PAN-PACIFIC ENTOMOLOGIST
65(2), 1989, pp. 132–145

Exotic Invertebrates and Their Effects on California

ROBERT V. DOWELL AND RAYMOND GILL

Division of Plant Industry, California Department of Food and Agriculture, 1220 N Street, Sacramento, California 95814.

Abstract.—Between 1955 and 1988, infestations of 208 exotic invertebrates were discovered in California. The greatest number were Homoptera, followed by Acari, Coleoptera, and Lepidoptera. The majority came to California from other regions of North America followed by the Pacific Region and Europe. Since 1980, there has been an increase in the rate of introduction of Diptera, Hymenoptera, and Homoptera and a decrease in Coleoptera and Lepidoptera. There have been increases in the rate of immigration from Asia, Australia, Europe, and the Pacific Region over the same time. Acari, Homoptera, and Thysanoptera immigrated significantly more often than expected based upon the number of species worldwide while Coleoptera and Hymenoptera did so significantly less often.

Sixteen insects were targeted for eradication with Diptera having the greatest number, followed by Lepidoptera. Asian insects, particularly dipterans, were targeted for eradication significantly more frequently than their proportion of the total immigrant fauna. These exotic invertebrates have had and will continue to have a tremendous negative impact on agricultural and urban pesticide use, and on California's environment. Future pest management programs must take into account this continuous immigration of invertebrate pests.

Human activity has been the primary force rearranging the geographic distribution of animals and plants over the last 500 yr. Thousands of organisms have been transported either accidentally or intentionally by man to places they were presumably incapable of reaching on their own (Sailer, 1978; Beardsley, 1962, 1979; Turnbull, 1979, 1980; Stephanova, 1981; Gillespie and Gillespie, 1982; Hoebeke and Wheeler, 1983; Moran, 1983; Brown 1986; Arzone et al., 1987; Vitousek et al., 1987).

This man-aided movement is especially important to California. The state is an ecological island bounded by desert, mountains, and ocean. It has a unique flora and fauna (Cochrane, 1985) and lacks many of the major plant pests found in other regions (Dowell, 1985, 1988; Dowell and Krass, 1988). California has over 200 crops, extensive native and exotic urban plantings, and large areas with benign climate making it likely that new phytophagous arthropods will find acceptable food and climate. Exotic plant pests are often extremely damaging in new habitats (Moran, 1983; Dowell and Krass, 1988). In 1978, exotic insects caused over $309,000,000 in crop losses in California (Papp, 1979). This represented 62% of all pest specific crop losses in the state for that year.

There is a continuous invasion of exotic organisms into California. In fiscal year 1986, over 22,000,000 motor vehicles passed through Agricultural Inspection Stations at the state borders with over 187,000 rejections because of quarantine violations. There were 104 species of intercepted organisms including burrowing nematode, imported fire ant, Mexican and Caribbean fruit flies, European cornborer, Japanese beetle, and gypsy moths. Malaysian, Mediterranean, and Oriental fruit fly larvae and pupae have been discovered in fruit mailed from Hawaii, and in a car shipped to California from Hawaii. In 1986, over 3000 Japanese beetles, many still alive, were found in cargo planes landing at Ontario, California, on flights which originated in the Eastern U.S.

This paper examines the result of this constant immigration of invertebrates into California. We have identified new additions to our invertebrate fauna from 1955 to 1988. We analyze the rate of introduction, composition by order and origin, and how the composition has changed over time. Lastly, we explore how these introduced organisms have affected and will continue to affect the State of California.

Criteria for Selection

The following criteria were used to develop a list of newly established invertebrates. Multiple individuals or life stages were present when detected. They were identified as a new state record. If multiple introductions occurred (e.g., the Mediterranean fruit fly) only the first introduction was included in our analysis. We excluded all organisms intentionally introduced in biological control programs. We also excluded all quarantine incidents. Thus wood borers found in shipping crates and plant pests found on nursery stock were not included since these were either destroyed or denied entry into the state. The origin of an organism is that area from which it came to California, not necessarily the area where it evolved (e.g., origin of Japanese beetles found in California is the Eastern U.S. and not Japan).

