1895

CHAPTER 5

Where Are the Exotic Insect Threats?

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I. INTRODUCTION

The past is prologue. Any speculation regarding geographic sources of potential pest arthropods from abroad should begin with the excellent summarization of the past record, as presented by Sailer (1978). It is abundantly clear that the immigrant arthropod fauna now present in North America originated for the most

ISBN 0-12-757880-3

part in the western Palearctic Region (Europe and the Mediterranean Basin). The same generalization holds for the complex of agriculturally important species. Next in importance, numerically, are the Orient (South Asia) and the eastern Palearctic (north Asia). South and Central America, Africa (the Sahara and southward), Australia and the outlying major islands, and the remainder of the earth's land surfaces have contributed much less generously to our immigrant fauna.

The reasons for the disparate source pattern are varied, but understandable, as analyzed by Sailer (Chapter 2, this volume). Quite obviously, as evidenced by the changes in the kinds of immigrants over time, the situation is fluid and likely to continue so for the foreseeable future. The "saturation point" for the arthropod fauna of North America is surely many eons away. Several factors suggest that although the general pattern of immigration may continue, some adjustments in relative numbers will probably occur.

In the context of discussions in this chapter, "exotic" organisms are construed as those organisms not indigenous to the Nearctic Region. Only the discussion of home-grown and cryptic hazards concerns indigenous species that may become crop pests.

If we accept as valid the idea that movement across latitudes has a greater chance of success than south–north movements, we should anticipate a continuing stream of immigrants from the western Palearctic. But surely some, and perhaps most, will be repeaters, i.e., species that have already breached the Atlantic Ocean barrier and are now established in North America. Although perhaps not so great a hazard as the initial invaders, these repeaters, by supplementing the range of genetic materials available in North American populations, increase the possibility of the development of more capable pest biotypes. Hazards of this sort will serve to keep attention focused upon the agricultural crop pests that occur in the western Palearctic Region.

Of course, North America has not been the sole recipient of emigrant pests, other major land masses have also been invaded by exotic pest species. This means that the country of origin is not necessarily the place from which a pest will depart for invasion of our continent. A case in point is the 1981 invasion of the Mediterranean fruit fly. The present known world distribution of the pest clearly shows many potential sources from which this recent infestation in California might have originated.

As noted, the record of immigrant species tends to support the hypothesis that exotic arthropods with the potential to damage crop plants in the United States are most likely to be found in climatically similar regions of the world. But climatic similarity alone is insufficient to identify regions where the greatest hazards likely occur; regions where floral or agroclimatic analogues occur should also be considered (Nuttonson, 1965). For example, the vegetative diversity of the southern and southeastern United States includes grasses and other herbaceous plants, broadleaf deciduous trees, and needleleaf evergreen trees. Global analogues of such a climatic and vegetative region include virtually all of western Europe, and also an extensive band across central Asia, including Manchuria, the far eastern USSR, and northern Japan (Espenshade, 1979). Thus, attention needs to be directed toward *regions* of the world, rather than specific countries, except as commerce and tourism may serve to facilitate movement of pest species. One of the best sources of information about the distribution of major insect pests of agricultural crops, worldwide, is a series of maps prepared and periodically updated by the Commonwealth Institute of Entomology (Anonymous, 1951–1980).

No reliable inventory of the world's crop pests exists. The number of species that are known to reduce yields is legion and includes 10,000 species of insects (Klassen *et al.*, 1975, p. 275). Even less certain is the number of phytophagous species in the world from which more pest species may emerge. There are some 55,000 known (i.e., described and named) species of the phytophagous beetle family Curculionidae, many of which are known pests. Yet, this number is believed to represent only about 10–20% of the world's species of that family (Batra *et al.*, 1977). These discouraging data are probably reasonably representative of the phytophagous insect fauna in general, although reliable inventories of described species are available for very few groups that contain numbers of known pest species.

Some comprehension of the limitations on our knowledge of insects of the world may be attained by scrutiny of data pertaining to some groups for which the published records have been summarized. One such is the homopterous family Cicadellidae (= Cicadelloidea of Metcalf). Metcalf's catalogues (1962–1968, incl.) covered the literature through 1955. He recorded 9078 species assigned to 1074 genera. In the 27-year period since 1955, the number of recognized genera has more than doubled, accompanied by an enormous increase in the number of recognized species. This explosive expansion of knowledge of the group involves all faunal regions, but is primarily due to increased attention to previously little known areas. Even so, an approximate inventory of many regions is as yet far from attained. For example, an analysis of the cicadellid fauna of Chile (Linnavuori and DeLong, 1977) revealed only 119 species. Of these, 43 were first described in the aforementioned report, and another 41 had been described since the cutoff date (1955) of Metcalf's catalogue. In brief, the as yet very limited survey of the Chilean leafhopper fauna increased the known number of species by more than 200% during the past quarter-century.

II. RECOGNITION OF INSECT PEST SPECIES

A. Status of Present Knowledge of Insect Pests Worldwide

Our knowledge of insect pests is best in the North Temperate areas of the world, particularly Western Europe and North America. The temperate regions of eastern Asia are less well known. This general knowledge is tied to the development of agriculture, coupled with a relatively high level of taxonomic activity supporting applied entomological investigations. The resurgence of interest in the entire insect fauna of agroecosystems, including beneficial species, has increased the taxonomic load considerably since the time when main target species received most attention and control relied heavily on chemicals only.

Information on the subtropical and tropical pests is limited largely to the major pests of main crops, and even here there are taxonomic problems of great magnitude. Detailed information on lesser pests and pests of lesser crops is still in short supply. The same is true of the vast array of beneficials. The general paucity of resident systematists in these regions is partly responsible for this condition. So much information is needed, and so few people are able to provide it. A strong effort should be made to establish priorities for investigations. Most of the systematic expertise lies outside the region, further delaying accurate identifications within a reasonable period of time. Well-organized Systematic Service and Research Centers are urgently needed (Lattin, 1980; Lattin and Knutson, 1982) to assist in the assemblage of the required data bases and to participate in the creation of new knowledge in appropriate languages. Quality investigations of the total insect fauna of crops in virtually every area, coupled with the preservation of adequate reference materials, is badly needed. It is anticipated that the production of literature will gradually shift from North Temperate systematists to resident systematists as the expertise is acquired. Greater utilization of existing centers and museums is needed, together with the establishment of new centers at appropriate sites. A more organized system of providing the proper education and training of resident applied systematists is needed to ensure the supply of an ever-increasing cadre of individuals capable of providing their own identification and training their own personnel.

B. Factors Complicating Species Recognition

The need for identification of the organisms involved is generally understood in dealing with pest situations. Unfortunately, in entomology, our ability to make precise identifications is severely handicapped by the multiplicity of phytophagous arthropods with which we must deal. Many of the species are polymorphic, and most of them occur in several quite different-appearing developmental stages, making identification of population samples a very complex task. The problem is further compounded by the fact that many insect "species" appear to be composed of a bewildering array of sibling species, host races, biotypes, or other infraspecific taxa that may interact differentially with different varieties of crop plants (Cronquist, 1977).

The ability of wild insects to adapt to changing environmental conditions is well established (Hendrick *et al.*, 1976), and the existence of genetic diversity in insects is amply illustrated among the pests of such major crop plants as rice, wheat, maize, and alfalfa. Among cereal insect pests, there are three biotypes of the greenbug [*Schizaphis graminum* (Rondani)] that differ in their ability to live on and damage varieties of wheat, barley, and sorghum. Another pest of sorghum, the corn leaf aphid [*Rhopalosiphum maidis* (Fitch)], has four or more biotypes that differ in fecundity or survival capacity on different host plants. And the Hessian fly [*Mayetiola destructor* (Say)] is now known to have eight biotypes which interact differentially with varieties of wheat that have different gene combinations (Gallun *et al.*, 1975). Biotypes of pest species in other major insect taxa are also known.

The noctuid genus *Spodoptera* (Lepidoptera) includes important pests of many crops in almost all parts of the world. Ashley (1981) mentions 23 species; the exact number is uncertain. The exotic species most frequently mentioned in the literature are *Spodoptera exempta* (Walker), *S. maurita* (Boisduval), *S. littoralis* (Boisduval), and *S. litura* (Fabricius). Unfortunately, which distribution record is applicable to which nominal species is far from clear. Under the name "*Prodenia litura*," the Egyptian cottonworm, *S. litura* was indicated as having a very wide distribution (Anonymous, 1957, No. 20, pp. 385–386). Rivnay (1962, p. 104) stated that the species "is reported from all continents except the American. However, not everywhere does it occur or cause damage in equal measure." Subsequently, Hill (1975, p. 307) considered the cotton leafworm of the Mediterranean basin to be *S. littoralis*, with *S. litura* absent from Africa but occurring in Asia and Australia. The five species of *Spodoptera* considered to be important agricultural pests in the tropics (*exempta*, *exigua* (Hubner), *littoralis*, *litura*, and *mauritia* (Hill, 1975, pp. 303–308) show considerable overlapping of distributions. Correct allocation of past records is clouded by time and may never be satisfactorily resolved. Situations such as this are very suggestive of species complexes, with the expectation that intergradation and possibly hybridization may occur.

Although biochemical methods promise to provide means for discrimination among biotypes, sibling species, etc. of a few intensively studied groups of insects (Berlocher, 1979, 1980), for pest species in general the state of our knowledge is such that we are still unable to make satisfactory predictions as to which species, species groups, or genera are likely to be of agricultural importance (Batra *et al.*, 1977, p. 289).

C. How Lacunae in Available Information Affect Determination of Pest Status or Potential

Among the most difficult questions to answer are these: What will be the status of an insect species detected for the first time in the United States? What will be the evaluation of an insect species likely to be introduced? Well-known species (e.g., the winter moth) offer fewer problems simply because we have considerable information on them. Even here, it is difficult to judge how any particular species will act in a new environment. The species cited above is a good example. The winter moth is not considered a pest in England, but we have a great deal of information on it provided by Varley and Gradwell (1968). Once introduced into eastern Canada (Embree, 1965), it took some time before it was apparent that it might reach pest status. The same situation occurred when it was detected in British Columbia (Gillespie *et al.*, 1978) and, somewhat later, in the northwestern United States (Ferguson, 1978; Miller and Cronhardt, 1982). Extensive information was available on the species in Europe, including detailed data on the wide array of parasites. Some of these were introduced into Canada and, later, into the United States. We are not so fortunate in most instances.

When an exotic species is first detected and its native home is determined to be Southeast Asia or the dry coast of South America or southern Brazil, we may not be so fortunate. Detailed knowledge of most exotic species—except for those coming from areas whose fauna is not only well known but for which extensive information is available on food plants, members of generations, and/or parasites and predators—is often fragmentary or not known at all. The extensive searches for biological control agents throughout the world provide ample evidence of that fact. Many of these searches must start with educated guesses and may involve years of work in order to narrow down the possibilities and gather sufficient data to permit intelligent decisions to be made. True parasite–host relationships may be obscured because of incomplete taxonomic knowledge. The lacunae in our knowledge of most of the insects of the world are embarrassingly large. The sheer numbers of species, combined with our limited biological information on them, makes the task exceedingly difficult. It is a tribute to the comparatively few people working in entomology (compared to the number of insect species) that we have done so well, and yet we are constantly surprised by our ignorance. Shortcuts must be taken to extrapolate from available information because the number of people able to acquire such data is so limited. The unknown factors involved in determining in advance just how a species will behave in a new environment are still unacceptably large. Some of the complicating factors are discussed in Section III.

