BIOLOGICAL CONTROL OF INSECT PESTS IN ALFALFA HAY

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Abstract: Certain native and introduced insect complexes associated with alfalfa hay fields in California provided the bases for the development of two important concepts of pest control which involve biological control. The endemic *Colias-Cotesia* system generated the concept of "Supervised Control" by A. E. Michelbacher and Ray F. Smith, and the spotted alfalfa aphid-predator system sparked the "Integrated Control" concept by Stern et al. (1959). Many native natural enemies adapted to attacking the fauna in the alfalfa habitat and helped to control the three exotic aphids that invaded alfalfa hay fields. The introduction of *Bathyplectes curculionis* from Europe spectacularly controlled the *Hypera postica* populations that invaded the middle coastal valleys during the early 1930's. The introduction of *Aphidius smithi* from India had an impact on reducing pea aphid populations in California and rapidly spread across North America, but now it plays a lesser role than *A. ervi* an Old World species which attacks both pea aphid and blue alfalfa aphid. Three introduced parasitic wasp species became established against the spotted alfalfa aphid (SAA) and began to have an impact on reducing SAA; however, the rarity of SAA since the 1960's is because of planting resistant cultivars of alfalfa to SAA. All insect pests of alfalfa hay except for the Egyptian alfalfa weevil are usually held under control in California by natural enemies and host plant resistance. Presently the Egyptian alfalfa weevil is the main target of the University's biological control group at Berkeley/Albany.

Keywords: Biological control, supervised control, integrated control, alfalfa butterfly pea aphid, blue alfalfa aphid, spotted alfalfa aphid, alfalfa weevils, parasitoids, predators and pathogens.

INTRODUCTION

Alfalfa has not only been one of the most important agricultural crops to man but it has served as an inspiring field laboratory for entomologists. The occurrence of various insect complexes associated with alfalfa hay led to significant developments in the strategies and tactics employed today in pest control, supervised control and integrated control have all been advanced and some of these concepts were conceived through the attempts to control insects in western hay fields.

The introduction of alfalfa to the New World led to the development here of many new ecological associations among the plant, its insect herbivores and their predators and parasites. In the Nearctic region, many native insects quickly adapted to alfalfa as a new host plant. Fortunately many of the native natural enemies followed their natural hosts and prey insects into the new alfalfa habitat. Also many endemic predaceous insects pounced on the newly introduced exotic pests that invaded the New World from the Old World. The three tactics of applied biological control (classical, augmentation, conservation) have been put into practice in alfalfa hay fields, as well as the integration of biological control with chemical control and host plant resistance.

ORIGINS OF MAJOR ALFALFA INSECT PESTS IN NORTH AMERICA

The first reports of insect damage to the newly planted alfalfa hay fields in North America were made in the late 1800's. In the Midwest grasshoppers and armyworms were the only insect pests mentioned by Coburn (1908). In the Southwest and California, it was the damage of the alfalfa caterpillar, *Colias eurytheme* Boisduval, that was first reported (Wildermuth 1914). Then came exotic pests from the Old World. The pea aphid, *Acyrthosiphum pisum* (Harris), was reported damaging peas at the turn of the century, but it was not considered a pest of alfalfa until the middle 1920's (Campbell 1926). The alfalfa weevil *Hypera postica* Gyllenhal, an Old World species, was first discovered in the United States near Salt Lake City in 1904 and spread to middle coastal California by 1932 (Essig

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and Michelbacher 1933). In 1951 there was another introduction of H. postica which became established and spread in the eastern United States (Bronson and Coles 1968, Day 1981). Furthermore another species or at least a distinct biotype, the Egyptian alfalfa weevil, H. brunneipennis (Boh.), appeared in Arizona in the middle 1930's and spread into California in the 1950's reaching the Central Valley by the middle 1960's (Clancy 1969, van den Bosch and Marble 1971). Besides the pea aphid, two more exotic Old World aphid species invaded North American alfalfa fields. The spotted alfalfa aphid (SAA), Therioaphis maculata (Bruckton), invaded the New World through southwestern United States in the early 1950's and swept through California (Smith 1959) and through most of the United States in the 1960's (Angalet 1970). The latest exotic aphid to be accidentally introduced into North America was the blue alfalfa aphid A. kondoi Shinji. It was discovered in California in 1975. This Old World species spread eastward from California beyond Kansas; southward to Argentina and northward into Oregon by the late 1970's (Gonzalez et al. 1978). A leafmining fly Agromyza frontella (Rondani), a little known fly in Europe invaded the northeastern United States in 1969, and by 1972 it was causing damage to alfalfa hay in several NE states (USDA Coop. Econ. Insect Rep. 1972, 22: 132-137).

