On Accidental Immigration and Establishment of Terrestrial Arthropods in Hawaii During Recent Years*

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INTRODUCTION

During the past several years, one of my duties at the Experiment Station, HSPA, has been the weekly screening of insects taken in light traps which we operate at two locations on the periphery of Pearl Harbor. Primarily, these traps are for the early detection of new pests of sugar cane which might become established here, but fortunately for the sugar industry, no new major pests of cane have been detected during the approximately 18 years these traps have been in operation. However, in that time, about 35 species of insects new to Hawaii, a number of them pests or potential pests, have been discovered in material from these traps (Beardsley, 1958). During this same period many other new immigrants were collected by various means by entomologists in the state. The number of new immigrant arthropods recorded each year is substantial, as a perusal of past numbers of these "PROCEEDINGS" will show. Since most recent immigrants of economic importance in Hawaii are of foreign origin, I think it pertinent to examine these records in some detail to determine the following: 1) the rate at which we are receiving new immigrant arthropods; 2) the kinds of arthropods which are becoming established here; and 3) the source areas from which such immigrants come to Hawaii.

At the outset I wish to state most emphatically that this address is not intended to be critical in any way of quarantine regulations or their enforcement by either Federal or State agencies. I am firmly convinced that were it not for the efficiency of these organizations, the number of harmful arthropods becoming established here each year would be far greater than at present. Indeed, in view of the high volume of overseas traffic flowing to and through Hawaii, and the susceptibility of the Hawaiian environment to new pests, it is a tribute to the effectiveness of our quarantine agencies that the rate of establishment remains as low as it is.

The data presented here are derived largely from the "PROCEEDINGS" of this Society and from the published volumes of the "INSECTS OF HAWAII" series. As "INSECTS OF HAWAII" is far from complete, the data pertaining to groups

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which have been covered by this work are more reliable than those, such as the Coleoptera, the Hymenoptera and much of the Diptera, that have yet to be treated. It is truly lamentable that the publication of additional volumes of this most valuable series now seems so uncertain.

Rate of Successful Immigration

I have chosen the period of the last 25 years, 1937 through 1961, for consideration in this analysis. The onset of this period coincides roughly with the advent of commercial air traffic to and from these islands (an important factor in the transport and establishment of arthropod immigrants), covers the unstable periods of World War II and the Korean conflict, and brings us up to the present era of jet aircraft that has brought Hawaii within a few hours of the eastern and western extremities of the Pacific Basin.

During these 25 years, about 400 species of insects and other terrestrial arthropods have been accidentally introduced and have become permanently established in Hawaii. In attempting to fix the date of arrival for each immigrant, the first reported collection is about the only criterion which can be employed. For large and conspicuous species, such as many Lepidoptera, aculeate Hymenoptera, Orthoptera, and certain families of Diptera and Coleoptera, this date is probably within a year or two of actual establishment. For minute species or those of cryptic habits, such as mites, midges, small beetles, aphids and the like, the date of first collection may well be several to many years later than the original introduction, and may more accurately reflect an increased interest in a particular group by one or more local entomologists than it does the actual date of establishment. The aphids are a case in point. Of the 17 species first recorded during the past quarter century, five were first collected during one year, 1939, due to a resurgence of interest in this group by entomologists at the University of Hawaii and the State Department of Agriculture.

Figure 1 represents, as nearly as I have been able to ascertain, the number of new immigrant arthropods collected here for the first time during each year of the years 1937 through 1961. I have eliminated from consideration records of some 14 species which have been reported here but once, and most of which, in my opinion, are probably species accidentally introduced but did not become permanently established. The lists of new immigrant records published annually in our "Proceedings" are not without errors of omission and duplication, and the dates of first collection reported therein are not always correct. In preparing the histogram I eliminated as many such errors as possible through recourse to data published subsequently in "Insects of Hawaii," by careful perusal of the "Notes and Exhibitions" section of each issue of the "Proceedings," and in some cases by checking data on specimens in local collections. New records of endemic or doubtfully endemic species are not included, although some in the latter category eventually may prove to be introductions. I feel that

the total of 400 species is probably a bit conservative. I know of a number of recent immigrants in groups of little or no economic interest, such as the coleopterous family Staphylinidae, which remain unidentified and unreported because no specialist is available or willing to undertake their study. Also, I believe, Dr. Hardy's unpublished manuscripts on Hawaiian Diptera contain additional records of unreported immigrants.