Source Data

We examined the following documents to develop an initial list of exotic invertebrates known to have established infestations in California between 1955 and 1988. (1) The Quarterly Bulletin of the California Department of Agriculture (volumes 44–56 covering 1955–1967), (2) Cooperative Economic Insect Report of USDA-ARS (volumes 5–25 covering 1955–1975), (3) Cooperative Plant Pest Report of USDA-ARS (volumes 1–5 covering 1976–1980), (4) California Plant Pest and Disease Report of California Department of Food and Agriculture (CDFA) (volumes 1–7 covering 1981–1988). This list was then reviewed by CDFA Insect Biosystematists to confirm the validity of each entry.

Results and Discussion

Infestations of 208 newly established invertebrates were discovered in California between 1955 and 1988 (Table 1). The annual rate of discovery of new organisms (6.1 ± 3.6 (SD)) is equal to that for the Northeastern U.S. and Eastern Canada for 1970–1982 (6.2/year) (Hoebeke and Wheeler, 1983) but less than that for the U.S. mainland for 1910–1980 (11.0/year) (Sailer, 1978, 1983) and Hawaii for 1937–1961 (14.5/year) (Beardsley, 1962) and for 1962–1976 (18.1/year) (Beardsley, 1979). Only 2 yr (1977, 1981) had no discoveries of new invertebrates and

Table 1. List of exotic invertebrates whose infestations were detected in California during 1955–1988.

Scientific name	Year first found	Probable origin
Acari		
Acalitus calycophthirus (Nalepa)	1984	E. U.S.
Acarapis nr. *dorsalis*	1959	?
Acarapis woodi (Rennie)	1986	E. U.S.
Aculodes teucrii (Nal.)	1968	E. U.S.
Aculops fuchsiae Keifer	1982	S. America
Aleuroglyphus ovatus (Troupeau)	1984	?
Cheyletiella yasguri (Megnin)	1973	E. U.S.
Eriophyes ajugae (Nalepa)	1958	?
Eriophyes celtis Kendall	1961	E. U.S.
Eriophyes spermaphaga Keifer	1979	?
Eriophyes vaga (Keifer)	1979	S. America
Eutetranchyus banksi (McGregor)	1968	E. U.S.
Fuscuropoda marginata (Koch)	1964	?
Lorryia formosa Cooreman	1984	Europe
Melittiphis alvearius (Berlese)	1988	Europe
Mononychellus erythrinae (McGregor)	1978	?
Oligonychus aceris (Shimer)	1959	E. U.S.
Petrobia nr. *apicalis* (Banks)	1978	E. U.S.
Phantacrus lobatus Keifer	1978	W. U.S.
Schizonobia sp.	1965	?
Siteroptes graminum (Reuter)	1965	Hawaii
Steneotarsonemus ananas (Tryon)	1980	Hawaii
Tegonotus carinatus (Keifer)	1964	Europe
Tetranychus evansi Baker and Pritchard	1965	Pacific region
Tetranychus merganser Boudreaux	1963	E. U.S.
Trisetacus pseudotsugae Keifer	1969	Oregon
Tyrophagus neiswanderi Johnston and Bruce	1982	Europe
Coleoptera		
Amblycerus robiniae (Fab.)	1970	E. U.S.
Anthonomus grandis Boheman	1984[1]	Arizona
Anthrenus coloratus Reitter	1969	Asia
Apion longirostre Oliver	1964	E. U.S.
Attagenus fasciatus (Thunberg)	1974	?
Carpophilus lugubris Murray	1974	?
Ceratophyus sp.	1963	Europe
Conoderus falli Lane	1966	E. U.S.
Crioceris duodecimpunctata (L.)	1975	?
Eleodes suturalis (Say)	1963	E. U.S.
Epitrix tuberis Gentner	1968	E. U.S.
Graphognathus leucoloma Boh.	1988	E. U.S.
Lissorhoptrus oryzophilus Kuschel	1969	E. U.S.
Listronotus hyperodes (Dietz)	1959	E. U.S.
Pharaxonotha kirschi Reitt.	1956	Texas
Phoracantha semipunctata F.	1984	Australia
Pissodes strobi (Peck)	1972	E. U.S.
Pityophthorus juglandis Blackman	1958	Arizona
Popillia japonica Newman	1961[1]	E. U.S.
Proctorus decipiens (LeConte)	1966	U.S.
Sitona cylindricollis Fahraeus	1957	U.S.
Sitona lineata (L.)	1966	Oregon

Table 1. Continued.

