinidae	Parasite	Fiji Islands
Icerya purchasi, Mask.	Homoptera	*Rodolia cardinalis*, Muls. ...	Coleoptera	Coccinellidae	Predator	California, New Zealand, Japan, etc.
Aspidiotus destructor, Sign. ...	Homoptera	*Cryptognatha nodiceps*, Mshl. ...	Coleoptera	Coccinellidae	Predator	Fiji Islands
Perkinsiella saccharicida, Kirk. ...	Homoptera	*Cyrtorhinus mundulus*, Bredd. ...	Hemiptera	Miridae	Predator	Hawaiian Islands

Highly Beneficial Control.

Pest Plant	Beneficial Organisms	Order	Family	Countries
Opuntia inermis ...	*Cactoblastis cactorum*, Berg....	Lepidoptera	Pyralidae	Australia
	Wet rots			
	Dactylopius opuntiae, Ckll. ...	Homoptera	Coccidae	
	Tetranychus opuntiae, Banks	Acarina	Tetranych-idae	
	Chelinidea tabulata, Burm. ...	Hemiptera	Coreidae	
Opuntia stricta ...	*Cactoblastis cactorum*, Berg....	Lepidoptera	Pyralidae	Australia
	Wet rots			
Opuntia streptacantha	*Dactylopius opuntiae*, Ckll. ...	Homoptera	Coccidae	
Opuntia tomentosa ...	*Chelinidea tabulata*, Burm. ...	Hemiptera	Coreidae	
Opuntia monacantha	*Cactoblastis cactorum*, Berg. ...	Lepidoptera	Pyralidae	Australia
	Wet rots			
	Dactylopius opuntiae, Ckll. ...	Homoptera	Coccidae	
	Dactylopius ceylonicus, Green	Homoptera	Coccidae	
	Dactylopius confusus, Ckll. ...	Homoptera	Coccidae	
	Chelinidea tabulata, Burm. ...	Hemiptera	Coreidae	
Opuntia imbricata ...	*Dactylopius newsteadi*, Ckll.	Homoptera	Coccidae	Australia
Opuntia dillenii ...	*Cactoblastis cactorum*, Berg. ...	Lepidoptera	Pyralidae	New Caledonia
Opuntia dillenii ...	*Dactylopius ceylonicus*, Green	Homoptera	Coccidae	South India
Opuntia monacantha	*Dactylopius opuntiae*, Ckll. ...	Homoptera	Coccidae	Ceylon
Opuntia dillenii ...	*Dactylopius coccus*, Costa ...	Homoptera	Coccidae	Madagascar
Opuntia tuna ...	*Dactylopius opuntiae*, Ckll. ...	Homoptera	Coccidae	Mauritius
Lantana camara ...	*Crocidosema lantana*, Busck	Lepidoptera	Tortricidae	Hawaiian Islands
	Agromyza lantanae, Frogg. ...	Diptera	Agromyz-idae	
	Teleonemia lantanae, Dist. ...	Hemiptera	Tingitidae	
Clidemia hirta ...	*Liothrips urichi*, Karny ...	Thysano-ptera	Phloeo-thripidae	Fiji Islands