NEW TRENDS IN BIOLOGICAL CONTROL METHODS
(Natural enemies)

by

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1. INTRODUCTION OF NATURAL ENEMIES INTO NEW AREAS

Biological control of the sugar cane borer Diatraea saccharalis F. in Barbados has been attempted for about 40 years. It started in 1929 with a mass release of Trichogramma. The larval parasite Lixophaga diatraeae T.T. (Dipt. Tachinidae) was released in 1930, 1934, 1935 and 1948 to 1950. It did not become established apparently because of the low genetic diversity of the imported stocks and also because of the insufficient biomass of the parasite. An intensive release campaign started in 1958 and during five years over half a million Lixophaga flies from different Caribbean islands were colonized and released. The fly became established at a very low level. It was detected in 1967 in six plantations with an average parasitism of 10 percent. In 1968 it was found in 18 plantations with a parasitism up to 73 percent and in 1969 in 42 plantations with a parasitism up to 95 percent. It appears that multiple introductions of large numbers have created a greater probability for post-colonization selection. In 1966, the Braconid Apanteles flavipes Cam. was introduced from Asia, where no sugarcane borer of the genus Diatraea exists. The parasite became immediately established and the combined effect of this species with the tachinid Lixophaga was the reduction of the damage to a tolerable level (5 percent infested joints) (Alam, Bennett and Carl, 1971; Simmonds, 1972). In this example there is an efficient parasite, A. flavipes, which became established easily and rapidly; a colonizer with delayed success (McC. Callan, 1970), L. diatraeae, which had to be introduced many times and in great number; and finally an inefficient indigenous oophagous parasite, Trichogramma fasciatum Perk., which failed to produce tangible results although released by the millions (up to 300 million per year).

The history of biological control of insects includes cases of natural enemies which have colonized new areas much easier and more rapidly than A. flavipes, and others which have been incapable of adaptation to a new environment. The analysis of past biological control projects of the conventional type has shown that it is nearly impossible to predict how an introduced species will evolve in new areas. A complex of four parasitic species was introduced in 1966 into the U.S.A. for control of the cereal leaf beetle, Oulema melanoplus L. In this complex there was a gregarious larval parasite, Tetrastichus julis Walker, which plays a very minor role in Europe, at least in areas where samples were taken. Within two or three years this parasite became the most effective regulating factor of Oulema populations. Parasitism increased to 100 percent in some areas during the second host generation. A selection of one parasite in the Oulema native habitats would have indicated the Mymarid Anaphes flavipes Förster as the most suitable species for introduction. This would have resulted in less effective biological control. Another example concerns the coconut hispid Promecotheca cumingi Baly in Ceylon. Three parasites were introduced into the island against this coconut pest and, against expectations, Dimmockia javanica Ferr. proved to be effective rather than Pediobius parvulus Ferr., which had been extremely successful previously in Fiji (Dr. Dharmidakari, pers. comm.). It seems, therefore, very difficult to predict not only the development of an entomophagous species in a new environment, but also it is difficult to select the parasite(s) which is best adapted to new ecological conditions. This applies also to phytophagous species, used for instance for biological control of weeds. Before introducing a phytophagous agent for weed control in new areas careful tests are obviously made to assess host specificity. However, the procedure does not eliminate certain risks that are known from phytophagous pests. The leafminer Lithocolletis messanniella Zell. which attacks only Castanea and Quercus species in its native Mediterranean habitats, has become polyphagous when accidentally introduced into New Zealand (Delucchi, 1958).

From past experience it has, nevertheless, been possible to define some criteria which should be considered in programmes for the introduction of entomophagous organisms (DeBach, 1970; Simmonds, 1972). One of these criteria is that individuals to be colonized have great genetic diversity and originate from populations located in the centre of the distribution area where individuals are mostly heterozygous (Remington, 1968; Messenger and van den Bosch, 1971). The adaptability of an introduced entomophagous species is often determined by the qualities of the source population from which the culture is derived. Intraspecific crossings have already shown to improve the degree of adaptability in natural enemies. A good procedure might also be the immediate release upon introduction of part of the material, without culturing under laboratory conditions, in order to avoid a supplementary man-made selection.

Another important criteria is to colonize and release the whole parasitic complex regardless of possible interspecific competition in the new area of introduction. Experience has shown that competitive displacement is not detrimental in biological control, since the most effective species will produce better host population regulation (DeBach, 1970). It is essential to colonize and release repeatedly a large number of individuals of each species, obtained from several populations.