Scientific name	Year first found	Probable origin
Sphenophorus venatus Chittenden	1968	E. U.S.
Stelidota geminata (Say)	1957	E. U.S.
Zabrotes subfasciatus Boheman	1965	Mexico
Diptera		
Aedes aegypti (L.)	1979	E. U.S.
Anastrepha suspensa (Loew)	1984[1]	Florida
Cecidomyia balsamicola (Lintner)	1963	E. U.S.
Ceratitis capitata (Wiedemann)	1975[1]	Hawaii
Chrysomya megacephala (F.)	1988	Mexico
Chrysomya rufifacies (Macq.)	1987	W. U.S.
Contarinia sorghicola (Coquillett)	1960	Asia
Dacus correctus (Bezzi)	1986[1]	Asia
Dacus cucurbitae Coquillett	1956[1]	Hawaii
Dacus dorsalis Hendel	1960[1]	Hawaii
Dacus zonatus (Saunders)	1985[1]	Asia
Dasineura gleditchiae (Osten Sacken)	1978	E. U.S.
Mayetiola violicola (Coquillett)	1967	W. U.S.
Melanagromyza splendida Frick	1967	Hawaii
Musca autumnalis De Geer	1968	E. U.S.
Neoexaireta spinigera (Wiedemann)	1966	Hawaii
Phytomyza crassiseta Zetterstedt	1962	Pacific region
Phytomyza ranunnculi (Schrank)	1965	Pacific region
Psila rosae (Fab.)	1963	Europe
Rhagoletis pomonella (Walsh)	1983[1]	Oregon
Hemiptera		
Aelia americana Dallas	1980	E. U.S.
Blissus insularis Barber	1967	E. U.S.
Campyloneura virgula (H.-S.)	1964	?
Corythuca montivaga Drake	1971	?
Elasmucha lateralis (Say)	1969	E. U.S.
Gargaphia arizonica Drake and Carvalho	1970	Arizona
Heterotoma meriopterum (Scopoli)	1964	E. U.S.
Lamprodema maura (Fab.)	1979	?
Nezara viridula (L.)	1986	E. U.S.
Homoptera—Aleyrodidae		
Aleurothrixus floccosus (Maskell)	1966[1]	Tropical America
Aleurotuba jelinekii (Frauenfeld)	1963	Europe
Dialeurodes citrifolii (Morgan)	1985	E. U.S.
Parabemisia myricae (Kuwana)	1978	Japan
Paraleurodes sp.	1978	Mexico
Paraleurodes sp.	1983	Mexico
Siphoninus phillyreae (Haliday)	1988	Europe
Tetraleurodes new sp.	1983	Mexico
Homoptera—Aphidae		
Acrythosiphon kondoi Shinji	1975	Asia
Acrythosiphon loti (Theobald)	1975	?
Brachycaudus rumexicolens (Patch)	1984	Europe
Brachycaudus tragopogonis (Kaltenbach)	1975	Europe
Brachycolus asparagi Mordvilko	1984	N.W. U.S.
Cinara piceicola (Cholodkovsky)	1957	E. U.S.
Diuraphis noxia (Mordvilko)	1988	W. U.S.

Table 1. Continued.