III. CHARACTERISTICS OF ORGANISMS THAT INFLUENCE PEST STATUS

A. Introduction

A natural reaction to the invasion and temporary establishment of any exotic arthropod, other than those considered as beneficial, is one of concern. If the invader is a known agricultural pest, the level of concern is immediately high; if the pest potential of the immigrant is unknown or uncertain, steps to determine it should be initiated. Unfortunately, our understanding of the fundamental biological processes that predispose some species to become pests is still far from adequate to permit accurate predictions, although the probability of a high degree of genetic plasticity may reasonably be assumed if the immigrant is one of a complex of biological races, semispecies, or subspecies, some of which are known pests.

But invasion and establishment are not necessarily equated with pest status. A considerable proportion of the immigrants are likely to be of no economic importance, or at most minor pests (Sailer, 1978), due in part to the different environmental conditions encountered. And even the pest species are usually "fine-tuned" to environmental conditions, so that their population levels tend to fluctuate from year to year. A major factor in such population fluctuations is the impact of natural enemies—pathogens, parasites, and predators—which, unfortunately, seldom accompany immigrants to their new homes. But, of course, other factors, such as agricultural practices, which may vary considerably from one region to another even in ecologically similar areas, may influence the impact of pest species. The value of *a priori* knowledge of the biology and behavior of a pest becomes evident during the decision-making period that follows detection of a new immigrant.

Environmental extremes that affect crop plants, especially temperature and humidity, are also critical factors in pest population dynamics. Species that are pests in environments lacking in temperature extremes and low humidities may not survive high summer or low winter temperatures and low humidity during periods of dormancy, even though tolerant of ambient temperatures during their active stages. Some pests, intolerant of either summer or winter climatic stresses, cause extensive damage in cropping areas to which they migrate seasonally. Such species, even though capable of invading different major land masses, may not always find suitable seasonal refugia that permit population survival during noncrop periods. Thus, available knowledge of a pest's lack of climatic tolerance will influence the level of concern accorded an invader. For example, the periodic occurrence of *Sogatodes orizicola* (Muir), and the outbreaks of hoja blanca disease of rice in Florida, Louisiana, and Mississippi during the late 1950s and early 1960s (Everett and Lamey, 1969), are presumed to indicate that the vector is unable to tolerate the winter conditions that usually prevail in the Gulf Coast region. Consequently, hoja blanca currently receives little attention in the United States, although it is a major rice disease in more southerly regions of the Western Hemisphere.

Food availability is obviously a very important factor in pest population dynamics. A species that depends primarily upon a single crop plant as a food source may go unnoticed, or be considered only a minor pest, when the crop plant is not routinely available. However, the same species may have the capacity to build up to damaging levels through succeeding generations if its food plant becomes available year after year through repetitious planting, conditions often dictated by economic considerations under our highly specialized crop production methods.

Although we cannot afford to be indifferent to the arrival of immigrant pests, it is important to remember that neither agriculture (Jones, 1973) nor the tactics and strategies for dealing with crop pests are static (Knipling, 1979). Pest management methods are constantly being improved, and these developments alter attitudes toward invading pests. The citrus blackfly (*Aleurocanthus woglumi* Ashby) caused a great deal of concern when infestations occurred in Texas and Florida during the 1960s and early 1970s. Nevertheless, the widespread occurrence of the pest in Florida in the late 1970s, considered in light of the success of a biological control program against it in Mexico (Smith *et al.*, 1964) and elsewhere, became less objectionable, leading to the decision to live with it in the southeastern citrus-growing region.

The concept and practice of coordinated control programs against pests in other parts of the world (Brader, 1979) will produce much useful information in dealing with potential invaders. Information about the natural enemies of those pests that may become permanent residents in our agroecosystem is especially important (U.S. Department of Agriculture, 1978). A great deal of useful information in this and other areas of pest management tactics in numerous countries has been acquired since the early 1960s through the U.S. Department of Agriculture's P. L. 480 program. Examples of the types of information available are contained in the following technical reports (Ghani and Muzzaffar, 1974; Grover and Prasad, 1976; Hamid, 1976; Ibrahim, 1979; Isa, 1979; Israel and Padmanabhan, 1976; Lipa, 1975; Niemczyk *et al.*, 1976; Shaikh, 1978; Tao and Chiu, 1971; Wiackowski *et al.*, 1976; Yen, 1973).

B. Factors Influencing the Potential for Translocation

The various avenues for dispersal or translocation of any potential pest are important considerations. Natural spread from adjacent geographic areas via prevailing winds might allow the establishment of a pest from a nearby country, i.e., island hopping in the Caribbean to Florida, or movement south on prevailing winds from western Canada or north into the Southwest from Mexico. Naturally, these same avenues for translocation may go, at times, in the opposite direction. Successful establishment will depend upon the survival of the vagile stage, whatever that stage might be.

Spread by human activity is probably a more common mode of translocation. According to Sailer (1978), approximately 750 of some 1300 immigrant species in the United States had become established by 1930. Another 150 or so were added by 1940. The greatly increased air traffic subsequent to 1940 may have

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contributed to the 400 or so species added since that time. Certainly, the rapid transit time, together with the increased ability to move foodstuffs over long distances, enhances the opportunity for successful movement of pest species from one area to another.

The phenology of an insect or its placement in time in association with its hosts may determine the potential for movement from one site to another. The coincidence of the life stage with suitable sustenance once in place in a new locality may determine successful colonization. Although phenological coordination with site is important in all such cases, it is particularly true for organisms moving from one hemisphere to the other. The reversal of seasons is an obvious barrier of considerable magnitude for most organisms. Comparatively few of the species introduced into United States have come from the Southern Hemisphere (Sailer, 1978).

The duration of the vagile stage influences the dispersal capabilities of any species. The longer the stage, the greater the opportunity for accidental or intentional dispersal. Although such statements are meant here to apply to accidental introductions, certain of these are relevant to persons interested in the purposeful introduction of biological control agents. Indeed, in the last instance, artificial prolongation of the vagile stage might be considered.

The specific niche association of the mobile or vagile stage will influence the potential for dispersal. Insects whose eggs are inserted into plant tissues or larvae or adults that are borers are more likely to go undetected than a larva on a leaf or a pupa attached to the trunk of a sapling. Control methods applied to such plant materials will have a greater degree of success with stages more vulnerable to those methods. Insects laying eggs on leaves are unlikely to be dispersed through commerce if the sapling is shipped as a leafless, bare-rooted whip or as a seed.

The degree to which individuals of a particular species are sensitive to control procedures applied prior to movement, i.e., fumigation or spraying of plant materials, will influence the potential success for movement. Normal resistance to the materials used would of course apply, but so would improper application of such lethal doses. Similarly, any control tactic applied at the point of entry may also influence the chance for survival essentially to the same conditions. The location of the life stage being moved is important. Eggs embedded in the tissue of plants may be much less susceptible to control than those on the surface of the plant.

Insects with narrow temperature tolerances present a much smaller "window" for potential transport than those whose movable stage shows great tolerance to temperature fluctuations. The latitude of origin may influence the transport potential since wider temperature fluctuations normally would be experienced in the mid-latitudes compared to the tropics. An egg or pupa in deep diapause in response to higher latitudinal conditions might provide more time for transport.

C. Factors Influencing Establishment, Survival, and Subsequent Spread

The type of reproduction possessed by a potential pest and/or beneficial species may influence the ease with which the organism becomes established. Bisexual species normally require both sexes, although, of course, that problem may be avoided if a female is fertilized prior to the introduction. Once introduced, the necessity of locating a mate in order to produce a generation may reduce the chances of a successful colonization.

Species able to reproduce parthenogenetically would seem to have a distinct advantage in successful establishment, other things being equal. Indeed, a number of pest species already introduced are parthenogenetic, e.g., the white-fringed weevil and many aphids. The life stage involved in transport would exert some influence, particularly if adults were required rather than eggs. Short-lived adults would require rapid transport. Parthenogenetic reproduction may permit very rapid spread once establishment occurs, e.g., the blue alfalfa aphid, *Acyrthosiphon kondoi* Shinji. Some of the flightless weevils may spread far more slowly. Hermaphroditism is rare in insects, but there is at least one example of a hermaphroditic pest species: the cottonycushion scale, *Icerya purchasi* Maskell.

The number of generations passed by any species may influence the success or failure of establishment. Given suitable host material, it would seem advantageous to have multiple generations simply to provide the possibility of building up the establishing population. On the other hand, if the species normally undergoes multiple generations, the absence of suitable host material for a second or third generation may prevent the establishment of the species. The synchrony of a single-generation species may be easier than that of a species with multiple generations.

A number of grass-feeding species of plant bugs (Hemiptera: Miridae) have been introduced into the United States from Western Europe: *Leptopterna dolobrata* (Fallén), *Megaloceroea recticornis* (Geoffrey), *Lopus decolor* (Fallén), etc. All have a single generation per year. Several very common grass-inhabiting mirids of Western Europe—*Notostira elongata* (Geoffrey), *N. erratica* (Linnaeus), and *Stenodema* (*Brachytropis*) *calcaratum* (Fallén)—have not yet been detected in North America. All have two generations per year, and all overwinter as adults. *Stenodema* (*Brachytropis*) *trispinosum* (Reuter) has two generations and also overwinters as an adult, but is considered a true Holarctic species, occurring naturally in both the Old and the New World (Wagner and Weber, 1964; J. D. Lattin, unpublished). It may be that multiple generations compound the problems of successful colonization.

Assuming that an adequate number of individuals arrived as an introduction, the generation time could exert a significant influence upon the success of establishment. Short generation time, combined with multiple generations, could enable an invading population to build up significant numbers to create a population large enough to ensure survival. Further, should the invaders arrive near the end of the season of the preferred host plants, there still might be time for a generation to complete its development. Species with long generation times require greater synchrony with the new environment if successful colonization is to occur since adequate resources must be available throughout the life cycle.

Even if close synchrony exists between the phenology of the invading species and the new physical environment, the absence of a suitable primary or secondary host plant would doom attempted colonizations to failure unless a dramatic host plant shift occurred. The possibility of such a host shift actually occurring might indeed be greater in a totally new environment, where host plants not previously encountered might be found. Naturally, the nutritional value of such plants may play an important role in survival.

Another factor to be considered is the accessibility of the host plants to the invader. Barriers of distance from the point of introduction and the occurrence of the host plant are important. The likelihood of successfully locating suitable host material is a function of distance.

Successful colonization depends upon the ability of an invading species to adapt to an environment different from that of its native home. Further, the points of introduction are likely to be sites where the environment has undergone considerable alteration, usually reducing the number or diversity of available host plants. Species arriving from areas that have already undergone extensive alteration (e.g., Western Europe) may have been exposed to selective pressures inherent in such environments and thus may show some preadaptation to similarly disturbed environments in new locations. This may account for the unusually large number of successful introductions from Europe.

Any invading species must be able to cope with the new environment as it exists at the time of arrival, regardless of the life stage of the invader. An active immature or adult stage would seem to face the greatest difficulty simply because food normally would be an immediate concern. The egg or pupal stage would face similar problems once that stage had ended.

Competition with existing native species is a form of environmental resistance that might make successful establishment difficult. An invading species coming into a balanced fauna where most of the habitats already are occupied might have a more difficult time than a species entering an imbalanced fauna associated with heavily disturbed environments. The latter are far more likely to be found around most points of introduction.

Species requiring both sexes for successful establishment of a colony face yet another barrier—that of locating the opposite sex. The great diversity of mate-finding tactics known for most species makes it difficult to generalize. Those species whose systems are the most highly developed are likely to be favored. Species requiring highly specific conditions for mate location may not become established if these conditions are not available. Where an immigrant flora has preceded the insect (whether weed or crop), the particular requirements may be met. Absence of the appropriate plants or conditions that may facilitate mate location would be a deterrent to successful establishment.