From the preceding discussion it is clear that there are two main sets of alfalfa pests in California: those that are native and those that are introduced. The difference between these two groups is very important for applied biological control. Thus the ten or so herbivorous species that are native to California or North America that can become abundant enough to cause damage are often controlled by their native natural enemies, therefore, they are usually under natural biological control. The accidentally introduced exotic insects usually arrive without their natural enemies and are often chronic pests like the weevils. In some cases, as with the introduced aphids, our native insect predators and fungus pathogens can often control them. However, to control exotic introduced insect pests of alfalfa, it is usually necessary to explore Old World alfalfa fields in regions of matching climate to find the more specific natural enemies for importation and release against target pests. This classical biological control tactic has been successful in restoring old natural associations of herbivores and their natural enemies for at least six introduced pest species.

ALFALFA INSECT PESTS AND THEIR NATURAL ENEMIES

A case by case examination of noteworthy insect pests of western alfalfa fields reveals how natural and applied biological control have reduced the impact of many past and potential insect pests. The natural enemies responsible for reducing the frequency of outbreaks in time and space of once major insect pests of alfalfa have been reviewed by Hagen et al. 1971, 1976, App and Manglitz 1972, Clausen 1978, Luck 1981, Van Driesche and Peters 1987. These pests belong to the following groups: lepidoptera, aphids, weevils and leafminers.

Alfalfa caterpillar. Colias eurytheme occurs across North America. It spread eastward as new alfalfa fields were cultivated, coming originally from native clovers (Smith and Allen 1954). In California, it is most commonly found in the Central Valley and southward into Mexico. If it were not for the native Cotesia medicaginis Muesebeck, a braconid parasitoid formerly placed in the genus Apanteles which is a specific parasitoid of C. eurytheme. Central Valley farmers would have had to pay millions of dollars more to control this pest. Michelbacher and Smith (1943) discovered among the natural factors that limited the abundance of the alfalfa caterpillar was C. medicaginis. This wasp deposits a single egg into either a first, second or third instar of the caterpillar and kills the host larva when parasitoid larva emerges from third or fourth instar caterpillars (Smith et al. 1945, Smith and Allen 1954, Allen 1958). Since this solitary endoparasitoid destroys the caterpillar while it is small, very little alfalfa hay is eaten. Thus during warm weather, the Cotesia can control the alfalfa caterpillar within a cutting period, and by dissecting caterpillars taken by a sweep net, one can predict how many larvae will become large. If ten caterpillars are not parasitized per one net sweep, they will become large and cause severe defoliation; thus an entomologist can predict the potential damage and alert the grower who then makes the decision how he wants to control the potential outbreak. As far back as 1943, Michelbacher and Smith stated that the choice of insecticide should be one that killed the caterpillar and not the parasite.

The establishment of an economic level of the alfalfa caterpillar, coupled with a simple parasite sampling technique, set the stage for the development of supervised control. In 1946 Ray Smith persuaded a group of alfalfa growers in the Dos Palos area of California to hire an entomologist for the summer to follow alfalfa caterpillar and Cotesia populations, (and) to advise the growers of impending damage to their specific fields and to give a prescription for control. The author was the first supervised control entomologist hired in California, and he alone was able to monitor over 10,000 acres of alfalfa during one summer. Later the supervised control system developed by Smith and Michelbacher evolved into the present situation in which pest control advisors promote the integrated control approach in many crops worldwide.

Reasons for the lack of control of the alfalfa caterpiller by C. medicaginis in certain Central Valley fields or in different cuttings is discussed by Allen and Smith (1958). When C. medicaginis fails to find infested fields and the Colias populations are beginning to cause damage, often a wilt disease epizootic is induced in the caterpillars and can prevent them from causing extensive damage. This "wilt disease" is an apparently native polyhedrosis virus and was reported by Wildermuth 1914 in the Southwest, by Dean and Smith (1935) in the Midwest, and by Michelbacher and Smith (1943) in the Central Valley of California. In southern California C. eurytheme is often controlled by a native egg parasitoid, Trichogramma semifumatum (Perkins) (Stern and Bowen 1963).

Colias philodice Godart is the most widely distributed species of the genus Colias in North America. It is found south of the tree-line in Alaska and is limited southward by desert areas in the West, by warm humid climates of the Gulf Coast and southern Atlantic coast states. In California it occurs north of the Central Valley (Hovanitz 1950). It originally was associated with red clovers and their larvae do not find alfalfa as suitable a food as C. eurytheme (Hovanitz 1948).