Scientific name	Year first found	Probable origin
Eucarazzia elegans (Ferrari)	1984	Africa
Hysteroneura setariae (Thomas)	1955	U.S.
Illinoia liriodendri (Monell)	1974	E. U.S.
Melanocallis caryaefoliae (Davis)	1958	E. U.S.
Myzus hemerocallis Takahashi	1959	China
Pemphigus bursarius (L.)	1955	E. U.S.
Rhopalomyzus poae (Gillette)	1955	E. U.S.
Rhopalosiphum insertum (Walker)	1955	E. U.S.
Therioaphis riehmi (Borner)	1956	?
Tinocallis nirecola (Shinji)	1985	Japan
Tinocallis platani (Kaltenbach)	1959	Europe
Vesiculaphis caricis (Fullaway)	1962	?
Homoptera—Cicadellidae and Fulgoridae		
Agalliz barretti Ball	1972	Arizona
Balcutha rosea Scott	1982	Mexico
Delphacodes fulvidorsum (Metcalf)	1982	Mexico
Idona minuenda Moznette	1970	Tropical America
Japananus hyalinus (Osborn)	1975	U.S.
Latalus misellus (Ball)	1980	Nevada
Macropsis ulmi (Scott)	1955	Europe
Negosiana dualis Delong	1979	Arizona
Niloparvata wolcotti Muir and Giffard	1975	Puerto Rico
Psammotettix emarginatus Greene	1979	Oregon
Sanctanus sonorus Delong and Hershenberger	1986	W. U.S.
Scaphytopius nitridus (Delong)	1975	Mexico
Siphanta acuta (Walker)	1983	Hawaii
Sogatella kolophon (Kirkaldy)	1985	Mexico
Stirellus prob. *bicolor*	1987	W. U.S.
Texananus gladius Delong	1963	E. U.S.
Trypanalebra balli Young	1983	Arizona
Homoptera—Coccidae and Diaspididae		
Antonina graminis (Maskell)	1957	E. U.S.
Clavaspis ulmi (Johnson)	1967	E. U.S.
Hemiberlesia candidula (Cockerell)	1957	Arizona
Kuwania quercus (Kuwana)	1966	Far East
Parthenolecanium fletcheri (Cockerell)	1963	Canada
Physokermes piceae (Schrank)	1958	E. U.S.
Quadraspidiotus ostreaeformis (Curtis)	1959	E. U.S.
Homoptera—Membracidae		
Idioderma sp.	1988	E. U.S.
Homoptera—Pseudococcidae		
Allococcus sp.	1980	Africa
Cataenococcus olivaceus (Cockerell)	1960	Mexico
Chorizococcus brevicruris McKenzie	1965	Hawaii
Ferrisia virgata (Cockerell)	1963	Mexico
Heterococcus nudus (Green)	1959	E. U.S.
Phenacoccus aceris (Signoret)	1971	E. U.S.
Pseudococcus comstocki (Kuwana)	1967[1]	E. U.S.
Pseudococcus importatus McKenzie	1963	Tropical America
Spilococcus geraniae (Rau)	1966	E. U.S.

Table 1. Continued.

Scientific name	Year first found	Probable origin
Homoptera—Psyllidae		
Acizzia acaciae-baileyanae (Froggatt)	1987	Australia
Blastopsylla occidentalis Taylor	1983	Australia
Calophya schini Tuthill	1984	Peru
Ctenarytaina longicauda Taylor	1983	Australia
Heteropsylla cubana Crawford	1986	Hawaii
Homotoma ficus (L.)	1969	Europe
Pachypsylla celtidis-vesicula Crawford	1960	E. U.S.
Psylla uncatoides (Ferris and Klyver)	1955	Hawaii
Trioza eugeniae Frogg.	1988	Australia
Hymenoptera		
Apis mellifera (Africanized honey bee) L.	1985[1]	Tropical America
Bathyplectes tristis (Gravenhorst)	1957	E. U.S.
Camponotus sayi Emery	1963	W. U.S.
Cardiocondyla nuda (Mayr.)	1958	Asia
Ditropinotus aureoviridis Cwtd.	1966	Oregon
Eumegastigmus transvaalensis Hussey	1960	S. Africa
Fenusa dohrnii (Tischbein)	1986	N.W. U.S.
Megastigmus pistaciae Walker	1967[1]	Asia
Paratrechina longicornis (Latreille)	1967	E. U.S.
Stilpnus gagates Grav.	1985	E. U.S.
Trichoscapa membranifera (Emery)	1963	S. U.S.
Vespula germanica (Christ.)	1986	E. U.S.
Lepidoptera		
Agrotis malefida Guenee	1960	Arizona
Apamea indocilis Walk.	1970	?
Athrips rancidella (H.-S.)	1983	Europe
Bucculatrix tridenticola Brown	1963	E. U.S.
Choristoneura conflictana (Walker)	1960	E. U.S.
Ectomyelois ceratoniae (Zell.)	1983	Arizona
Endothenia albolineana (Kearfott)	1957[1]	E. U.S.
Eumysia mysiella (Dyar)	1975	?
Euxoa ochrogaster (Guenee)	1970	?
Homadaula anisocentra Meyrick	1963	?
Leucoma salicis (L.)	1960	E. U.S.
Lymantria dispar (L.)	1976[1]	E. U.S.
Macronoctua onusta Grote	1970	E. U.S.
Mirificarma formosella (Hub.)	1969	Europe
Oiketicus townsendi (Townsend)	1968	U.S.
Pectinophora gossypiella (Saunders)	1965[1]	Mexico
Periploca nigra Hodges	1962	?
Phyllocnistis sp.	1963	E. U.S.
Podosesia syringae (Harris)	1979	E. U.S.
Rhyacionia frustrana (Comstock)	1971	E. U.S.
Sibine stimulea (Clemens)	1965	E. U.S.
Sideridis rosea Harv.	1970	?
Stenolechia bathrodyas Meyrick	1980	Asia
Zeiraphera vancouverana McD.	1970	U.S.
Mollusca		
Arion ater L.	1960	U.S.
Cecilioides acicula (Muller)	1967	?