Although range extensions depend upon dispersal, such dispersal does not necessarily result in range extension. The biological and behavioral traits of species (populations) that make them successful usually enable them to expand their ranges rapidly once they are established in North America or some comparable land mass. Those that were initially dependent upon human activities for their successful invasion will still be largely dependent upon humans for further dispersal, barring certain atmospheric conditions to be mentioned later. The utility of regulations designed to prevent domestic translocations of pests in general is limited to pests of this category.

Vagile pest species that disperse or migrate by flight pose quite different problems (Johnson, 1969). Such species will presumably spread to the limits of their bioclimatic tolerance, with corresponding gradients in pest states. Rapidity of spread by such species usually depends upon the direction and magnitude of prevailing air mass movements during times of population dispersal and the availability of suitable hosts along dispersal pathways. A few examples of successful invaders will illustrate some of the conditions that favor spread of pests.

The boll weevil (*Anthonomus grandis* Boheman), an exotic species in the sense of not being native to the United States, became a pest when extension of the cotton culture made a favored plant readily accessible to it. Even so, the rate of spread was not especially rapid. In contrast, the spotted alfalfa aphid (*Therioaphis maculata* Buckton), a highly vagile species with a great reproductive capacity, was able to expand its occupied territory to the limit within a few growing seasons. This rapid development was aided by parthenogenetic reproduction, *a priori* climatization, and the existence of the favored host plant, alfalfa, at virtually all places where airlifted immigrants landed. In both cases, the direction of spread was from southwest to northeast, and was aided by the prevailing movement of summer air.

In contrast to the boll weevil–spotted alfalfa aphid pictures, the gypsy moth [*Porthetria dispar* (Linnaeus)] made relatively little progress on its own in westward extension of its range, major population extensions being attributable to transport by humans. Within and immediately adjacent to areas where major infestations of the species occur, some extension of the occupied areas occurs by "ballooning" by early instars.

Other contrasts that should be noted are those exemplified by pests established in the Northern Hemisphere that spread northward, and those that spread southward from their initial points of establishment. Elsewhere, mention is made of the periodic northward movement of essentially tropical insect pests that may become established temporarily, either for a single season or for two or more seasons during periods of mild winters. Such pests, intolerant of the usual climatic conditions in the continental United States, are but occasional visitors, unlikely to develop biotypes capable of becoming permanent resident pests. Their invasions are presumably possible because of favorable atmospheric conditions at a suitable time. Thus, the range of these northward-moving pests may be visualized as a sort of accordion effect, expanding and contracting with climatic conditions, with permanent survival in the southern refugia.

The pattern of north-to-south spread of invading pests is somewhat different. Prevailing winds during periods of population dispersal seldom favor long-range movements of migrants, so the extension of infested areas is a more gradual process. However, once a southward expansion of range is accomplished, populations appear to persist. Examples are as follows:

Macropsis fuscula (Zetterstedt), a leafhopper vector of the *Rubus* stunt mycoplasma in Europe, was first discovered in North America in British Columbia in 1952 (Bierne, 1954). In 1969, it was found to occur in northwest Washington on wild blackberry, and by 1981 was well established southward at numerous sites in the Willamette Valley of Oregon, most abundantly on wild *Rubus*. A continued southward spread in the western mountains and valleys where *Rubus* is abundant is to be expected.

Eight of the species listed in this section as potential new pests are already present in North America. If the foregoing assumptions of dispersal and range extension are valid, those known to be established in Canada (*Acleris comariana*, *Incurvaria rubiella*, *Psylla mali*, and *Psylloides chrysocephala*) will eventually arrive within our borders. Range extension of *Acleris comariana* southward along the west coast will be aided by prevailing summer air movement. If *Chaetocnema concinna* proves to be established in Massachusetts, a gradual range extension will occur. *Stenoma catenifer*, present in Central America and Mexico, is likely to invade northern areas where its host (avocado) is grown. The two beetles that occur in Mexico and Central America (*Diabrotica speciosa* and *Epicaerus cognatus*) probably pose less of an immediate threat because of the bioclimatic conditions that will be encountered as they move northward.

Some species require a dispersal flight prior to the development of the ovaries. For such species, at least three major factors are involved in successful dispersal and colonization: (1) the dispersal itself, (2) the location of a mate, and (3) the location of a suitable habitat. The second step would not be of concern to a parthenogenetic form. Species whose ovaries develop prior to dispersal might have two dispersal states—unfertilized and fertilized. The timing of the dispersal flight relative to the development of the eggs could influence the duration and distance of the dispersal flight.

Any consideration of a potential pest should include the potential of that organism for the development of biotypes to fit particular habitats. This type of information may not be readily available but must be surmised from available evidence. Does the species occur over a wide geographic area in its homeland, or does it have a restricted range? Does the species occur in a wide range of habitats, or is it limited to one or several restricted habitats? Does the species show considerable morphological variation, or is it rather uniform in appearance? Is the species known to be associated with a wide range of hosts, or is it quite host specific? Does the species have multiple generations, or is it univoltine? Does the species have more than one form—i.e., is it parthenogenetic, is there a migratory phase, or is it polymorphic? The problem may be less difficult if the species is from a well-known fauna, so that answers to some or all of the above questions may already be known. Species originating in countries where the fauna is poorly known may make predictions difficult or impossible. Detailed, systematic knowledge may make it possible to extrapolate from closely related taxa whose habitats are better known. Recent systematic revisions may be of enormous assistance in the evaluation of the potential pest status, e.g., the recent revision of *Epilachna* in the Coccinellidae by Gordon (1975).

Introduced species may have the capacity to become established in a new environment and effectively replace an existing species, whether the second species is itself an introduced species or a native. This replacement may be due to the ability of the newly introduced taxon to overcome the normal environmental resistance and compete with a species already in place. The resident species may not have been exposed to vigorous competition from another species, or it may be occupying a marginal environment to which it is poorly adapted but able to survive in the absence of a competitor. A habitat that has been perturbed but not yet exposed to invasion is an example of such a condition. Any preadaptation that may have occurred in the invading species, such as adapting to disturbed environments in its own original home, may make it a superior competitor in a new environment on this continent. Species introduced from Europe, where completely natural environments are comparatively rare, may be those in which some preselection has taken place. A variety of grass-inhabiting plant bugs (Hemiptera: Miridae) that occur today on grasses in disturbed situations in Europe are found in similar environments in the United States, often replacing native U.S. species. *Leptopterna dolobrata* (Fallén) from Europe replaces *L. ferrugata* (Fallén), a Holarctic species common in the United States, in the Willamette Valley of western Oregon (J. D. Lattin, unpublished) in disturbed habitats. The winter moth, *Operophtera brumata* (Linnaeus), may have replaced the native species, *O. occidentalis* (Hulst), in the northern portion of the Willamette Valley, western Oregon, in the urban area of Portland and vicinity (Miller and Cronhardt, 1982).

The distribution and availability of host plants suitable for the successful establishment of a newly arrived pest species are of great importance. Acceptable plant species that are commonly encountered, particularly at points of introducand about methods for dealing with them should they arrive in North America. Pest management strategies are constantly being improved, making less distasteful the sometimes inevitable decision to live with an immigrant pest.

D. Potential New Pests

The following list of exotic pests is far from exhaustive and provides only examples of the kinds of arthropods of concern to American agriculture. The names are arranged alphabetically by order, family, genus, and species. Some general comments regarding the potential for certain taxa to invade or establish are given for each order. Entries following each pest species listed are, in sequence: common name, abbreviated summary of hosts attacked, summary of distribution, notation concerning biology if deemed significant to emigration potential, and source(s) of additional detailed information.

Acarina

Agriculturally important mites usually infest a variety of hosts, primarily broad-leaved plants. That trait, together with their small size and the fact that females customarily overwinter as adults, make them well adapted for dispersal in commerce. Four species deserve consideration as potential immigrants. Mite–plant associations are discussed in an evolutionary context by Krantz and Lindquist (1979).

EUPODIDAE

Halotydeus destructor Tucker. Red-legged earth mite. Vegetables. South Africa, Australia, New Zealand (Anonymous, 1958, No. 16, pp. 313–314).

TENUIPALPIDAE

Cenopalpus pulcher (Canestrini and Fanzago). Flat red mite. Pome and stone fruit. North Africa, Western Europe, and Middle East (Anonymous, 1968, No. 51, pp. 1143–1144).

TETRANYCHIDAE

Eutetranychus orientalis (Klein). Oriental red mite. Citrus and general. Northeast Africa, South Africa, Middle East, and India (Anonymous, 1969, No. 34, pp. 673–674).

Tetranychus viennensis Zacher. Fruit-tree spider mite. General. Europe (Anonymous, 1963, No. 31, pp. 897–898).

Collembola

Springtails are not usually considered crop pests, but one species is a troublesome pest of clover and alfalfa in the moister parts of Australia.

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tion, and whose occurrence is continuous or almost so, in contrast to those with a very patchy distribution, should enhance the likelihood of contact, establishment, and subsequent spread. The vagility of the invading species plays an important role, but the even distribution of some plants, e.g., those commonly occurring along roadsides or found commonly in disturbed habitats or other types of agroecosystems, may enhance the successful location of a suitable host. Pure or almost pure stands of many western tree species, coupled with current harvesting and reforestation plans, may make these habitats vulnerable to successful colonization and subsequent spread of introduced forest insect pests. Once established, the wide range occupied by some of these tree species would make it comparatively easy for the spread of a new species of pest. Thus far, the western forests are remarkably free of such pest species. Increased trade with eastern Asia, where, for example, the closest relatives to the Douglas fir (*Pseudotsuga menziesii*) are found, may change the present situation.

Invading species combining the characteristics of comparatively easy detection (e.g., pheromone traps) and slow buildup of an adequate population to permit successful dispersal may lend themselves to containment or eradication. Early detection of invasion and the availability of acceptable eradication methods may allow successful spot treatment. Species for which no readily available assay method has been developed, or species whose successful control and possible eradication may involve practices unacceptable for a variety of practical and/or environmental reasons, present an entirely different problem. For example, although assay methods are available for the gypsy moth, environmental–political factors may complicate the implementation of an eradication program. Assay methods are unavailable, at present, for a wide variety of pest species either because of undeveloped methodology or lack of interest.

It is axiomatic that any exotic phytophagous pest species that invades our domain concerns American agriculture. Yet invasion, even if followed by establishment, does not necessarily result in crop damage. In viewing the array of exotic pests, it becomes evident that there is a wide range of potential for damage, as well as for invasion. Thus, the degree of concern generated by an invader is likely to be tempered by the realization that some pest management strategies and tactics against it have already been tested. The unintentional widespread dispersal of agricultural pests and the intentional global movement of crop plants have brought many pest species into contact with new and different hosts. The increasing implementation of integrated pest control programs (Brader, 1979), exploitation of genetic diversity in crop plants to counter pests (Chiang, 1978; Gallun *et al.*, 1975; Kiritani, 1979; Singh and van Emden, 1979; Radcliffe, 1982), and ongoing international cooperative research programs such as those conducted at International Agricultural Research Centers and by the U.S. Department of Agriculture under Public Law 480, produce a wealth of useful information about the pest potential of species in many parts of the world

SMINTHURIDAE

Sminthurus viridis Lubbock. Lucerne flea. Legumes and other field crops. Throughout most of Europe, including Britain, northern coast of Africa, Middle East, Japan, Iceland, China, Australia, and New Zealand (Anonymous, 1958, No. 13, pp. 253–254).