Both C. eurytheme and C. philodice occur in the same alfalfa fields in Siskiyou and Lassen counties of California. Cotesia flavico nchae Riley is a gregarious endoparasitoid of large larvae of C. philodice in eastern United States. During the 1950's an attempt was made to introduce this parasitoid into California. It was cultured successfully on C. eurytheme in the Albany insectary and released in the Central Valley. It developed at least one generation in the field but then disappeared. A survey of Colias parasitism in extreme northern California revealed that both Colias species were present and both Cotesia spp. were present. Thus it appears that either the host or climate limits the existence of C. flaviconchae in the Central Valley of California (Hagen, unpublished data).

Armyworms, Spodoptera spp. The western yellow-striped armyworm, S. praefica (Grote), is native to Western North America. It has a wide range of host plants including alfalfa which suffers periodic outbreaks from larval feeding. Generalist predators: chrysopid larvae, three Geocoris spp., two Nabis spp., Collops adults and Lygus hesperus Knight accounted for most of the mortality that occurred during the egg-small larval age interval based on a partial age-specific life table studies conducted in alfalfa hay fields near Davis, California (Bisabri-Ershadi and Ehler 1981). Parasitism of S. praefica larvae was generally low and involved five parasitoid species which are all generalists in their host selection. The two most common parasitoids were Hyposoter exiguae (Viereck) and Cotesia marginiventris (Cresson) (Miller and Ehler 1978). Here again we have a native moth shifting to alfalfa and kept relatively in check by native natural enemies.

Beet armyworm, Spodoptera exigua (Hbn.). Detailed studies on the natural biological control of the beet armyworm populations in alfalfa hay fields apparently have not been conducted. However, since this armyworm biology is similar to that of the yellow-striped armyworm, the natural enemies present would probably have the same influence on control of the beet armyworm. Eleven species of parasitoids listed as attacking the beet armyworm in cotton are among the 13 species attacking S. praefica larvae in cotton (van den Bosch and Hagen 1966) and include the five generalist parasitoids listed as attacking S. praefica in alfalfa. Again a generalist native armyworm is often held under treatment levels in alfalfa by native natural enemies. The same natural enemy complexes are probably operating against other native lepidopterous pests such as cutworms and webworms in the alfalfa system.

Aphids. The three most important aphid pests of alfalfa in the New World are the pea aphid, blue alfalfa aphid and the spotted alfalfa aphid. These aphids were all accidentally introduced from the Old World. Aphids in general attain outbreak proportions if their natural enemies are insufficiently present or differentially hindered by climatic conditions, agricultural practices or asynchrony between aphid and natural enemy phenologies. The impact of natural enemies on aphids is reviewed by Hodek (1966, 86), Hagen and van den Bosch (1968), Hagen et al. (1976), Carver (1989) and Hughes (1989). The role of predators on aphid abundance has been recently reviewed by Minks and Harrewijn (1988) and Frazer (1988); the role of parasitoids on aphid abundance is reviewed by Stary (1988a,b) and the impact of pathogens on aphids is reviewed by Latgé and Papierok (1988).