Table 1. Continued.

Scientific name	Year first found	Probable origin
Cochlicella ventrosa (Fer.)	1964	?
Hawaiia minuscula (Binnex)	1963	Hawaii
Helicilla maritima (Draparnaud)	1975	Africa
Pupoides albiabris (Adams)	1963	?
Rumina decollata (L.)	1966	Arizona
Orthoptera		
Allonemobius fasciatus (DeGeer)	1969	?
Blatta lateralis Walk.	1978	Africa
Gryllodes supplicans (Walker)	1966	W. U.S.
Neoconocephalus robustus (Scudder)	1959	E. U.S.
Periplaneta brunnea Burmeister	1970	E. U.S.
Periplaneta fuliginosa (Serville)	1966	E. U.S.
Pyconscelus surinamensis (L.)	1988	E. U.S.
Thysanoptera		
Dendropthrips ornatus (Jablonowski)	1968	E. U.S.
Echinothrips americanus Morgan	1982	Hawaii
Gynaikothrips ficorum (Marchal)	1959	?
Haplothrips clarisetis Pries.	1959	Africa
Oedaleothrips hookeri Hood	1973	Texas
Scirtothrips inermis Priesner	1972	Spain
Thrips hawaiiensis (Morgan)	1985	Hawaii

[1] Target of state-mandated eradication program.

only 1963 and 1966 had more than 10 (Fig. 1). The composition by taxon (Table 2) for the new arthropods differs significantly from that based upon the number of species in each taxon (Borror et al., 1981) in the world ($\chi^2 = 457.6$, df = 8, $P \ll 0.001$). Coleoptera ($P \ll 0.001$) and Hymenoptera ($P < 0.01$) occur significantly less frequently than expected while phytophagous Acari ($P < 0.001$), Homoptera ($P \ll 0.001$), and Thysanoptera ($P \ll 0.001$) occur significantly more frequently than expected (Table 1). Each of these latter taxons are closely tied to plants throughout their lifecycles. These data and those concerning the increased immigration of tephritid fruit flies indicate that most of our new introductions are being carried in or on plants. These taxon trends in introductions are similar to those found in Hawaii (Beardsley, 1962, 1979) and the U.S. (Sailer, 1978) for Coleoptera, Homoptera, and Thysanoptera, while differing for Lepidoptera (significantly fewer in all studies). Hoebeke and Wheeler (1983) found significantly greater than expected numbers of exotic Hemiptera and Homoptera in the Northeastern U.S. and Eastern Canada.

The rate at which California is accumulating new invertebrates is less than that for the U.S. as a whole or Hawaii (Sailer, 1978, 1983; Beardsley, 1962, 1979). This appears to be due to the stringent exclusion and eradication efforts of the California Department of Food and Agriculture (Dowell, 1988). Despite these efforts and those of the USDA and other governmental bodies, large numbers of exotic invertebrates are being moved throughout the world (Hamilton, 1983; Hamilton and Langor, 1987; Belskaya and Popova, 1978; Sturgeon, 1971, loc. cit.).