If we assume that the number of unreported recent immigrants is approximately equal to the number first collected and reported during the past quarter century but which were actually present earlier (*i.e.*, that these two sources of error approximately cancel each other) we may then conclude that during the past 25 years new immigrant arthropods have become established here at the rate of about 16 species per year. Compared to the prehistoric rate of one successful immigrant per 20,000 years postulated by Zimmerman (1948) as sufficient to account for the development of the entire endemic insect fauna of Hawaii, this is indeed an impressive rate of immigration.

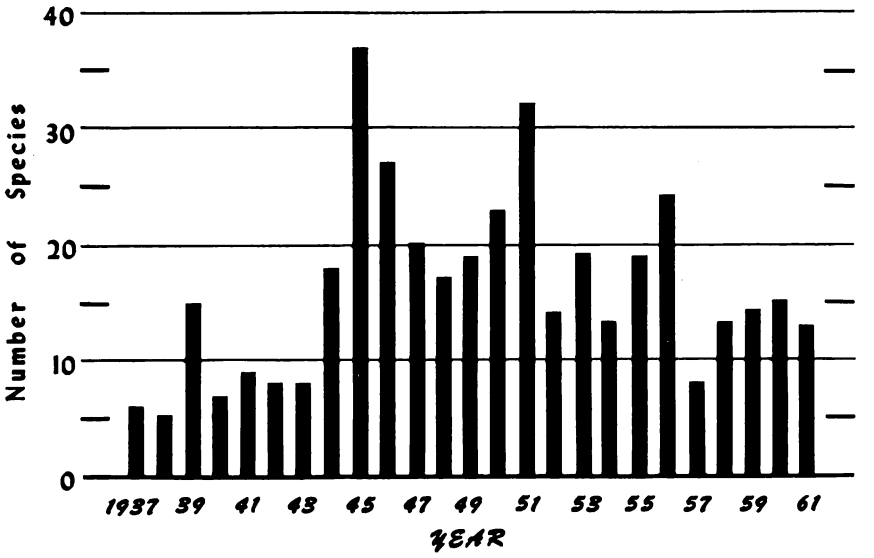

FIG. 1. Number of newly established immigrant arthropods collected each year, 1937–1961.

It would be of interest to compare our present rate of arthropod immigration and establishment with such rates for other parts of the world. Unfortunately, information about new immigrants such as is published in the "PROCEEDINGS" is not readily available for other areas. Lists of immigrants newly established in the continental U.S. during each of the past two years have been published in the COOPERATIVE ECONOMIC INSECT REPORT of the Agricultural Research Service, U.S. Dept. of Agriculture. This publication reported four new species in 1960 and 10 in 1959. In 1959 this journal published a list of 100 of the more important introduced insect pests found established in the continental U.S. since

1900. Of these, only 14 species were first found during the period of 1937 to 1959. Of course, this list is by no means a complete compilation of all accidental immigrants which were detected during 1900 to 1959. Of the species found established in Hawaii during the past 25 years, I estimate that about 75 have been pests of some economic or medical importance. From this admittedly meager evidence, it seems that the relatively small area of the Hawaiian Islands has been receiving new arthropod immigrants at a rate as great as, or greater than that of the whole of the continental United States. Figures 2 and 3 illustrate a few of the more important recent accidental immigrants.

There are probably several reasons for the relatively high rate of arthropod immigration and establishment in Hawaii. One of major importance has to do with the nature of the endemic Hawaiian insect fauna. Most of our endemic insects exhibit a very high degree of host specificity which, with few exceptions, has restricted them to the remaining areas of native vegetation. The absence of competition from native species has made Hawaii's man-made gardens and fields a veritable land of opportunity for immigrant insects by providing a multitude of ecological situations available for exploitation.

During the 25 years prior to 1937 (1912–1936) about 310 species of immigrant arthropods were collected here for the first time. This period antedates the era of the airplane and the vast wartime movement of men and materials to and through the islands, yet the rate of successful arthropod immigration appears to have been almost as high as during the succeeding 25 years. That the rate of successful immigration has increased relatively little undoubtedly is a reflection of the increasing effectiveness of our quarantine enforcement agencies.