Orthoptera

Although migratory locusts and some other saltatorial Orthoptera are notorious pests in many parts of the world, they are unlikely candidates for translocation to North America because of their reproductive requirements, large size, and conspicuous appearance. One species of mole cricket appears to have a high capacity for emigration.

GRYLLOTALPIDAE

Gryllotalpa africana (Beauvois). African mole cricket. Potatoes, turf, and a great variety of crop plants. Africa, southern Spain, Australia, South and Southeast Asia, Philippines, Japan, Guam, and Hawaii (Anonymous, 1974, No. 5, pp. 41–43).

Hemiptera/Heteroptera

The potential for invasion by true bug pests seems greatest for those species that either overwinter as adults (Lygaeidae, Pentatomidae, Piesmidae, Tingidae) or oviposit in plant tissue (Miridae).

LYGAEIDAE

Dimorphopterus pilosus (Barber). Rice chinch bug. Upland rice; also maize and several soft-stemmed grasses, not a pest of paddy rice. Papua, New Guinea (Anonymous, 1976, Nos. 48–52, pp. 897–899).

Macchiademus diplopterus (Distant). South Africa grain bug. Graminaceous plants and fruit. South Africa, but intercepted in North America (Anonymous, 1973, No. 40, pp. 693–694).

Nysius vinitor (Bergroth). Rutherglen bug. Wheat, cotton, vegetables, and fruit. Australia and Tasmania (Anonymous, 1957, No. 40, pp. 799–800).

MIRIDAE

Dionconotus cruentatus (Brullé). Orange blossom bug. Grasses, citrus blossoms, legumes, and other plants. Eggs laid in grasses and remain in the diapause state for long periods. Southern Europe, Near East, Tunisia (Anonymous, 1968, No. 18, pp. 377–378).

Plesiocoris rugicollis (Fallén). Apple capsid. Fruit and ornamentals. Palearctic regions of Eurasia (Anonymous, 1958, No. 24, pp. 523–524).

Pentatomidae

Aelia rostrata (Boheman) and related species of *Aelia*. Wheat stink bugs. Graminaceous plants, cultivated and wild. Throughout Western Europe, Near and Middle East, and parts of North Africa (Anonymous, 1962, No. 27, pp. 749–750; Paulian and Popov, 1980, pp. 70–71).

Coridius janus (Fabricius). Red pumpkin bug. Principally cucurbits. Burma, India, Sri Lanka, Pakistan (Anonymous, 1973, No. 13, pp. 197–198).

Eurydema oleraceum (Linnaeus) and related species of *Eurydema*. Cabbage bugs. Generally on crucifers; also numerous other vegetable crops. Throughout Europe, Turkey, Turkestan, and sections of Siberia (Anonymous, 1959, No. 6, pp. 81–82).

Scotinophara lurida (Burmeister). Rice stink bug. Rice and related grasses. Japan, China, and Sri Lanka. Adults aestivate between rice crops (Hill, 1975, p. 216, as *S. coarctata*).

Scutelleridae

Eurygaster integriceps (Puton) and two related species of *Eurygaster*. Senn (or Sunn) pest. Grain crops and numerous other plants. Present in essentially all Middle East countries, Eastern Europe, and some parts of North Africa (Anonymous, 1957, No. 5, p. 88; Paulian and Popov, 1980, pp. 70–76).

Piesmidae

Piesma quadratum (Fieber). Beet bug. Completes development only on Chenopodiaceae, but feeds on many plants. Transmits leaf crinkle virus of sugar beets in Europe. Throughout Europe, including British Isles, the USSR, and Tunisia (Anonymous, 1957, No. 47, pp. 891–892).

Tessaratomidae

Rhoecocoris sulciventris (Stål). Bronze orange bug. Citrus. Overwinter as second instars in protected places underneath leaves on trees. Coastal areas of New South Wales and Queensland, Australia (Anonymous, 1961, No. 5, pp. 51–52, under Pentatomidae).

Tingidae

Monosteira unicostata (Mulsant and Rey). Almond bug. Apple and pear; also stone fruits. Mediterranean region and Middle East (Anonymous, 1960, No. 12, pp. 207–208).

Stephanitis pyri (Fabricius). Pear lace bug. Foliage of a wide variety of deciduous fruits. Generally distributed in Europe; also in the Near and Middle East, Afghanistan, and the USSR (Turkestan Caucasus, Siberia) (Anonymous, 1960, No. 18, pp. 345–346).

Hemiptera/Homoptera

Among the Homoptera, those belonging to the series Sternorrhyncha (psyllids, aphids, coccids, and aleyrodids) are well known for their capability to emigrate. The Homoptera in general have contributed more species to our immigrant fauna than any other order, and most of them are Sternorrhyncha (Sailer, 1978). This group also includes many species that transmit plant pathogens, although their chief damage may result simply from the enormous numbers that develop. In contrast to the Sternorrhyncha, the Homoptera Auchenorrhyncha are primarily of concern as vectors of plant pathogens, with leaf hoppers (Cicadellidae) and plant hoppers (Delphacidae) being the more important culprits. The role of the Homoptera as vectors of plant pathogens is discussed elsewhere (Section IV).

CICADELLIDAE

Cicadulina, Nephotettix, Orosius (Ghauri, 1966, 1971a, 1971b; Nielson, 1968, 1979; Ruppel, 1965; Shikata, 1979).

DELPHACIDAE

Laodelphax, Nilaparvata, Sogatella, Sogatodes (Harpaz, 1972; Mochida *et al.*, 1978).

ALEYRODIDAE

Aleurocanthus spiniferus (Quaintance). Orange spiny whitefly. Citrus primarily, also several other trees or shrubs. Asia, including Japan, and Guam (Anonymous, 1959, No. 17, pp. 321–322).

APHIDIDAE

Aphis citricidus (Kirkaldy). Oriental black citrus aphid. Citrus, the primary vector of tristezia disease. Most of Asia, Africa (generally south of the Sahara), Australia, New Zealand, citrus-growing regions of South America, Pacific islands (Samoa, Fiji, Hawaii) (Anonymous, 1957, No. 38, pp. 767–768).

Cuernavaca noxius (Mordvilko). Barley aphid. Small grains. Southern USSR, Mediterranean basin, eastern Africa, Zimbabwe, Libya, Morrocco, Spain, and Great Britain (Anonymous, 1963, No. 47, pp. 1357–1358).

Pterochlorus persicae (Cholodkovsky). Clouded peach bark aphid. Stone fruits. Middle East to Afghanistan and Pakistan, southern USSR, and Egypt (Anonymous, 1969, No. 43, pp. 809–810).

Coccoidea

Ceroplastes rusci (Linnaeus). Fig wax scale. Fig primarily, but also various other hosts. Mediterranean area (Anonymous, 1960, No. 38, p. 886).

Icerya aegyptica (Douglas). Egyptian flued scale. More than 100 recorded hosts; among the important ones are citrus. Australia, China, Japan, South Asia, Somaliland, Tanganyika, Zanzibar, Tahiti, and Wake Island (Anonymous, 1960, No. 31, pp. 727–728).

Parlatoria ziziphi (Lucas). Black *Parlatoria* scale. Citrus. Southern Europe, Mediterranean area, South Africa, China, South Asia, Philippines, Okinawa, Micronesia, northern Australia, West Indies, Guiana, Argentina (Anonymous, 1960, No. 8, pp. 111–112).

Unaspis yanonensis (Kuwana). Arrowhead scale. Citrus. China (citrus areas of the southeast mainland), Japan, France (Cote d'Azur) (Anonymous, 1968, No. 17, pp. 349–350).

Psyllidae

Diaphorina citri (Kuwayama). Citrus psylla. Citrus and other Rutaceae. Widespread in tropical and subtropical Asia (Anonymous, 1959, No. 26, pp. 593–594).

Psylla mali (Schmidberger). Apple sucker. Apple and other Pomaceae. Western Europe, northeastern Australia (Nova Scotia and New Brunswick) (Anonymous, 1957, No. 50, pp. 925–926).

Spanioza erythreae (Del Guercio). Two-spotted citrus psyllid. Citrus and other members of the family. East Africa, Ethiopia, South Africa, Sudan (Anonymous, 1967, No. 34, pp. 801–802).

Thysanoptera

As with the Homoptera Sternorrhyncha, thrips have demonstrated the ability to move about in commerce far out of proportion to the number of species involved, in comparison with other major groups of insects. A considerable number of economically important species have attained essentially cosmopolitan distribution (Ananthakrishnan, 1971). The biology of thrips, and taxonomic problems encountered in the group, have been reviewed by Ananthakrishnan (1979). The following exotic species are of concern:

THRIPIDAE

Kakothrips pisivorus (Westwood). Pea thrips. Legumes, especially peas and beans; also numerous wild and cultivated plants. Throughout Europe, including the Caucasus (Anonymous, 1958, No. 7, pp. 121–122).

Retithrips syriacus (Mayet). Black vine thrips. Numerous hosts, the more favored being grape, cotton, and a variety of fruits. Eastern Mediterranean, eastern Africa, India, and Brazil (Anonymous, 1967, No. 17, pp. 354–355; Ananthakrishnan, 1971).

Scirtothrips aurantii Faure. South African citrus thrips. Citrus, cotton, and numerous other plants. Egypt, Malawi, Sudan, South Africa, Zimbabwe (Anonymous, 1967, No. 43, pp. 965–966).

Taeniothrips laricivorus (Kratochvil and Farsky). Larch thrips. Responsible for die-back disease of larch through injection of a toxin. Occurs extensively in Central Europe and into the USSR; precise range not known (Anonymous, 1960, No. 25, pp. 541–542).

Thrips imaginis Bagnall. Apple thrips. Flowers of deciduous fruit. Indigenous to Australia, occurs throughout southern Australia and Tasmania (Anonymous, 1958, No. 52, pp. 1029–1030).

Thrips angusticeps Uzel and *T. linarius* Uzel. Cabbage thrips. A wide variety of field and vegetable crops, including flax and crucifers. Western Eurasia and North Africa (Anonymous, 1962, No. 16, pp. 400–402).

Coleoptera

Numerous families of beetles include crop pests, but those most likely to join our immigrant fauna, by virtue of their biologies and behavior, are thought to be members of the families Chrysomelidae and Curculionidae and the phytophagous representatives of the Coccinellidae. Several exotic species of Buprestidae and Cerambycidae are important pests, but their long developmental periods and association with living wood probably severely limit their potential for invasion. Turf pests and defoliators (chafers, family Scarabaeidae), although obviously capable of invading, as illustrated by past performances [e.g., *Amphimallon majalis* (Razoumowsky), the European chafer, and *Phyllophaga brunneri* Chaplin a turf pest, *Popillia japonica* Newman (the Japanese beetle), and several others], presumably invade primarily as adults. Under present quarantine policies, their large size should make them rather unlikely to escape notice. The U.S. Department of Agriculture reports contain information regarding Buprestidae (Anonymous, 1960, No. 49, pp. 1129–1130), Carabidae (Anonymous, 1960, No. 10, pp. 151–152), Cerambycidae (Anonymous, 1962, No. 4, pp. 57–58; 1967, No. 18, pp. 373–374; 1968, No. 30, pp. 717–718), Scarabaeidae (Anonymous, 1959, No. 30, pp. 693–694, No. 45, pp. 989–990, No. 48, pp. 1025–1026; 1962, No. 20, pp. 505–506; 1963, No. 6, pp. 98–100; 1969, No. 28, pp. 535–536; 1971, No. 20, pp. 335–336), and Scolytidae (Anonymous, 1959, No. 8, pp. 125–126; 1967, No. 51, pp. 1077–1078). Burke (1976) has provided a review of the bionomics of the anthonomine weevils, many of which are of economic importance.