An additional criteria concerns the host spectrum. A. flavipes is a parasite of stem borers in southeast Asia. It was introduced into the Caribbean islands against Diatraea and has become an extremely effective biological control agent against the borer. Thus, attention has to be paid to host species closely related to the target pest. These host species might offer a key to a more effective biological control. Because ecological research is long-term and phytosanitary problems need urgent solutions, it is suggested that only a minimum of information should be assembled prior to natural enemy introductions. This has often been done in the past and the results of this procedure are well known. Research on population ecology and on genetics of colonizing species should receive more attention, but should not reduce the efficiency of current procedures (DeBach, 1970; Simmonds, 1972).

2. PERIODIC RELEASE OF NATURAL ENEMIES

Although natural enemies often play a very important role in regulating insect populations, they do not always prevent them from reaching levels at which there is economic damage. One way of augmenting the effectiveness of natural enemies is their periodic colonization. The technique of periodic insect releases has often been considered in biological control, but has been used in relatively few cases on a commercial scale, except in California. One element of major importance is the mass-rearing of both the natural enemy and, for the time being, a suitable host. The mass-rearing must be cheap enough to make the control technique competitive with others. Another element of equal importance is the selection of the species which have a high potential of success in inundative release programmes. Species are favoured which are not limited in their increase by natural factors of the environment and use their searching ability where the prey is located (Ridgway, 1969).

A noteworthy example of an inundative release concerns the mass-reared lacewing Chrysopa carnea Steph. which has been used in Texas against Heliothis in cotton fields. Two releases in one acre totalling 292 000 Chrysopa larvae per acre (73 larvae/m^2) reduced a Heliothis population of 18 000 individuals by 96 percent and tripled the cotton yield (Ridgway and Jones, 1969; Ridgway, 1969). Another example concerns the periodic release of the Braconid parasite Opius concolor Sz. against the olive fly, Dacus oleae Gmel., in Sicily and adjacent islands. The most significant experiment was performed in 1966 and 1967 in a rather isolated area of 2 800 ha near Palermo with about 300 000 olive trees. The first release of Opius was made when the threshold of 10 percent olive infestation was exceeded and release was continued until October. By the end of the season a total of about 30 (1966) to 100 (1967) mass-reared Opius per tree had been released. The results obtained were very satisfactory, particularly in 1967, as fruits remained at the tree until maturity, i.e. two to three months longer than in untreated neighbouring areas. It is interesting to note that in both experiments a comparison was made with chemically treated plots. The cost of production of natural enemies, which appeared 10 years ago to be a critical factor for the development of the technique (DeBach and Hagen, 1964), has been considerably lowered and the technique may compete today with chemical control. To control Heliothis on cotton with conventional insecticides the Texas farmer often spends (1968) US$ 65 to 125 per ha, whereas the same immediate effect by releasing green lacewings was obtained with US$ 15 per ha (Ridgway, 1969). The results achieved by releasing Opius against the olive fly were compared with those obtained by two chemical aerial sprays in the same conditions. The estimated costs of periodical inundative releases were 65 percent of those for chemical treatments (Monastero and Delanoue, 1966). Rearing and releasing techniques can be further improved and costs further reduced. This appears particularly true in the case of Opius, of which the most (medfly) was cultured on a rather expensive diet and for which big investments were made for a short period of time. A joint project for the autocidal control of the medfly and for the mass-rearing of Opius in the same area would considerably reduce operational costs. The mass-rearing of parasites is by far more complicated, and in general more expensive, than that of predators which can be released at an earlier developmental stage. However, they both rely on the existence of a mass-rearing technique for a host and this remains the most costly part of the technique (Ridgway, Morrison and Bradgley, 1970). Experiments have already been undertaken to replace the host with artificial diet and substantial progress has been made with Chrysopa (Vanderzant, 1969). Parasites have also been successfully reared on synthetic diet (Yazgan and House, 1970), but the induction of oviposition still implies the use of a host, even in the case of ectoparasitic species (J.R. Raulston, USDA, personal communication). The replacement of the host by an artificial one might result in sufficiently reduced cost to make the technique economically feasible, especially for pupal (Arthur et al., 1969) or for oophagous parasites.