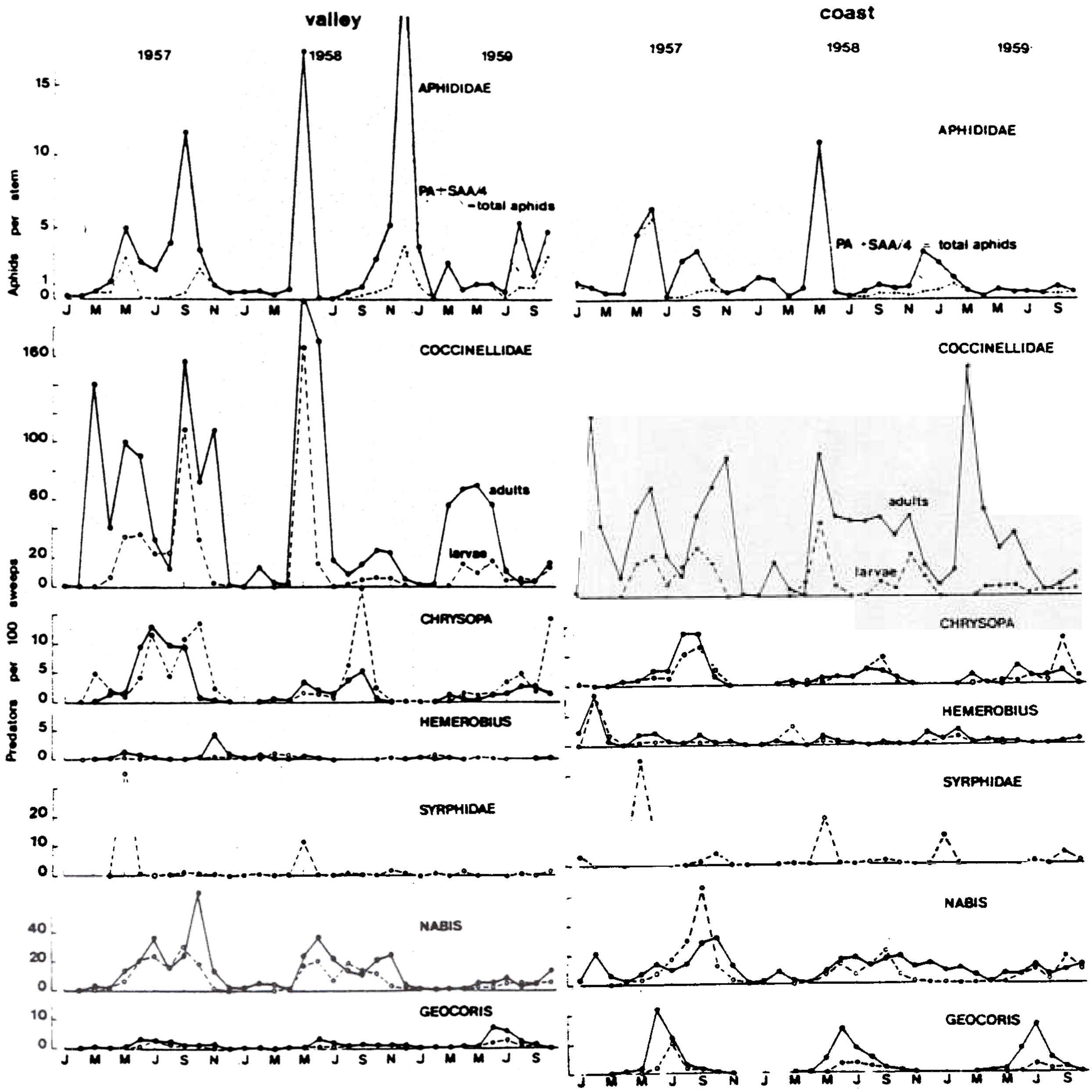

Fig. 1. Phenologies of aphids and their predators in the Central Valley and coastal valleys of California. Black circles represent adults (except for Chrysoperla, where only gravid adults are shown). White circles indicate immature stages. Number of aphids is expressed in terms of biomass units (4 SAA = 1 PA). From Neuenschwander et al. (1975).

Pea Aphid. Acyrthosiphon pisum (PA) is not a chronic pest of alfalfa hay. From studies made in the Central Valley and coastal valleys in California in the late 1950's the pea aphid was controlled mainly by native predators during the spring and fall (Smith and Hagen 1959, 1966; Neuenschwander et al. 1975). It appears from these studies that it was the whole predator complex (Fig. 1) in both the Central Valley and coastal valley fields that kept both the PA and SAA populations below economic thresholds during the spring and fall of our three year study (1957-1959). These studies were made before any introduced parasitoids or aphid host plant resistant varieties occurred widely.

The most abundant predators were coccinellid beetles, and in both coastal and Central Valley alfalfa fields, Hippodamia convergens Guerin and H. quinquesignata ambigua Le Conte were the most common species present. Coccinella californica Mannerheim only occurred in California's coastal fields (Smith and Hagen 1966), while in British Columbia alfalfa fields C. californica is the most abundant species feeding on PA (Baumgaertner et al. 1981). The above Hippodamia spp. are facultative in their diapause response to low temperatures and short photoperiods and can remain reproductively active if there are ample aphids and the temperature is warm enough (Hagen 1974). In eastern and midwestern U.S. an introduced C. septempunctata is becoming widely established (Obrycki et al. 1987), and it will have an impact on a variety of aphid species including PA in alfalfa.