ALLECULIDAE

Omophlus lepturoides (Fabricius). Damages flowers of many plants; also cole crops, grain, and late-blooming fruit trees. Overwinter as larvae in the soil; adults emerge in spring. Southern Europe, Southeast Asia, and the USSR from the Ukraine to the Caucasus (Anonymous, 1980, No. 22, pp. 424–426).

CHRYSOMELIDAE

Aphthona euphorbiae (Schrank). Large flax flea beetle. A major pest of flax, feeding also on beets, Euphorbiaceae, and other plants; flax required for sexual maturity. Western Europe, Syria, Libya, European USSR, and some Far Eastern areas (Anonymous, 1969, No. 44, pp. 821–822).

Aulacophora abdominalis (Fabricius). A pumpkin beetle. Cucumber, melons, and other cucurbits. Northeastern Australia, Indonesia, New Guinea, Solomon Islands, and islands within this distributional range. Adults overwinter in dead vegetation or under dead bark (Anonymous, 1979, No. 1, pp. 13–14).

Chaetocnema concinna (Marsham) and *C. tibialis* (Illiger) Flea beetles. Sugarbeets; also numerous other plants. *Chaetocnema concinna* is present in most of Europe and eastward into Siberia; *C. tibialis* occurs throughout Mediterranean Europe and middle Eurasia, and in the Ryukyu Islands. Hibernate as adults (Anonymous, 1961, No. 37, pp. 879–882). N.B.: *C. concinna* is recorded in Massachusetts as of 1979 (Anonymous, 1980, No. 20, pp. 374) and is presumed to be established in the United States.

Chaetocnema aridula (Gyllenhall) and *C. hortensis* (Geoffrey). Flea beetles. Grains, primarily oats, wheat, and rye. Throughout Europe and eastward into Asia; *C. hortensis* also occurs in northern Africa. Overwinter as adults (Anonymous, 1961, No. 37, pp. 879–882).

Colaspidema atrum (Olivier). Black alfalfa leaf beetle. Alfalfa, but in the absence of the favored host will feed on other plants of diverse families. Iberian Peninsula, Algeria, Morocco; possibly also in Italy and the Kiev district of the USSR. Overwinter as adults in soil (Anonymous, 1959, No. 42, pp. 943–944).

Diabrotica speciosa Germar. Cucurbit beetle. Foliage, flowers, and fruit of cucurbits, maize, sorghum, beets, crucifers, peas, beans, cotton, potato, tomato, apple, peach, and citrus. Argentina, Brazil, Uruguay, Colombia, Bolivia, Costa Rica, Peru, Venezuela, Panama (Anonymous, 1957, No. 52, pp. 949–950).

Dicladispa armigera (Olivier). Rice hispid. Paddy rice. South and Southeast Asia, Indonesia, Taiwan, and coastal China mainland (Anonymous, 1958, No. 40, pp. 857–858).

Galerucella tenella (Linnaeus). Strawberry leaf beetle. Strawberry, ladysmantle, European meadowsweet, spirea. Throughout most of Europe and into western Siberia. Overwinter as adults (Anonymous, 1960, No. 51, pp. 1137–1138).

Marseulia dilativentris (Reiche). A leaf beetle. Many cultivated hosts, wheat, and barley preferred. Israel, Jordan, Lebanon, Syria, and Turkey (Anonymous, 1967, No. 13, pp. 237–238).

Medythia suturalis (Motschulsky). A striped leaf beetle. Peas and beans. South China, east India, Philippines, Ryukyu Islands, Sunda Island, Taiwan, Vietnam; also a subspecies in north and central China (including Manchuria), Japan, Korea, and southeastern Siberia in the USSR (Anonymous, 1979, No. 9, pp. 95–96).

Phytodecta fornicata Brüggemann. Lucerne beetle. Alfalfa and black medic. Throughout most of middle Europe and parts of the Near East; possibly also in England and North Africa. Overwinter as adults in the soil (Anonymous, 1962, No. 35, pp. 985–986).

Psylloides attenuata Koch. Hop flea beetle. Hop, hemp, and *Urtica dioica*. Throughout most of Europe except the extreme north and some southern areas, and eastward into Siberia in the USSR. Overwinter as adults in debris, crevices, hop poles, and hop bins (Anonymous, 1961, No. 49, pp. 1101–1102).

Psylloides chrysocephala (Linnaeus). Cabbage stem flea beetle. Primarily cultivated and wild crucifers; also sugarbeet, flax, vetch, soybeans, and *Mathiola incana*. Throughout Europe; also in Newfoundland, Canada. Overwinter as adults (Anonymous, 1958, No. 44, pp. 923–924).

Raphidopalpa spp. [*R. foveicollis* (Lucas) and others]. Red pumpkin beetle. Cucurbits preferred, but also numerous other plants. Many areas in Australia, Asia, Africa, Europe, and islands near those continents. Overwinter as adults under debris and fallen leaves (Anonymous, 1961, No. 4, pp. 39–40).

Coccinellidae

Epilachna chrysomelina (Fabricius). Twelve-spotted melon beetle. Watermelon, muskmelon, cucumber, pumpkin, and other cultivated and wild species of cucurbits; also other crop plants. Widespread in Africa, southern Europe, Middle East, and Near East. Hibernate as adults (Anonymous, 1959, No. 33, pp. 765–766).

Epilachna paenulata (Germar). A leaf-feeding coccinellid. Many hosts, the most important being cucurbits and beans. South America, about 12° to about 40° south latitude, except the west coast area. Overwinter as adults (Anonymous, 1958, No. 42, pp. 885–886).

CURCULIONIDAE

Amnemus quadrituberculatus (Boheman). Clover root weevil. Subterranean, red, crimson, and white clovers primarily. Coastal districts of New South Wales and Queensland, Australia. Adults survive winters (Anonymous, 1959, No. 36, pp. 837–838).

Anthonomus pomorum (Linnaeus). Apple blossom weevil. Pomaceous fruit primarily. All of Europe across the USSR to China, Korea, and Japan. Hibernate as adults from midsummer to the following spring (Anonymous, 1959, No. 41, pp. 925–926).

Anthonomus vestitus Boheman. Peruvian square weevil. Cotton. Peru and Ecuador (Anonymous, 1959, No. 13, pp. 227–228; Burke, 1976, p. 288).

Baris granulipennis (Tournier). Melon weevil. Watermelons, melons, and cucumber. Egypt, Iran, Israel, and adjacent USSR (Anonymous, 1967, No. 20, pp. 431–432).

Ceutorhynchus pleurostigma (Marsham). Turnip gall weevil. Most crucifers. Larval feeding damage causes galls that enlarge as plant growth continues. Throughout most of Europe (Anonymous, 1957, No. 43, pp. 843–844).

Curculio elephas (Gyllenhal). Chestnut weevil. Chestnuts and acorns. Southeast Europe and Algeria. Overwinter as larvae, normally in soil, but pupation may occur in nuts, from which adults emerge (Anonymous, 1958, No. 50, pp. 1003–1004).

Epicaerus cognatus Sharp. Potato weevil. Potato and other *Solanum* species. Mexico (DF, Puebla, Tlaxcala, Veracruz, Hidalgo) (Anonymous, 1959, No. 44, pp. 971–972).

Furcipus rectirostris (Linnaeus). Stone fruit weevil. Stone fruits, primarily cherries. Northern and Central Europe, the USSR, and Japan (probably also China). Overwinter as adults in ground debris (Anonymous, 1973, Nos. 1–4, pp. 23–24).

Hylobius abietis (Linnaeus). Large pine weevil. All conifers and many hardwoods including oak, birch, and sycamore. Scotch pine and Douglas fir are favorite hosts in Britain. Throughout Europe and northern Asia to Korea and Japan (Anonymous, 1961, No. 30, pp. 707–708).

Hyperodes bonariensis (Kuschel). Wheat stem weevil. Wheat, oats, barley, Italian and perennial ryegrasses, orchard grass, and other cultivated and wild grasses. Native to Argentina and adventive to New Zealand (Anonymous, 1961, No. 3, pp. 31–32).

Lixus junci (Boheman). Beet curculionid and related species. Sugarbeets. General in the Mediterranean area. Overwinter as adults (Anonymous, 1959, No. 4, pp. 43–44).

Pissodes notatus (Fabricius). Banded pine weevil. Pine, spruce, larch, and fir. Most of Europe, including Britain, into eastern Siberia: also Uruguay and Algeria. Adults long-lived (Anonymous, 1958, No. 14, pp. 271–272).

Premnotrypes spp. Andean potato weevils. Potato: may also attack *Solanum wittmackii*. Bolivia, Peru, Chile, Colombia, Ecuador (Anonymous, 1960, No. 48, pp. 1107–1108).

Rhabdoscelus obscurus (Boisduval). New Guinea sugarcane weevil. Sugarcane, coconut, several species of palm and banana. Australia, Indonesia, Taiwan, numerous South Pacific islands, Hawaii, Japan (greenhouses) (Anonymous, 1967, No. 32, pp. 749–750).

Rhynchites cupreus (Linnaeus). Plum borer. Stone and pome fruits: also *Sorbus* spp., hazel, birch, hawthorne, and grape. Throughout most of Europe, the USSR, and Japan. Hibernate as adults (Anonymous, 1959, No. 7, pp. 101–102).

Rhynchites heros Roelofs. Fruit weevil, peach weevil. Peach, pear, apple, cherry, apricot, plum, quince, and loquat. Japan, Korea, Taiwan, and some parts of China (Anonymous, 1958, No. 15, pp. 289–290).

Tanymecus dilaticollis Gyllenhal. Gray corn weevil. Maize and sorghum preferred: also on many other crop plants, including sugarbeets, wheat, and vegetable and fruit crops. Southern USSR, Southern Europe, Turkey, and Cyprus. Overwinter as adults (Anonymous, 1973, No. 26, pp. 413–414).

Lepidoptera

There are a great many important agricultural pests among the Lepidoptera, especially in the family Noctuidae, which includes a large number of polyphagous species. However, under present quarantine regulations and practices, the noctuids are probably less likely than some others to invade North America. One species stands out as a potentially high-risk invader because it deposits eggs in batches and overwinters in that stage: the nun moth, *Lymantria monacha* (Linnaeus), family Lymantriidae. Another species with similar overwintering and egg deposit habits is the lackey moth, *Malacasoma nuestria* (Linnaeus), family Lasiocampidae. However, the lackey moth larvae are gregarious and spin conspicuous webs as they develop, so that establishment of a breeding population in a new area should be readily detected. Larvae of the pine processionary moth are also gregarious and web spinners. *Tortrix viridana* Linnaeus, a defoliator of deciduous trees, also overwinters in the egg stage.

Stem borers of the genus *Chilo,* family Pyralidae, are notorious as pests of graminaceous crops. Hill (1975, pp. 258–262) discusses two important species not mentioned in the following list.

Carposinidae

Carposina niponensis Walsingham. Peach fruit moth. Pome fruit, peach, pear, plum, apricot, quince, nectarines, and others. Damage to peaches easily confused with that caused by the Oriental fruit moth. Japan, Korea, Manchuria, China, and Soviet Far East (Anonymous, 1958, No. 34, pp. 751–752).

Gelechiidae

Gnorimoschema heliopa (Lower). Tobacco stem borer. Cultivated and wild tobacco and egg plant; possibly also wild Solanaceae. Australia, Indonesia, Fiji, New Guinea, Samoa, Philippines, South Asia, southern Africa, Greece, Turkey, and Israel (Anonymous, 1957, No. 26, pp. 523–524).