Kinds of Arthropods Accidentally Introduced

Table 1 is a breakdown by class and order of the immigrant species of terrestrial arthropods collected here for the first time during the past 25 years. As might be expected, the larger orders of insects (Diptera, Hymenoptera, and Coleoptera) have provided the largest numbers of successful immigrants. Among the smaller

Table 1. Classes and orders of recent arthropod immigrants reported established during 1937–1961.

	no. species		no. species		no. species
Class ARACHNIDA		Class INSECTA			
Acarina	35	Diptera	95	Anoplura	6
Araneida	10	Hymenoptera	66	Mallophaga	6
Chelonethida	1	Coleoptera	57	Collembola	2
Class SYMPHYLA	2	Homoptera	42	Neuroptera	1
Class CHILOPODA	1	Thysanoptera	27	Ephemeroptera	1
Class TARDIGRADA	2	Lepidoptera	25	Trichoptera	1
		Heteroptera	10	Corrodentia	1
		Orthoptera	6		
Total non-insects	51			Total insects	352

orders, the Thysanoptera are represented by a disproportionately large number of recently discovered immigrants (27 species). Two factors suggest themselves as possible explanations of this. Firstly, the small size and cryptic habits of Thysanoptera make them well suited for stowing away in produce, cut flowers, and similar situations; and secondly, there have been two active thrips specialists working in Hawaii during the period under consideration, and their efforts have probably resulted in the early detection of species which otherwise would have been overlooked.

The large number of mites recorded during the past few years reflects an increase in interest in this group among local workers. Unquestionably, many additional immigrant species of mites and spiders await discovery and identification here. Similarly, the large number of immigrant Diptera reported in recent years may also reflect a recent increase in interest in this group, although these insects seem well adapted for spread by modern means of transportation, particularly aircraft, and new species are becoming established here almost every year.

TABLE 2. Orders and families of recent immigrant insect species reported established in Hawaii during 1937–1961.

	no. spp.		no. spp.		no. spp.		no. spp.
ORTHOPTERA		HOMOPTERA		HETEROPTERA		LEPIDOPTERA	
Gryllidae	3	Aphididae	17	Reduviidae	3	Noctuidae	13
Tettigoniidae	1	Coccoidea	13	Miridae	2	Gelechiidae	2
Acrididae	1	Cicadellidae	6	Coreidae	1	Tineidae	2
Mantidae	1	Delphacidae	2	Cryptostem-matidae	1	Pyralidae	1
		Aleyrodidae	1	Lygaeidae	1	Pterophoridae	1
		Cercopidae	1	Pentatomidae	1	Geometridae	1
		Membracidae	1	Tingidae	1	Agonoxenidae	1
		Psyllidae	1			Olethreutidae	1
						Acrolepiidae	1
						Cosmoptery-gidae	1
						Elachistidae	1
TOTALS	6		42		10		25
DIPTERA		HYMENOPTERA		COLEOPTERA			
Cecidomyiidae	14	Encyrtidae	15	Curculionidae	10		
Ephydridae	13	Sphecidae	9	Scolytidae	7		
Drosophilidae	7	Braconidae	7	Tenebrionidae	6		
Sphaeroceridae	6	Eupelmidae	4	Nitidulidae	5		
Phoridae	6	Vespidae	4	Carabidae	3		
Muscidae	5	Apoidea	3	Dermestidae	3		
Sarcophagidae	5	Chalcididae	3	Anthribidae	3		
Agromyzidae	5	Eulophidae	3	17 others	20		
Chironomidae	5	Pteromalidae	3				
19 others	29	13 others	15				
TOTALS	95		66				57

In Table 2, the more important orders of insect immigrants have been broken down by family. It is apparent that certain families within these orders are more

strongly represented among our recent immigrants than are others of comparable size. For example, among the Lepidoptera 13 species of Noctuidae have become established in the past 25 years, while only one species of the almost equally large family Pyralidae succeeded in establishing itself during the same period. In the Homoptera, the sternorhynchous families Aphididae and Coccoidea are well represented, with 17 and 13 species respectively, while new immigrants among the Auchenorhyncha are much fewer; the maximum being six species in the family Cicadellidae. Among the Diptera, the families Cecidomyiidae (14 species) and Ephydridae (13 species) are particularly well represented. The relatively large number of cecidomyiids reported may be due in large part to recent intensive studies of our nematocerous Diptera by Dr. Hardy, and many of the species may have been present for a number of years before they were first collected. The muscoid Diptera, a group of particular interest to medical entomologists, is well represented with 12 successful immigrants during the past quarter century, yet, in contrast, during this period not a single accidentally introduced species of mosquito became established (Joyce, 1960).