The green lacewings which were primarily Chrysoperla carnea (Stephens) as adults are not predaceous and must ingest some protein for egg production. A common source of protein is in honeydew excreted by Homoptera or in pollen. It requires about eight aphids per stem to have enough honeydew to attract the adults and lay eggs (Hagen 1976). Thus by spraying artificial honeydew, a high aphid population density is simulated and C. carnea can be attracted and oviposit even when aphid populations are low, providing evening temperatures are warm enough for the lacewings to be active (Hagen et al. 1970). Even though C. carnea larvae appear in rather high aphid populations (Fig. 1), they can be sustained because they are general predators and can be present when the coccinellid adults have dispersed.

The brown lacewings, Hemerobius spp., (Fig. 1) were in greater abundance in coastal fields than in the Central Valley since they can develop at lower temperatures than any of the other predators, but cannot tolerate high summer temperatures. Syrphid larvae occur only at the time of aphid peaks (Fig. 1).

The heteropterous predators (Fig. 1) represented by two Nabis spp. and three Geocoris spp. apparently can play an important role when the aphid populations are low and are sustained by feeding somewhat on plants.

During our three year study fungi played a minor role in controlling both PA and SAA, and the fungal pathogens appeared in only some of the highest peaks of aphids, but today apparently the fungus Erynia neoaphidis can cause mortality of PA even when the populations are at low densities (Pickering and Gutierrez 1990).

Parasitization of the pea aphid prior to the introduction of Aphidius smithi Sharma and Rao was negligible (Smith and Hagen 1966, Neuenschwander et al. 1976). But by 1960 A. smithi introduced from India was becoming widespread in California (Hagen and Schlinger 1960). During the late 1960's and 1970's PA outbreaks did occur in the Central Valley during midsummer, but only on solid-cut alfalfa fields. If the alfalfa is strip cut (Stern 1981), giving habitat continuity, A. smithi survives sufficiently and controlled the PA (van den Bosch et al. 1967). Aphidius smithi became widely distributed in North and South America, but during the late 1960's the parasitoid declined in abundance in eastern North America and in western North America during the mid-1970's (Kambhampati and Mackauer 1988). The introduction of Aphidius ervi Haliday which attacks both PA and blue alfalfa aphid may have had some influence on the decreased abundance of A. smithi. The author still finds A. smithi attacking PA on alfalfa and bur-clover at Albany, CA.

Blue Alfalfa Aphid. Acyrthosiphon kondoi became a greater pest of alfalfa hay during the winter and spring than the PA. It has a lower temperature for development than the PA (Kodet et al. 1982); therefore, it was more immune to the attack by our native natural enemies whose temperature thresholds for development and reproduction are all higher except for the brown lacewings. Fortunately the introduction of Aphidius ervi from several widely separated climatic regions in the Old World has helped to control the blue alfalfa aphid

(Gonzalez et al. 1978, 1990). This aphid becomes scarce in Central Valley alfalfa fields during the summer. The lethal temperature for this aphid is 30°C (Kodet et al. 1982).

Gutierrez et al. (1990) evaluated the interactions of natural enemies and dominant herbivores found in alfalfa near Fresno, CA. between March 2, 1977 and February 15, 1978. By using time-varying life table simulation methods involving the interactions between PA, blue alfalfa aphid, their natural enemies and the Egyptian alfalfa weevil, the results generated by the simulations fit the observations made in the field.

Spotted Alfalfa Aphid (SAA). Therioaphis maculata was a devastating pest of alfalfa in the New World during the late 1950's and early 1960's. With the development of resistant alfalfa cultivars to SAA the aphids became scarce. However during its early invasion into California our native predaceous insects played an important role in controlling SAA during the spring and fall in Central Valley and coastal alfalfa fields (Fig. 1). The same coccinellids that prey upon pea aphids also ate SAA, but one female H. convergens has to eat four times more SAA than PA to produce a batch of eggs; she must ingest about 100 mg live weight of aphids to produce the first batch of eggs (Hagen and Sluss 1966). When the aphid populations are reduced below one aphid per stem, the coccinellids disperse and the SAA now can quickly increase during the summer cuttings because of lack of sufficient predators. By changing the aphid/coccinellid ratio after an aphid crash and at the beginning of an SAA resurgence in the early summer control of SAA can be achieved. If a selective insecticide that kills aphids and not predators is applied and if favorable aphid/predator ratios are restored and the predators reproduce, the SAA populations will be reduced. This numerical response of predators to aphids results in control of the aphids and reduces the need for repeated insecticide treatments. If broad spectrum insecticides are used the natural enemies are also killed and cannot respond in time to stop the pest increase requiring additional insecticide treatment. The approach of integrating chemical control with biological control resulted in developing the integrated control concept (Stern et al. 1959).