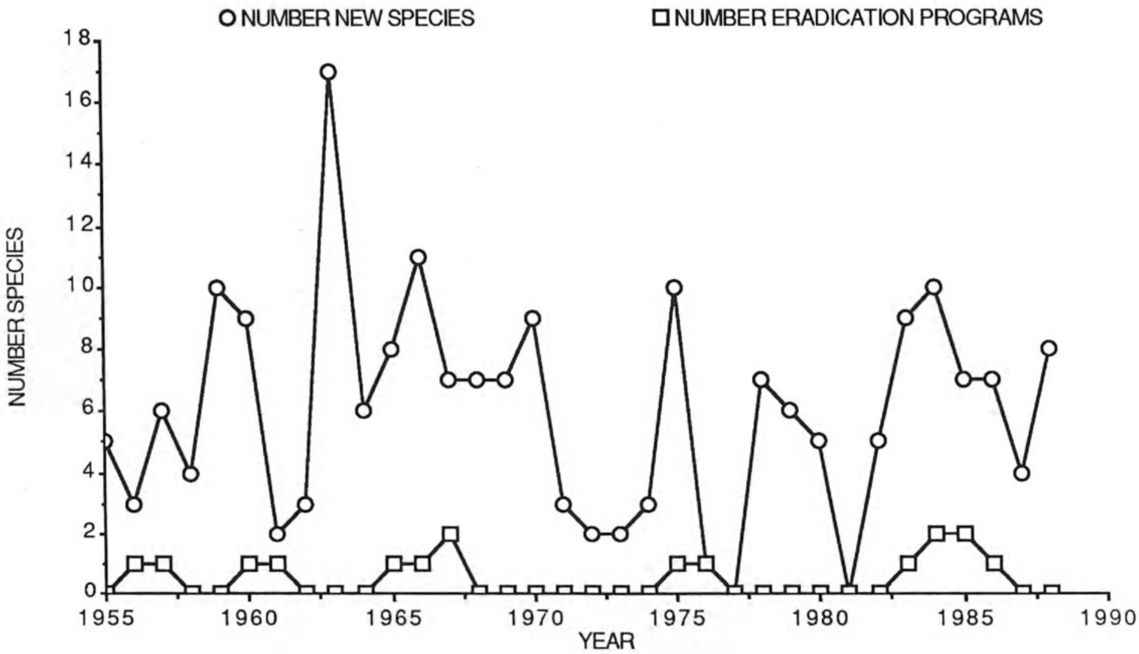

Figure 1. Annual detections of newly established invertebrates and annual number of new eradication programs in California from 1955 to 1988.

Regional Analysis

The largest number of exotic invertebrates came to California from the rest of North America (U.S., Canada, Mexico) (Table 3). The Pacific Region (mostly Hawaii), Europe, and Asia follow with the fewest coming from Africa and Australia. California received 1.5–4.5 times as many of its exotics from Asia, Australia, and the Pacific Region than either the entire U.S. or the Northeastern U.S. and Canada (Sailer, 1978, 1983; Hoebeke and Wheeler, 1983). These figures reflect differences in the trade and tourist routes used on the east and west coasts of the U.S.

There are distinct differences in the origins of the various taxons of exotic invertebrates found in California (Table 4). North America accounted for the

Table 2. Number of newly established exotic invertebrates by order.

Taxon	Number established (%)	Number targeted for eradication	Percentage of total eradication projects
Acari	27 (13.0)	0	0
Coleoptera	25 (12.0)	2	12.5[1]
Diptera	20 (9.6)	7	43.8
Hemiptera	9 (4.3)	0	0
Homoptera	70 (33.7)	2	12.5
Hymenoptera	12 (5.8)	2	12.5
Lepidoptera	24 (11.5)	3	18.8
Mollusca	7 (3.4)	0	0
Orthoptera	7 (3.4)	0	0
Thysanoptera	7 (3.4)	0	0
Total	208 (100)	16	100

[1] Based upon $n = 16$.

Table 3. Probable origins of newly established invertebrates in California (1955–1988).

Region	Number of organisms	% of total	Eradications	
			n	%
Africa	6	2.9	0	0
Asia	10	4.8	3	30.0[1]
Australia	5	2.4	0	0
Europe	16	7.7	0	0
North America[2]	118	56.7	8	6.8
Pacific region[3]	19	9.1	3	15.8
Tropical America	7	3.4	0	0
Unknown	27	13.0	0	0

[1] Based upon number of organisms.
[2] Includes Mexico.
[3] Includes Hawaii.

majority of all Acari (55%), Coleoptera (86%), Hemiptera (100%), Homoptera (61%), Hymenoptera (75%), Lepidoptera (83%), and Orthoptera (83%). Only 33–45% of all Diptera, Mollusca, and Thysanoptera came from North America.