The validity of the technique of periodic release of organisms for biological control under field conditions has been assessed for orchard pests, such as diaspine scales, mealybugs (DeBach and Hagen, 1964) and tortricids (Fedorintchik, 1970). The classical example is certainly the periodic release of Cryptolaemus montrouzieri Muls. (Col.:Coccinellidae) against Pseudococcus species attacking citrus in California, which started on a large scale in the 1920's and reached a peak some years later with the production and distribution of 40 million beetles per year (10 beetles/tree released). Releases are continuing, particularly in those orchards in which the biological balance has been upset by pesticide treatments. However, examples like this are unique and plans for periodic release of natural enemies too often do not go beyond the experimental phase. It is difficult to believe that the economic aspect is the only obstacle to the large scale application of the technique. As compared with chemical methods, which are also periodically applied, periodic releases of parasites and predators are handicapped by the fact that they deal with living organisms, which present many inconveniences, even if used under particularly favourable conditions as in glasshouses. The value of Encarsia formosa Grahan (Hym. Encyrtidae) against the white fly, Trialeurodes varporariorum Westw. was recognized before World War II. A mass-rearing technique was developed at an experiment station in England, which produced and distributed 1.5 million parasites every year (Hussey, Read and Hesling, 1969). The technique was nearly abandoned when DDT arrived. After this first attempt other natural enemies were used with success in periodic release programmes. The most important of these was the use of predatory mites against phytophagous mites in many parts of the world. In the U.S.S.R. it has been estimated that for each rouble invested in treatments of winter glasshouses with Phytoseiulus, a return from 9.5 to 14 roubles was realized, with a maximum of 32.5 roubles under certain conditions (Begliarov, 1970). Similar prospects are known for other mites. There are also proposals for the use of other interesting natural enemies, like Diaeretiella rapae M'Int. (Hym. Aphidiidae) against the aphid Myzus persicae Sulz., which has developed pesticide resistance (Lyon, 1970). Despite the favourable environment which a glasshouse offers to the application of biological control strategies, it appears that the periodic release of natural enemies can be applied on a commercial basis (i.e. by private industry) only under certain conditions. Like insecticides, the technique is applicable only in areas where the market is sufficiently large to permit mass-rearings on an industrial basis. When the market is too small, the industry cannot afford to maintain large stocks of natural enemies to meet a variable demand. The consequence is that the user is no longer interested in a technique which does not satisfy his needs. Under European conditions there are additional difficulties with customs formalities and shipments are often lost. As the price of natural enemies for a periodic release can be set as high as the cost of a chemical application, there is not a problem of profit, but of organization. In Switzerland private industry plans to discontinue in 1973 the supply of predatory mites after about eight years culturing.

3. MANIPULATION OF THE ENVIRONMENT WITHOUT CHANGING CULTURAL PRACTICES

The third approach in classical biological control is the manipulation of the environment to increase the efficiency of existing natural enemies without changing cultural methods. The development of modern agriculture has greatly modified the relationship between organisms. Certain pests have become less important and new pests have appeared. The factors responsible for these changes are not always the same. It happens that sometimes the efficiency of natural enemies has decreased and that a relatively small effort is needed to re-establish a situation economically favourable to man. There are two main aspects involved here, i.e. the quality of the environment and the technique to be applied.

Floral diversity is an important ecological aspect in biological control. This diversity provides food, shelter and supports alternate hosts for entomophagous species. Many authors have observed the role of non-crop plants as a food source (pollen, nectar and honeydew) for natural enemies. On the basis of these observations some diversity has been introduced into existing agroecosystems. By sowing Anethum graveolens (Umbell.) in Ukrainian beet fields, the percentage parasitism of Gnorimoschema ocellata Boyd by the Tachinid Catharosia pygmaea Fall. has been increased from 4.4 - 7.5 percent to 81 - 99 percent (Diadetchko, 1970). Additional examples from the U.S.S.R. and other countries are cited by DeBach and Hagen (1964), Wilson (1966), Lawson (1970) and Biliotti (1972). The non-crop plants may be an indispensable source of alternate hosts for the development of pre-imaginal stages of natural enemies instead of food for the adults. The efficiency of the Mymarid Anagrus epos Girault which attacks the grape leafhopper Erythroneura elegantula Osborn in California depends on a non-economic leafhopper, Dikrella cruentata Gill. for survival during the winter (Doutt, 1967). Dikrella develops on Rubus and interplanting of this species in vineyards creates the necessary diversification for success of the parasite. The importance of non-crop species has also been demonstrated for natural enemies of the olive fly