Among the Hymenoptera the Encyrtidae, mostly species which are parasites or hyperparasites that develop on scale insects and mealybugs, has provided 15 recent accidental immigrants. Several of these are known hyperparasites which attack beneficial species which were introduced purposely. The continued influx of such hyperparasitic species could eventually have an adverse effect on the degree of biological control which has been obtained with purposely introduced parasites of scales and mealybugs. Among the larger aculeate Hymenoptera we have received 17 successful immigrants during the past 25 years, while but two species of ants have been able to establish themselves during the same time.

On the general subject of the differential abilities of different insect groups to colonize new areas, particularly islands, a recent paper by Leston (1957), which treats Hawaii and several similar isolated islands areas, is of particular interest. Also, Gressitt (1961) gives additional information.

At this point I would like to offer a few speculations on what factors may influence the successful immigration and establishment of new arthropods in Hawaii. It is almost certainly true that individuals of many species arrive here in a viable condition and yet fail to establish themselves as permanent additions to our fauna. The 14 or more immigrant species reported in our "PROCEEDINGS" from single captures and never found again doubtlessly represent but a small fraction of such unsuccessful immigrants. One reason many accidentally introduced species fail to become established here may be the necessity of an obligatory period of diapause, usually initiated by low temperatures, in many temperate climate insects with annual life-cycles. Such insects obviously stand little chance of establishing themselves in lowland areas of Hawaii.

In general, the factors which affect the success or failure of a newly arrived immigrant arthropod can be divided into two major categories; intrinsic factors

characteristic of individuals of the species, and extrinsic factors characteristic of the environment. Among the former I would include such things as flight habits, tropisms, oviposition or nesting habits, mating habits, mode of reproduction, fecundity, longevity, hardiness, dispersal habits, host searching ability, etc. Obviously, a long-lived hardy insect is better able to withstand environmental extremes, such as heat, cold, desiccation, and the like which it may encounter en route. A species of high fecundity or one possessing the ability to locate favorable hosts or other oviposition sites at considerable distances will stand a better chance of establishment upon arrival; and one which can locate mates at very low population densities, or is gregarious (at least not given to long range premating dispersal flights) would seem better equipped to establish and maintain a population "beach head" during the critical initial phase of its invasion than would one not possessed of these qualities.

Small, cryptic species such as aphids, scales, thrips, and mites are more likely to be overlooked on produce and other vegetable material. Insects belonging to groups in which the adults are strong-flying nocturnal forms attracted to light, such as the noctuid moths, may find their way on board night-loading aircraft and reach Hawaii in the adult stage. Those of certain other groups, such as many aculeate Hymenoptera, probably arrive as immature stages, in mud nests attached to crates, etc., or in nests in holes, hollow twigs, and other such situations. Species which produce large concentrated masses of eggs, such as *Spodoptera mauritia* (Boisduval), may arrive in the egg stage attached to the surface of almost any container, possibly even attached to the outside of aircraft.

The mode of reproduction and habits of mated females may also be of importance. Many species probably arrive here as mated female adults. A species such as our Anomala beetle, *Anomala orientalis* (Waterhouse), which mates and deposits its eggs at or near the point where the adult female emerges, would seem to stand little chance of being imported as a gravid female on aircraft. In spite of its occurrence in areas near Oahu airfields, *Anomala* is still confined to Oahu after more than 50 years of establishment here. On the other hand, gravid females of many noctuid moths are frequently attracted to lights, and most of the species which have become established here in recent years have spread from Oahu to other islands within a few months or years of their discovery.