If the SAA resistant cultivars of alfalfa had not been developed, the SAA problem would have been reduced in time because of the introduction of three parasitoids from the Old World. The first introductions began in the middle 1950's in southern California. Aphelinus asychis Walker, Praon exsoletum (Nees) and Trioxys complanatus Quilis all became established in California and began reducing SAA during the summer cuttings in southern California (van den Bosch et al. 1959). Today if susceptible alfalfa cultivars are planted both the SAA and Trioxys soon appear. Also in Australia where SAA also invaded and caused much damage to susceptible cultivars, SAA was brought under control by the introduction of the above parasitoids with T. complanatus being the most important natural enemy causing the SAA decline from over 100 SAA/stem in 1979 to less than 10/stem in 1984 (Hughes 1989).

Alfalfa Weevil. Hypera postica invaded eastern California from the Old World via Utah in the early 1920's and reached the Central Valley in the 1930's and was strikingly controlled in middle coastal valleys of California by the introduction of Bathyplectes curculionis (Thomson) which originally came from Italy and Switzerland (Michelbacher 1943). This ichneumonid wasp is a solitary endoparasitoid of weevil larvae and was first introduced into Utah, but in Utah the control of H. postica by the wasp is not very satisfactory, perhaps because of climate and hyperparasitoids (Davis 1976). The fantastic control that occurred in the middle California coastal region because of a more moderate climate is masked today because of the invasion of the Egyptian alfalfa weevil, which has a much more broader tolerance to climatic extremes compared to the original H. postica biotype.

In 1959, the USDA began importing and releasing natural enemies against a biotype of H. postica that invaded northeastern United States in the early 1950's. During six years of introductions from Europe, ten parasitoids and one predator were involved and, of those, five parasitic wasps became established and two more were discovered already here. This complex of parasitoids caused an average net weevil mortality of 70% per generation, and this reduced the weevil populations below economic threshold levels without the use of insecticides from 1968 to date (Day 1981). The main parasitoids involved were an egg parasitoid Patasson luna (Girault), three larval parasitoids: B. curculionis, B. anurus (Thompson) and Tetrastichus incertus (Ratzeburg) and two parasitoids of adult weevils: Microctonus aethiopoides Loan and M. colesi Drea. These parasitoids and coupled probably with some predators (Barney and Armbrust 1981) have saved farmers and consumers nearly eight million dollars a year since 1968 (Day 1981).

Egyptian Alfalfa Weevil. Hypera brunneipennis has not yet come under any significant biological control since its invasion into southwestern United States and California, even though there has been much energy devoted to controlling it biologically (van den Bosch et al., 1959, 1971; Clancy 1969; Hagen 1971; Gonzalez et al. 1980). The original B. curculionis from Utah, which was so effective in controlling the H. postica in California in the 1930's readily attacked the Egyptian alfalfa weevil larvae but their eggs became encapsulated (van den Bosch et al. 1971). Therefore, further exploration, particularly in the Middle East, for parasitoids was conducted and van den Bosch (1964) found no encapsulation of B. curculionis eggs in H. brunneipennis. B. anurus was collected in Iran and introduced into California in 1971 (van den Bosch et al. 1971) and importations were continuing to be made from the Middle East into the 1980's (Gonzalez et al. 1980).

With the tremendous biological control success of H. postica in eastern United States, the USDA APHIS agency began a program of collecting the established parasitoids in the east and releasing them into western United States during the 1980's. There were five different parasitic wasp species released in cooperation with the Division of Biological Control at U.C. Berkeley/Albany. Even though there were records of establishment of B. curculionis, B. anurus, M. aethiopoides and Tetrastichus incertus prior and after APHIS releases of parasitoids, only B. curculionis and T. incertus were permanently established by 1985 according to L. Etzel (U.C. Albany researcher). According to L. Etzel, during years when the peak weevil population is delayed by cool temperatures, B. curculionis appears to be more effective, by by itself is generally unable to suppress the weevil populations below the economic threshold. Bathyplectes anurus has become established recently at two sites in the Central Valley; however, at this time it is only found at very low levels. Microctonus aethiopoides is well-established and abundant in bur-clover rangeland in Glenn County, but has not yet become established in the Central Valley.

We are optimistic that the Egyptian alfalfa weevil will be controlled biologically in the future in California if the research is supported. With the biological control of this weevil, far less insecticides will be used on alfalfa hay and the hay fields will be the major field insectaries for natural enemies of not only insect pests of alfalfa, but for most of the surrounding crops.

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