Mediterranean areas and of other pests under monocultural conditions. In many cases the lack of an adequate food source or of an alternate host goes together with the lack of natural refuges. The manipulation of the environment through diversification by means of non-economic crops may present certain disadvantages. One of these is the re-sowing of the non-economic crop. Another is the need to synchronize the plant development with a life stage of natural enemies. An additional disadvantage is of an ecological nature; in fact, it is today still uncertain whether additional natural food sources and shelters are more advantageous to natural enemies or to pests (Hagen, 1970). Therefore, efforts are being made to use artificial components which have selective action. A sucrose solution sprayed on maize under field conditions is attractive to coccinellids and chrysopids and the population of _Rhopalosiphum maidis_ Fitch on these treated plants is correspondingly reduced (Schiefelbein and Chiang, 1966). Research on the mass-rearing of _Chrysopa carnea_ Steph. has shown that a mixture of enzymatic protein hydrolysate of brewers' yeast with sugar and water greatly stimulates oogenesis and has an effect comparable to that produced by honeydew of citrus mealybugs, or even greater (Hagen and Tarsan, 1966). Sprayed at given intervals on alfalfa fields for five years in California, the mixture gave very encouraging results: the artificial food attracted _C. carnea_ and induced the predator to deposit over three times the number of eggs as observed in untreated fields. In addition, other predators were attracted (Syrphids) or stimulated in their fecundity (Coccinellids) or arrested at the food (predatory _Collops_ beetles). In cotton fields the mixture could not be sprayed on plants because of its toxicity, but was successfully used by placing it on wax paper sheets supported on stakes which acted as feeding stations (Hagen, Sawall and Tassan, 1970). Later a non-phytotoxic mixture was prepared by replacing the brewers' yeast hydrolysate with a similar inexpensive product obtained from the dairy industry. When oviposition is induced early enough in the season and the predator population density is not too low, aphids in alfalfa and _Heliothis_ in cotton are prevented from attaining economic levels. The increased population of natural enemies has then to be maintained by providing adequate artificial shelters. This has been accomplished for _Semiadalia undecimnotata_ Schneid. in overwintering places (Iperti, 1966; Hodek, 1970), _Formica rufa_ L. in forests, _Polistes_ wasps in tobacco fields (Rabb, 1969; Lawson, 1970) and _Cryptolaemus_ in orchards. A combination of release of _Chrysopa_ early in the season and of food application to increase fecundity might also prove to be feasible over large areas (Hagen, 1970). It is essential that natural enemy populations are capable of increasing before pests become abundant.

However, regulation of organism populations through modification of the environment may be much more complex. It has often been observed that the decline of populations of natural enemies follows the regression of those of the host and that a subsequent increase of the host does not result in a substantial increase of the natural enemies. A similar situation can be observed in temperate zones between autumn and spring. Various factors may be responsible for this fact, such as a limited searching capacity of the parasite or predator, or the lack of coincidence between them and the host. _Trichogramma_ (Hym.) is incapable of finding _Pieris rapae_ eggs in Brassica fields when the density is below one egg/plant. This density is therefore needed to support a parasite population under field conditions. Thus, when the host density is too low early in the spring and the parasite is present in the field, it might be advantageous to raise the host density in order to increase the efficiency of the parasite. Experiments carried out in Missouri, U.S.A., along these lines did not produce the expected results; although the host density was artificially increased by 4.5 times as compared with check plots, the parasite did not increase sufficiently during the first host generation to keep the pest under economic control (Parker, Lawson and Pinnel, 1971). In further experiments, parasites _and_ the host were released at the beginning of the season and the combined effect was a reduction of 95 percent of the host during the first generation. As a practical result, a marketable crop of cabbage was produced in the experimental area, compared with none in the check plots. Additional experiments confirmed that parasites can effectively keep the pest under the economic injury level if populations of both host and parasite are present at effective levels early in the season. The release of the host alone increases the pest density to such a level that the action of the parasite is too slow to achieve economic control. The release of the parasite alone reduces the pest population to such a low level that the parasite population is also reduced, resulting in the need for further parasite releases. For parasitic species which are efficient at high densities of a host with overlapping generations, this approach in pest control may be the key solution. The idea is not new, as the technique has already been suggested against the cyclamen mite, *Steneotarsonemus pallidus* Banks in California by artificially inoculating strawberry fields with *Typhlodromus* sp. and the pest (Huffaker and Kennett, 1956).

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