Parthenogenetic forms are special cases since individuals in almost any stage of development are capable of establishing the species. All of our aphids reproduce continuously by parthenogenesis, which may explain, at least in part, why so many have become established. Many of the most successful and widely distributed scale insects, such as the cottony cushion scale, *Icerya purchasi* Maskell; the soft brown scale, *Coccus hesperidum* L.; and the green scale, *Coccus viridis* Green; are parthenogenetic (or, in the case of *I. purchasi*, hermaphroditic) species or races.

Among the more important extrinsic factors which can influence the success

or failure of a newly arriving immigrant species I would include, firstly, the population level of the species at the port of embarkation. Obviously, other things being equal, insects which occur in large numbers in the immediate vicinity of airfields and port facilities are more likely to find their way aboard conveyances headed for Hawaii. The case of the Fiji leafhopper *Perkinsiella vitiensis* Kirkaldy, is a graphic example. Large numbers of these insects, attracted to night loading aircraft at Nandi, Fiji, arrived in viable condition in Honolulu on several occasions during 1953 and 1954, although disinsectization of the aircraft apparently prevented the species from becoming established here. At the time, these insects were reportedly abundant in cane fields adjacent to the Nandi airfield. The factors which influence insect populations around American and Pacific ports and airfields are, therefore, of direct concern to us here.

The degree of similarity of climate, vegetation, and other environmental factors between points of embarkation and points of disembarkation in Hawaii is probably also important. It is interesting, I believe, that many of the insect species which in recent years have first established themselves here on the dry Ewa Coral Plain of Oahu have come to us from semiarid regions of southwestern North America [*e.g.*, *Paraidemona mimica* Scudder, *Circulifer tenellus* (Baker), *Kunzeana kunzei* (Gillette), *Chrysobothris octocola* LeConte, and a number of others]. The flora of our dry lowland areas has a number of common wild elements which also occur in the American southwest, such as *Prosopis* and *Acacia farnesiana*, as well as many common cultivated plants, which may partially explain why we have received so many immigrants from this area.

Among other extrinsic factors of importance I would include the length of time in transit (which is dwindling steadily), the extremes of temperature and humidity to which traveling insects are exposed, and, perhaps, even the accuracy of aim of the irate passenger with a folded newspaper who is attempting to swat an annoying bug.

The great majority of new insect immigrants are first discovered in lowland areas on the island of Oahu, a natural consequence of the concentration of port facilities, and also entomologists. A few species, however, have first established themselves on other islands of the Hawaiian group. Some of these have subsequently spread to Oahu (*e.g.*, the reduviid bug *Polididus armatissimus* Stål, first found on the island of Hawaii in 1953, and discovered on Oahu only within the past few months), but many are still confined to those areas where they were first discovered. A number of these are temperate climate species which are found only at higher elevations on Maui and Hawaii, which are areas with "islands" of temperate conditions surrounded by more tropical lowlands. A good example of such an insect is the meadow spittlebug, *Philaenus spumarius* (L.), which is still confined to the Kilauea area of Hawaii where it was first discovered in 1944.