Gnorimoschema ocellatella (Boyd). Sugar beet crown borer. *Beta cicla, B. vulgaris, B. maritima,* and *B. sacchariera.* Europe, North Africa, and Middle East (Anonymous, 1960, No. 7, pp. 91–92).

Geometridae

Bupalus piniarius (Linnaeus). Pine looper. Pine. Most of Europe except Iberian Peninsula and small areas in southern Europe (Anonymous, 1959, No. 20, pp. 397–398).

Gracillaridae

Phyllocnistis citrella Stainton. Citrus leafminer. Citrus. Throughout tropical Asia and the western Pacific islands; also Japan and adjacent Asiatic mainland. Overwinter as adults (Anonymous, 1958, No. 45, pp. 935–936).

Incurvariidae

Incurvaria rubiella (Bjerkander). Raspberry moth. A bud borer of raspberry, blackberry, and loganberry. Overwinter in canes as larvae. Western Europe. N.B.: Established in Canada (New Brunswick, Prince Edward Island) (Anonymous, 1958, No. 18, pp. 355–356).

Lasiocampidae

Dendrolimnus pini Linnaeus. Pine lappet. Pine. Throughout Europe and Asia; also in Morocco (Anonymous, 1957, No. 39, pp. 785–786).

Gastropacha quercifolia (Linnaeus). Lappet moth. Various deciduous shade trees and fruit trees. Widespread in Western and Central Europe and adjacent USSR, eastern areas of mainland China and USSR, Japan (Anonymous, 1971, No. 26, pp. 463–464).

Malacosoma nuestria (Linnaeus). Lackey moth. Almond, apple, pear, plum, peach, cherry; also deciduous shade trees and woody ornamentals: a defoliator. Throughout most of Europe and Asia (Anonymous, 1958, No. 6, pp. 101–102).

Lycaenidae

Lampides boeticus (Linnaeus). Bean butterfly. Legumes of many kinds. Throughout tropical and temperate parts of Africa and most of Asia; also Pacific islands, including Hawaii (Anonymous, 1960, No. 30, pp. 695–696).

Lymantriidae

Dasychira pudibunda (Linnaeus). Red-tail moth. Deciduous forests and shrubs. A defoliator. Throughout the British Isles, Europe, and most of Asia (Anonymous, 1959, No. 47, pp. 1013–1014).

Lymantria monacha (Linnaeus). Nun moth. Major defoliator of conifers and deciduous trees. Throughout Europe and Asia, including Spain in the south, Britain in the west, and Japan, Korea, and China to the east (Anonymous, 1957, No. 12, p. 227).

Noctuidae

Agrotis segetum (Denis and Schiffermuller). Turnip moth. General feeder (cutworm) on grains, crucifers, beets, cotton, potatoes, and many other crops. Throughout Europe, Asia, Africa, and the Azores (Anonymous, 1957, No. 41, pp. 819–820).

Autographa gamma (Linnaeus). Silver-Y moth. A general feeder on potatoes, beets, crucifers, flax, hemp, and legumes: also cereals and grasses at times. Throughout Europe eastward through Asia to India and China: also in North Africa (Anonymous, 1958, No. 23, pp. 497–498). Rivnay (1962, pp. 125–127) provides a detailed account of the species in the Near East.

Busseola fusca Fuller. Maize stalk borer. Maize, sorghum, millet, and numerous other graminaceous hosts. Widespread in maize-growing areas south of the Sahara, Africa (Anonymous, 1957, No. 24, pp. 477–478; Walters, 1979).

Mamestra brassicae (Linnaeus). Cabbage moth. A general feeder, although crucifers are the most frequent hosts. Tomatoes, tobacco, lettuce, maize, beans, etc. are also attacked. Throughout Europe and Asia (Anonymous, 1958, No. 41, pp. 873–874).

Panolis flammea (Denis and Schiffermuller). Pine moth. Pine preferred, but also attacks silver fir, Douglas fir, spruce, juniper, European larch, and some broad-leaved trees. British Isles, continental Europe, and Asia (Anonymous, 1958, No. 51, pp. 1017–1018).

Sesamia calamistis Hampson. Pink stalk borer. Maize, sorghum, millet, rice, and sugarcane. Occurs in most of Africa but is important primarily in the sub-Saharan region (Hill, 1975, p. 298–299; Walters, 1979).

Sesamia cretica Lederer. Durra stalk borer. Maize, broomcorn, and sorghum. Mediterranean region generally; also Sudan (Anonymous, 1957, No. 7, p. 128).

Spodoptera exempta (Walker). African armyworm. Maize, rice, sorghum, and a wide range of grasses and other cereals. Africa south of the Sahara generally, southern Asia, and islands between southern Asia and Australia, also areas on both east and west coasts of Australia (Hill, 1975, pp. 303–304; Anonymous, 1960, No. 47, pp. 1095–1096).

Spodoptera littoralis (Boisduval). Egyptian cottonworm. A general feeder that attacks many crops, most commonly cotton, tobacco, tomatoes, and maize. Mediterranean basin and many areas of Africa south of the Sahara (Hill, 1975, p. 307).

Spodoptera litura (Fabricius). A polyphagous species; cotton, rice, tomato, and tobacco preferred. South and Southeast Asia from Japan and Korea to Indonesia; also coastal areas of eastern, northern, and western Australia, and Fiji and Hawaii (Hill, 1975, p. 308).

Spodoptera mauritia (Boisduval). Paddy armyworm. Rice, primarily; also maize, sugarcane, other graminaceous crops, and Cruciferae. Essentially the same distribution as *S. litura*, but not including Japan and Korea (Hill, 1975, p. 306; Anonymous, 1960, No. 38, pp. 887–888).

OLETHREUTIDAE

Leguminivora glycinivorella (Matsumura). Soybean pod borer. Soybeans; also cowpeas and *Lupinus perennis*. Throughout Japan, Korea, parts of China, and the Soviet Far East (Anonymous, 1958, No. 1, pp. 11–12) [as *Grapholitha glycinivorella* (Matsumura)].

Lobesia botrana (Schiffermuller). Vine moth. Primarily grapes, but also other hosts, including berries. Southern and middle Europe, North Africa, Near East, and Japan (Anonymous, 1957, No. 30, pp. 611–612).

PAPILIONIDAE

Papilio demoleus (Linnaeus). Lemon butterfly. Citrus, especially young nursery plants. Throughout Africa, southern Asia, and northern Australia (Anonymous, 1958, No. 46, pp. 949–950).

PIERIDAE

Aporia crataegi (Linnae
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PYRALIDAE

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Crocidolomia binotalis
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Dichocrocis punctiferal
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New Guinea (Ano

Leucinodes orbonalis G
and other cultivate
Somalia, Uganda,
numerous other A
17, pp. 321–322).

PIERIDAE

Aporia crataegi (Linnaeus). Black-veined white butterfly. A general feeding defoliator; prefers rosaceous plants but also attacks shade trees. Throughout Europe and temperate Asia; also northwest Africa adjacent to the Mediterranean (Anonymous, 1962, No. 52, pp. 1280–1282).

Colias lesbia (Fabricius). Lucerne caterpillar. Alfalfa. Argentina only, although other subspecies are present in southern Brazil, Uruguay, Chile, Peru, and Ecuador (Anonymous, 1960, No. 2, pp. 21–22).

Pieris brassicae (Linnaeus). Large white butterfly. Crucifers preferred, and many kinds attacked; also feeds on garden crops and ornamentals. A migratory species that occurs as a pest throughout Europe, North Africa, and Middle East generally; range extends through northern India and southern Siberia to Tibet and China (Anonymous, 1958, No. 28, pp. 621–622).

PYRALIDAE

Chilo partellus (Swinhoe). Spotted stalk borer. Maize, sorghum, bulrush millet, sugarcane, rice, and various wild grasses. Afghanistan, India, Nepal, Bangladesh, Sri Lanka, Sikkim, Thailand, East Africa, Sudan, and Malawi (Hill, 1975, pp. 258–259).

Chilo suppressalis (Walker). Rice stalk borer. Rice, maize; also various millets, wild species of *Oryza*, and many wild grasses. Southeast Asia from Japan, Korea, and adjacent areas of eastern China south to include Pakistan, India, and the islands north of Australia; also northern Australia, Egypt, Nyasaland, Zanzibar, Spain, Portugal, and Hawaii (Anonymous, 1967, No. 44, pp. 855–856; Hill, 1975, p. 262).

Crocidolomia binotalis Zeller. Cabbage caterpillar. A wide range of crucifers, nasturtium, and various flowering plants. Much of Africa south and east of the Sahara, South Asia, northeastern Australia, and Australasian islands (Anonymous, 1968, No. 52, pp. 1153–1154).

Dichocrocis punctiferalis Guneeé. Yellow peach moth. General feeder on foliage and fruit of many plants, although typically a pod borer. Peach in China and cotton in Australia (boll damage) are major crops and areas of concern. Southern and eastern Asia, including Sri Lanka, Burma, Malaya, China, Taiwan, Japan, and Korea; also Australia, Indonesia, and New Guinea (Anonymous, 1957, No. 34, pp. 697–698).

Leucinodes orbonalis Guneeé. Eggplant fruit borer. Eggplant, potato, tomato, and other cultivated and wild solanaceous plants. Zaire, Sierra Leone, Somalia, Uganda, South Africa, South Asia, Indonesia, and probably numerous other African and Asiatic localities (Anonymous, 1960, No. 17, pp. 321–322).

Omphisa anastomasalis Gueneé. Sweet potato stem borer. Sweet potato. China, Taiwan, India, Sri Lanka, Japan, Burma, Indonesia, New Guinea, Thailand, Philippines, Malaya, and Hawaii (Anonymous, 1960, No. 44, pp. 1047–1048).

PSYCHIDAE

Kotochalia junodi (Heylaerts). Wattle bagworm. *Acacia decurrens mollis* and other species of *Acacia*. South Africa (Anonymous, 1961, No. 45, pp. 1039–1040).

SCYTHRIDIDAE

Syringopais temperatella (Lederer). Cereal leafminer. Wheat, barley, and oats preferred, but many additional hosts recorded. Cyprus, Turkey, Lebanon, Syria, Jordan, Iraq, Israel, and Iran (Anonymous, 1959, No. 38, pp. 873–874).

STENOMIDAE

Stenoma catenifer Walsingham. Avocado seed moth. Avocado (*Persea americana*), coyo (*P. schiedeana*), wild species of *Persea*, and species of *Beilschmedia*. Brazil, Colombia, Ecuador, Peru, Mexico, and all Central American countries (Anonymous, 1980, No. 18, pp. 352–355).

THAUMETOPOEIDAE

Thaumetopoea pityocampa (Denis and Schiffermuller). Pine processionary moth. *Pinus* spp. Italy, Spain, Switzerland, Southern Europe, Syria, and Turkey (Anonymous, 1959, No. 50, pp. 1045–1046).

TORTRICIDAE

Acleris comariana (Zeller). Strawberry tortrix. Plants of the family Rosaceae, especially *Fragaria*, *Rosa*, *Rubus*, and *Potentilla*. Middle and Southern Europe, the Balkans, eastern USSR, Japan (Hokkaido), and Canada (British Columbia) (Anonymous, 1973, No. 10, pp. 141–142).

Austrotortrix postvittana (Walker). Light brown apple moth. Apple and a great many other hosts of diverse plant groups. Damage is from defoliation and pitting fruit. Indigenous to Australia and now in Tasmania and parts of New Zealand; also in New Caledonia, England, and Hawaii (Anonymous, 1957, No. 10, p. 187).