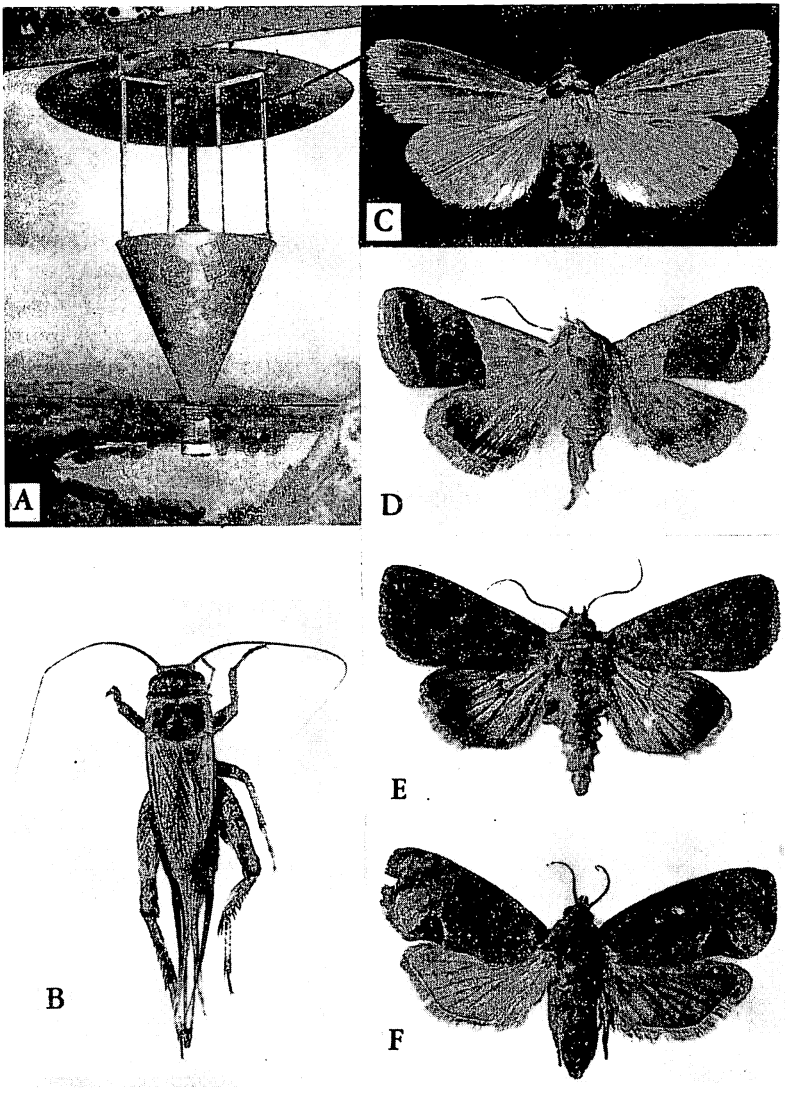

FIG. 2. A, H.S.P.A. ultra-violet light trap at locality overlooking margin of Pearl Harbor, Oahu. B–F, recent immigrant insects first collected in HSPA light traps: B, *Achaeta domesticus* L. (Gryllidae) length 30 mm. to tip of ovipositor; C, *Meliana* sp., (Noctuidae) wingspread 29 mm.; D, *Eublemma anachoresis* (Wallengren), (Noctuidae) wingspread 15 mm.; E, *Platysenta illecta* (Walker), (Noctuidae) wingspread 32 mm.; F, *Crytophlebia ombrodelta* (Lower) female, (Olethreutidae) wingspread 20 mm.

Origin of Recent Immigrants

As a matter of zoogeographical interest, I would like to consider briefly the major source areas from which our recent insect immigrants have come. In many cases the source of a species is difficult or impossible to fix as many are of cosmopolitan or pantropic distribution. A few others which appear to be immigrants have been described from Hawaii and are as yet unreported from any other area. The geographic distributions of many of the larger, more conspicuous, or economically important species are fairly well known, and for many of these we can at least determine the general area from which they must have come. Table 3 gives a breakdown by region of origin of recently immigrant species belonging to several such groups. For simplification, directions of origin have been reduced to "east" for species presumed to have originated in the Americas, "west" for those which evidently arrived here from Polynesia, Austro-Malaysia, or the Orient, and "undetermined" for those which could have come to us from either direction. Further subdivision as to origin would be most difficult as the majority of these species are of rather widespread distribution in one or the other of the two areas. It appears that in spite of differences between the individual groups, the total number of species from "east" and from "west" are reasonably close in this small sample. Among these groups of insects at least, there does not seem to be any significant difference in the numbers of recently established immigrants originating in these two broad areas.

Table 3. Direction of origin of some recent immigrant insects.

Taxonomic group	Total number of species	Direction of origin		
		East	West	Undetermined
ORTHOPTERA	6	1	4	1
HOMOPTERA (Auchenorhyncha)	10	8	1	1
HETEROPTERA	10	3	4	3
HYMENOPTERA (Aculeata)	17	7	10	0
LEPIDOPTERA (Noctuidae)	13	3	8	2
TOTALS	56	22	27	7

This may seem a bit surprising in view of the greater volume of air and surface traffic which arrives here from North America. However, it should be remembered that the bulk of the traffic from the Americas originates in the temperate regions of the United States, whereas much of that from the "west" originates, or calls en route, at tropical ports where climate and vegetation are more like our own, and where, presumably, a greater proportion of the insect species possess the ability to adapt to our Hawaiian conditions.

It is unlikely that the flow of new immigrant arthropods into Hawaii can ever be completely halted. However, in spite of the increasing speed and volume of commercial and military traffic to and through these islands, I believe that with

the steadily increasing effectiveness of state and federal quarantine enforcement agencies, we need not expect any marked increase in the rate of introduction. Indeed, I would not be surprised to find, 25 years hence, that the rate of accidental immigration of arthropods had decreased noticeably. Increasing attention is being given to educating the traveling public to an awareness of the hazards posed by foreign arthropods to our agriculture and public health. With new methods of disinsectization and increased public awareness of the value and problems of quarantine inforcement, we may, perhaps, look forward to the time when our annual list of new arthropods will be composed largely of purposely introduced beneficial species.

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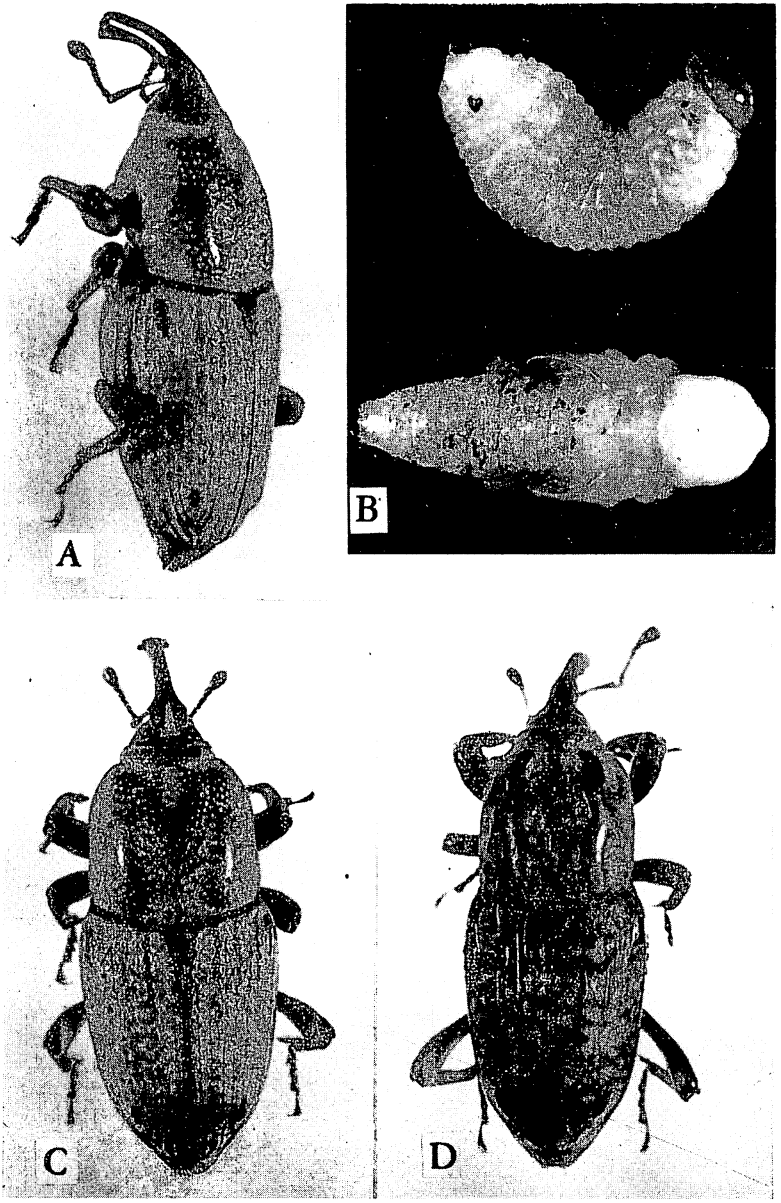

FIG. 3. A–C, *Sphenophorus venatus vestita* Chittenden: A, adult, semilateral view; B, larva and pupa; C, adult, dorsal view (length 10 mm.); D, *Sphenophorus cariosa* (Olivier), adult, dorsal view (length 11 mm.) Note differences in sculpture of the pronotum.