Cryptophlebia leucotreta Meyrick. False codling moth. Fruit of many plants, especially citrus and cotton; also sorghum, maize, tangerine, walnut, okra, plum, peach, and many others. Tropical and south temperate Africa from Ethiopia, Senegal, Ivory Coast, Togo, and Upper Volta south to Africa, Madagascar, and Mauritius (Anonymous, 1960, No. 5, pp. 67–68; Hill, 1975, pp. 252–253).

Grapholitha funebrana (Treitschke). Plum fruit moth. Plum, peach, cherry, and other stone fruits. Temperate Europe through Siberia (USSR), Asia Minor, and North Africa (Anonymous, 1958, No. 49, pp. 989–990, as *Laspeyrisia funebrana*).

Tortrix viridana Linnaeus. Green oak tortrix. Defoliator of oak forests; may also attack beech, linden, maple, and other deciduous trees. Throughout Europe, including Britain; also Turkey and Morocco (Anonymous, 1958, No. 12, pp. 229–230).

Yponomeutidae

Acrolepia assectella (Zeller). Leek moth. Onion, leek, garlic, chives. General in Europe, including the British Isles; also reported from Hawaii (Anonymous, 1960, No. 14, pp. 241–242).

Prays citri Millière. Citrus flower moth. Many species of citrus. Algeria, France, Spain, Italy, Greece, Syria, Israel, Morocco, Pakistan, India, Malaysia, Mauritius, Philippines, Sri Lanka, Fiji, Australia (New South Wales) (Anonymous, 1967, No. 50, pp. 1061–1062).

Diptera

Among the Diptera, several species of fruit flies, family Tephritidae, stand out as successful invaders, e.g., the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), and species of the genus *Dacus*. Fortunately, through long periods of study of these species in Pacific islands where they did or now occur, very effective suppressive tactics have been developed. As of 1982, all incipient infestations in the United States have been eradicated.

Diptera least likely to be eradicated, should populations become established in our region, are members of the family Cecidomyiidae.

Agromyzidae

Agromyza oryzae Munakata. Japanese rice leafminer. Cultivated and wild rice, reed, and foxtail grasses. North temperate Japan (Anonymous, 1959, No. 10, pp. 163–164).

Ophiomyia phaseoli (Tyron). Bean fly. Primarily beans, including snap and lima; also cowpeas, chickpeas, soybeans, and some nightshades. Africa (Tanganyika, South Africa, Kenya, Uganda, Belgian Congo, Egypt), East Asia, Philippines, Indonesia, Australia, New Guinea, and adjacent islands (Anonymous, 1957, No. 37, pp. 751–752, as *Melanagromyza*) (Hill, 1975, pp. 329–330).

ANTHOMYIIDAE

Hylemya coarctata Fallén. Wheat bulb fly. Winter wheat, primarily; also winter rye and barley. Western Europe, British Isles, and USSR (European and Siberia) (Anonymous, 1957, No. 48, pp. 903–904).

CECIDOMYIIDAE

Contarinia medicaginis (Kieffer). Alfalfa flower midge. Alfalfa and spotted medic. Widely distributed in Europe, its northern limits vague; also in southeastern USSR (Anonymous, 1961, No. 9, pp. 139–140).

Contarinia nasturtii (Kieffer). Swede midge. Cultivated and wild crucifers. Western Europe and the Ukraine (USSR) (Anonymous, 1962, No. 21, pp. 541–542).

Pachydiplosis oryzae (Wood-Mason). Rice stem gall midge. Various parts of Southeast Asia and the islands northwest of Australia; may also be in the Sudan (Anonymous, 1959, No. 49, pp. 1035–1036; Hill, 1975, pp. 320–321).

CHLOROPIDAE

Chlorops pumilionis (Bjerkander). Gout fly. Winter and spring wheat, barley, rye, and *Agropyron repens* (quackgrass), thought to be its only wild host. Throughout Europe and into the Siberian USSR. Presumably also in the Soviet Far East (Anonymous, 1961, No. 48, pp. 1093–1094).

TEPHRITIDAE

Acanthiophilus eluta (Meigen). Safflower fruit fly. Safflower and native Compositae. Occurs from England and Canary Islands across Southern and Central Europe and North Africa to the Mediterranean area, Middle East, northern Himalayas, and India (Anonymous, 1963, No. 49, pp. 1389–1390).

Ceratitis rosa (Karsch). Natal fruit fly. Most kinds of orchard fruit, peaches, and guavas especially favored. Africa, Angola, Kenya, Mozambique, Nigeria, Malawi, South Africa, Zimbabwe, Swaziland, Tanganyika, Uganda, and islands of Mauritius, Reunion, and Zanzibar (Anonymous, 1963, No. 38, pp. 1132–1134; Hill, 1975, pp. 328–329).

Dacus ciliatus (Loew). Lesser melon fly. Cucurbits primarily; also numerous other hosts. Eastern and central Africa, Mauritius, Arabian Peninsula, and India (Anonymous, 1960, No. 52, pp. 1149–1150).

Dacus cucurbitae (Coquillet). Melon fly. Cucurbits preferred, but also attacks tomato, beans, cowpeas, eggplant, papaya, mango, peach, and others, more than 80 in all. Eastern Africa, South Asia, Philippines, Indonesia, Guam, Saipan, Tinian, Hawaii, Ryukyu Islands, northern Australia (Anonymous, 1959, No. 19, pp. 367–368; Hill, 1975, p. 323).

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l, 1975, p. 323).

Dacus dorsalis Hendel. Oriental fruit fly. Fruit of many kinds; more than 150 hosts recorded. Southeast Asia, Bonin Islands, Mariana Islands, Hawaii (Anonymous, 1959, No. 24, pp. 529–530).

Dacus tsuneonis Miyake. Japanese orange fly. Citrus. Japan (Kyushu and Amami-O-shima); also reported from Szechwan Province, China (Anonymous, 1961, No. 51, pp. 1122–1124).

Dacus tyroni (Froggatt). Queensland fruit fly. Pome and stone fruits; also some varieties of citrus and a wide range of other fruit and vegetable hosts. Australia (New South Wales, Queensland, South Australia, and Victoria) (Anonymous, 1957, No. 3, pp. 43–44).

Euleia heraclei (Linnaeus). Celery fly. Celery and parsnip; also *Heracleum* and *Angelica* as wild hosts. Generally throughout Europe; also Morocco, North Africa, and Asia Minor (Anonymous, 1958, No. 19, pp. 375–376, as *Acidia heraclei*).

Myiopardalis pardalina (Bigot). Baluchistan melon fly. Watermelon, cucumber, musk melon, snake melon, pumpkin. India, Pakistan, Iran, Iraq, Israel, Lebanon, Syria, Turkey, and the Caucasus of the USSR (Anonymous, 1957, No. 6, p. 108).

Platyparea poeciloptera Schrank. Asparagus fly. Asparagus the only cultivated host. Generally throughout Central and Southern Europe, Sweden, and the Kiev district of the USSR (Anonymous, 1958, No. 38, pp. 823–824).

Rhagoletis cerasi (Linnaeus). Cherry fruit fly. Cherries preferred, but also other species of *Prunus*, with two species of *Lonicera* as alternate hosts. Most of continental Europe, parts of Turkey and Iran, and the USSR from southern Leningrad Province to the Crimean and southeastern Kazakhstan (Anonymous, 1958, No. 30, pp. 663–664).

Hymenoptera

Among the phytophagous Hymenoptera, several species of sawflies have demonstrated their ability as emigrants. The following species should be considered as potential invaders of North America.

Diprionidae

Diprion pini (Linnaeus). Pine sawfly. Periodic defoliator of pines, particularly Scotch pine, but will attack spruce and fir. Throughout most of Europe, Algeria, and into Siberia; exact eastward limits uncertain (Anonymous, 1959, No. 35, pp. 817–818).

Tenthredinidae

Athalia colibri (Christ). Turnip sawfly, beet sawfly. Cultivated and wild crucifers, sugarbeet, carrot, flax, grape. Throughout most of Europe, Asiatic

USSR, China, Japan, Korea, Taiwan, Iran, Turkey, Morocco (Anonymous, 1957, No. 28, pp. 563–564).

Hoplocampa brevis (Klug). Pear sawfly. Pear; also plum and apple. European USSR, Western and Southern Europe, Syria, and Turkestan (Anonymous, 1958, No. 26, pp. 573–574).

Pristophora abietina (Christ). Small spruce sawfly. Engleman, Norway, Sitka, Blue and Siberian spruce. Finland, Sweden, Estonian SSR, Denmark, Poland, Netherlands, Germany, France, Switzerland, Czechoslovakia, Belgium, and Yugoslavia (Anonymous, 1963, No. 4, pp. 59–60).

IV. DOMESTIC PEST THREATS

A. Home-Grown and Cryptic Hazards

Pest situations that arise from home-grown or hidden hazards are not unlike those caused by the invasion of exotic pests except in their geographic points of departure. Such hazards may be of several sorts. They may be recognized (i.e., known) as likely to occur under certain bioclimatic conditions; they may be suspected to be pests that occur occasionally in the absence of information on the circumstances that trigger them; or they may be completely unknown and unsuspected except as experience reminds us that wherever life exists, things are in a state of flux and changes should be anticipated. These hidden hazards become pest situations when some disturbance alters the status of one or more components of a balanced environment, a phenomenon similar to that of invasion by an exotic pest. The combination of circumstances that enabled a cicada, *Mogannia minuta* (Matsumura), to become a pest of sugarcane on Okinawa is an example of such a situation (Ito and Nagamina, 1981).

Organisms evolve in a variable environment (den Boer, 1968, 1971, 1977), a generalization that applies to both plants and the phytophagous arthropods they host. It is important to remember that very few of our crop plants are indigenous to North America (Waterworth, 1981), and that the genetic composition of those few, as well as that of the many brought here from abroad, has been materially altered during the domestication process. The domestication process to which crop plants have been subjected has, generally speaking, resulted in reduction of their genetic diversity. With few exceptions, phytophagous arthropods have not been subjected to domestication, with the result that most species have retained the ability to adjust to environmental variation within reasonable limits. Therein lies the explanation of the potential for home-grown pest situations to be generated by genetic homogeneity in crop plants and/or monocultural agricultural practices. Development of crop plant varieties resistant to insect attack is an attempt to reverse the domestication trend by restoring to plants the characteristics that make them resistant to specific herbivore species. But that is a one-to-one adjustment, and the agroecosystem is an exceedingly complex structure involving many physical and biological variables (Stinner *et al.*, 1982). No methodology has as yet been developed to permit *a priori* recognition of the many kinds of home-grown threats, such as the European corn borer (an adventive species) becoming a serious pest of snap beans in some bean-producing areas (Sanborn *et al.*, 1982).

Soybean is native to Eastern Asia. Although introduced into North America in the early 1800s, its exploitation as a widely grown crop plant in the United States has been relatively recent, and in 80% of the production areas of the world, the crop has been grown for less than 50 years. Survey data from four states (Illinois, Missouri, North Carolina, Ohio) showed a total of 453 phytophagous species recorded on soybean. Of these, 40 are oligophagous, restricted to legumes; 101 are polyphagous, feeding on soybean only as a secondary host; and the remainder are of somewhat uncertain food habits or only incidentally associated with soybean (Kogan, 1981). Of 10 major pest species attacking the crop in the midwestern, southern and eastern United States, all but three are indigenous to the Nearctic Region and only one, the southern green stink bug [*Nezara viridula* (Linnaeus)] is of Asiatic origin. The other nine are either polyphagous or are oliogophagous legume feeders that existed in the area before the introduction of soybean as a crop. However, even this fauna is not specialized to soybean feeding, as is much of the Oriental soybean fauna, certain species of which are highly adapted to the plant, and some of which depend upon perfect synchronization with crop phenology (Kogan, 1981). Thus, in comparison with soybean arthropod communities in the Orient, those in North America seem immature. Although immigrant species already well adapted to soybean must continue to be viewed as the greater potential threat, it is clear that shifts in food preference by native species, and greater adaptation to soybean feeding together with range expansion, still constitute serious threats.

One of the major soybean pests is the velvetbean caterpillar (VBC), *Anticarsia gemmatalis* (Hubner), a tropical species that apparently cannot tolerate winter temperatures in the regions where it causes major damage (Buschman *et al.*, 1981). Like many other tropical and subtropical species that are crop pests, including other species of noctuid moths, VBC moths migrate north during each growing season. The areas where damage occurs often depend upon the vagaries of air currents associated with storm systems at the times when moth populations are dispersing from their more southerly breeding area.

Another moth species, *Homoesoma electellum* (Hulst), the sunflower moth, is a serious pest of the cultivated sunflower in California, Texas, Kansas, and Nebraska, but only occasionally so in the Dakotas, Minnesota, and the Canadian prairie provinces. As with the VBC, the pest status of the species in the more northerly regions depends upon the arrival of female moths when newly opened sunflower blooms are available. This timing depends upon the development of weather systems that cause warm southerly winds during late June and early July (Arthur and Bauer, 1981).

Cropping practices may considerably influence the development of home-grown problems. The western corn rootworm (WCRW), *Diabrotica virgifera* LeConte, was first reported to be damaging corn in Colorado in the early 1900s (1909–11), and was first noted in the southwest corner of Nebraska in 1929–30, although it caused little damage during the drought years of the 1930s. It continued its eastward spread and is now the dominant rootworm species throughout most of Nebraska, having displaced the northern corn rootworm as a result of the change from corn in short rotation, a practice deleterious to the WCRW populations, to continuous corn planting in much of the region. An increase in irrigation farming apparently also favored the WCRW (Hill and Mayo, 1980), although that practice may be helpful in reducing spider mite populations in field corn (Chandler *et al.*, 1979). Clearly, the economic status of the several species of corn rootworms is changing as agronomic practices change (Krysan *et al.*, 1980).

Urbanization may cause changes in a pest situation. Lethal yellowing disease of palms was first discovered on the Florida mainland in 1971. Adults of the fulgorid planthopper, *Haplaxius crudus* (Van Duzee), are commonly associated with palms and are thought to transmit the disease agent. However, the *H. crudus* populations develop on turf grasses that are widely used in southern Florida landscapes, including house lawns, industrial plantings, parks, and golf courses where palms are also planted (Reinert, 1977, 1980).

Transmission of plant diseases by phytophagous sucking arthropods is one of the more insidious and complex problems involving crop plants. The imponderables in problems of this sort may include uncertainty about vector species; variation among populations of vectors in their ability to transmit pathogens (Kisimoto, 1967); environmental sources of disease agents; vector–pathogen compatibility; species or strains of pathogens; plant and vector host range of pathogen(s); and numerous other plant–arthropod interactions, including the role of agronomic practices in the maintenance of reservoirs of disease agents.

Aphids transmit about 60% of all known insect-borne plant viruses and other pathogens. There are 192 known vector species that transmit about 164 viruses. But this statistic gives a much too conservative picture of the situation. Out of some 3742 species of aphids, only about 300 have been tested as vectors of any of about 300 different viruses known to occur in about the same number of plant species (Harris, 1979). Further, a discussion of aphid involvement in plant pathogen transmission should not ignore the poorly understood phenomenon of aphid polymorphism. Alary and sexual polymorphism in aphids are environmentally determined, with temperature and photoperiod as factors of special significance. Other important factors include crowding, nutrition, and host plants. Aphids can exhibit alary and sexual polymorphism in one population at the same time, thus possessing the capacity to respond rapidly to either favorable or unfavorable conditions for survival. This biological diversity contributes to making aphids the most capable of all vectors of plant diseases (Lees, 1966; Hille Ris Lambers, 1966; Kodet and Nielson, 1980; Sylvester, 1980).

Weed species in or adjacent to agricultural areas are often sources of both plant pathogens and vectors. In studies in the Yakima Valley in Washington (Tamaki and Olsen, 1979; Tamaki *et al.*, 1980; Tamaki and Fox, 1982), production of winged migrants of the green peach aphid (GPA) was estimated to be as high as 70 million per hectare. The GPA is a vector of beet western yellows virus (BWYV), and disease readings of indicator plants from 15 weed species upon which the GPA had fed showed production of more than 500,000 BWYV vectors per hectare on weeds in peach orchards.

Peach is not a host of BWYV, but is affected by X disease, the causal agent of which is believed to be a mycoplasma-like organism (MLO) transmitted by several species of leafhoppers, most of which develop on wild hosts (McClure, 1980, and references cited therein). Studies in Connecticut showed that the highest incidence of X disease in orchards occurred where leafhopper vectors were most abundant, and that vector abundance was greatest in orchards with ground cover comprised primarily of wild host plants of vector species (Lacy *et al.*, 1979). The proximity and composition of wild host plants of vector species also affected colonization of an orchard (McClure, 1982).

An understanding of the cause(s) and source(s) of arthropod-borne plant diseases may be obscured by variation among different populations in the ability to transmit viruses to healthy plants or to their progeny. Whitcomb and Davis (1970, p. 442) point out that clones of vectors, derived from different geographic localities (or for selection from laboratory stock), can differ widely in transmitting ability. The inheritance of such characters is usually, but not always, complex.

The fortuitous association of plant pathogens and potential vectors may often bring to light previously unsuspected pest situations. Present evidence suggests that MLOs are likely candidates for transmission by a broad spectrum of vector species. "Flavescence doree" of grape (*Vitis*) in Europe may be caused by an MLO (Whitcomb and Davis, 1970). The disease is not known to occur in North America, yet it is transmitted in Southern Europe by a leafhopper [*Scaphoideus littoralis* (Ball), considered by Barnett (1977, p. 537) to be conspecific with *S. titanus* (Ball)] indigenous to North America but adventive to Europe.

Corn stunt was first observed in the early 1940s in south Texas. Initial studies revealed that the causal agent was transmissible by two species of leafhopper, *Dalbulus maidis* (DeLong and Wolcott) and *D. eliminatus* (Ball). Following the discovery and spread of the disease in the southern and midwestern United States, several additional leafhopper species (*Graminella nigrifrons* (Forbes), *G. sonorus* (Ball), and *Baldulus tripsaci* (Kramer and Whitcomb) were shown to be capable of transmitting the disease agent, a spiroplasma [see Nault and Bradfute (1979) for a summary of the discovery and subsequent investigations of vector species].

Citrus stubborn disease has been observed in California since 1915. It is caused by an MLO, *Spiroplasma citri*. The organism is now known to be transmissible by three species of leafhoppers [*Scaphytopius nitridus* (DeLong), *S. acutus delongi* (Young), and *Circulifer tenellus* (Baker)] and is known to occur in numerous field plants and weeds, both inside and outside the citrus culture area (Kaloostian *et al.*, 1979). *Spiroplasma citri* may have numerous leafhopper vectors and may be the cause of a disease in turnips.

B. Pest Potential of New Crop Development

The development of a new crop from a native plant or from a newly introduced plant creates a new set of conditions for native and introduced arthropod species. It may be difficult to anticipate exactly which group of organisms may utilize the crops. Cultivars of the new seed oil crop meadowfoam were developed from several native species of *Limnanthes* occurring in California and Oregon (Jolliff *et al.*, 1981). Insects occurring on the native species of *Limnanthes* were surveyed for possible pest species (K. J. West and J. D. Lattin, unpublished). Insect species judged most likely to be pests were native *Lygus* (Hemiptera: Miridae) and the 12-spotted cucumber beetle, *Diabrotica undecimpunctata undecimpunctata* (Mannerheim) (Coleoptera: Chrysomelidae), also a native species. Several other native insects were considered potential pests, none of them found on *Limnanthes* exclusively. Several species of crested wheatgrass, *Agropyron* spp., have been introduced into western North America from central Asia for rangeland improvement. *Labops hesperius* (Uhler), a native species of Miridae (Hemiptera) known to feed on several native grasses, moved over to the introduced grass species and caused damage (Todd and Kamm, 1974). At least one species of *Labops* occurring in central Asia is reported to occur on *Agropyron* in that area. One might have anticipated the likelihood of a native North American species becoming a pest on the introduced plant. Conversely, the development of new grass cultivars from native grass species provided suitable host plant material for several species of Miridae (Hemiptera) introduced into the Pacific Northwest from Europe, or secondarily introduced from a primary introduction on the eastern seaboard [e.g., *Leptopterna dolobrata* (Fallén) and *Megaloceraea recticornis* (Geoffrey)] (J. D. Lattin, unpublished).

C. Internal Movement of Pests Already Established

Although entirely new pests are now being introduced into North America, perhaps the most common occurrence is the internal movement within the United

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States of pests already established here. Both native pest species and introduced pests may be involved. Perhaps the most notorious example is the gypsy moth, long established on the East Coast, having been introduced from Europe and now being discovered along the West Coast. The easy transport of the egg masses on vehicles provides countless opportunities for relocation, often over great distances. The apple maggot is another example; a native pest on apples in the East, it has now been detected in the Pacific Coast states of Oregon and Washington. That the movement also occurs from west to east is documented in the occurrence of a native western species of the ash bug, genus *Tropidosteptes*, on ornamental ash trees in the eastern state of Pennsylvania (Wheeler and Henry, 1974). The possibility of transporting species introduced into the United States from Europe to other countries such as China should not be overlooked. There has been little faunal exchange between China and Western Europe, but the possibility of accidental introduction into China of European species already established in North America does exist.

V. CONCLUSIONS AND RECOMMENDATIONS

Environmental similarity of geographic regions is an inadequate criterion for determining potential sources of agricultural pests. Although species inhabiting such regions may be intrinsically well suited to survive in North American crop areas, the importance of environmental similarity as a major factor is tempered by the realizations that (1) the more capable immigrants from such regions have already arrived, and (2) the capacity for invasion and establishment involves different biological and behavioral traits than the capacity to cause damage.

The great increase in world commerce, the wide global dissemination of crop varieties, and explosive tourism have greatly increased the number of source points from which pest species may emigrate; hence, there is a need for greater concern about species attributes, as opposed to geographic points of departure. Species attributes that enhance the potential for invasion and establishment include (1) long periods of quiescence (diapause, aestivation, hibernation), especially if the quiescent stage has a small size, secretive habits, or noncrop-associated traits that tend to make detection difficult; (2) development in plant parts that are customarily transported outside commercial channels and consumed without cooking (e.g., fruits, nuts) by individuals unfamiliar with exotic pest risks; (3) high levels of fecundity, especially if followed by short developmental cycles; high fecundity is naturally enhanced by efficient mate finding of bisexual species or by parthenogenesis.

Species complexes (sibling species, semispecies, biotypes, etc.) with wide geographic ranges are indicative of genetic plasticity, and in consequence, the ability to adjust to a wide range of environmental conditions. Such species complexes are potential sources of hidden hazards and deserve particular scrutiny as potential pests.

Given the complexities and volume of modern commercial shipping, the increasing levels of tourist traffic, and the limited personnel engaged in quarantine enforcement, our first line of defense against exotic pests is inadequate and likely to remain so. The logical alternatives include (1) a greatly expanded, cooperative effort to improve knowledge of the world's phytophagous arthropod fauna and (2) more effective surveillance and detection methods, and implementation of vigorous eradication and/or containment programs against invading pest species.

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