There have been increases in the rate of introductions of Diptera (233%), Homoptera (179%), and Hymenoptera since 1980 compared to the previous decade (Table 5). The rate of introduction of Coleoptera and Lepidoptera has declined (40% and 67%, respectively) during the same period. Only one new Molluscan has been found since 1966. There are no significant differences in the number of new introductions in each 5-yr interval ($\chi^2 = 8.2$, df = 6, $P > 0.05$) (Table 5).

There have been increases in the rate of introductions from Asia (300%), Australia, Europe (300%), Pacific Region (300%) and Tropical America (150%) since 1980 compared to the previous decade (Table 6). There has been a 92% decline in the number of introductions whose origins are unknown for the same period.

CDFA staff have assumed that with increasing numbers of Asians moving to California over the last 10–15 yr there would be an increase in the importation of native foods and an increase in the rate of introduction of pests from that region. Both of these events have occurred (Pemberton, 1988) (Table 6).

Two trends in the composition of exotic invertebrates coming into California

Table 4. Taxon by region composition of new invertebrates introduced to California.

Order	Africa	Asia	Australia	Europe	North America	Pacific region	Tropical America	Unknown
Acari	0	0	0	4	11	3	2	7
Coleoptera	0	1	1	1	19	0	0	3
Diptera	0	3	0	1	9	7	0	0
Hemiptera	0	0	0	0	6	0	0	3
Homoptera	2	3	4	7	41	6	4	3
Hymenoptera	1	2	0	0	8	0	1	0
Lepidoptera	0	1	0	2	15	0	0	6
Mollusca	1	0	0	0	2	1	0	3
Orthoptera	1	0	0	0	3	0	0	1
Thysanoptera	1	0	0	1	2	2	0	1
Totals	6	10	5	16	118	19	7	27

Table 5. Order specific introductions by 5-yr intervals.

Taxon	Number established years						
	1955–1959	1960–1964	1965–1969	1970–1974	1975–1979	1980–1984	1985–1988
Acari	3	4	6	1	5	6	2
Coleoptera	5	4	8	4	1	2	1
Diptera	1	5	4	0	3	2	5
Hemiptera	0	2	2	2	1	1	1
Homoptera	16	8	7	4	10	14	11
Hymenoptera	2	3	3	0	0	0	4
Lepidoptera	1	7	4	6	3	3	0
Mollusca	0	4	2	0	1	0	0
Orthoptera	1	0	3	1	1	0	1
Thysanoptera	2	0	1	2	0	1	1
Totals	31	37	40	20	25	29	26
Avg./year	6.2	7.4	8.0	4.0	5.0	5.0	6.5

since 1980 are especially disturbing. The first is the increase in the immigration of Asian and Australian insects (Table 6). The second is the increase of fruit-attacking Diptera (Table 5). These trends are heightened if detections of single individuals are included. Since 1985, CDFA has trapped a single Queensland fruit fly (*Dacus tryoni*) from Australia and single specimens of *Dacus scutellatus* and *Dacus* sp. from Africa, bringing the total number of new Diptera since 1985 to seven with all but two from Asia or Australia. Considering the tremendous potential these fruit flies have to inflict crop losses and increase pesticide use (Dowell, 1983, 1985) these trends do not bode well for California in the future.

CDFA Response

CDFA targeted 16 of the 208 detected invaders for state mandated eradication programs (Table 7). Nine of these programs were successful, six were not successful and one is still in progress. Six of these organisms (e.g., gypsy moth, Oriental fruit fly) have been the objects of repeated, successful eradication programs (Table 7). Diptera have accounted for 43.8% of all eradication programs followed by Lepidoptera and Coleoptera, Homoptera, and Hymenoptera (Table 2). Over 35% of all new Diptera were the object of CDFA mandated eradication programs. This rate is 2.5 to 12.5 times higher than for any other order.

Table 6. Region specific introductions by 5-yr intervals.

Region	Number established years						
	1955–1959	1960–1964	1965–1969	1970–1974	1975–1979	1980–1984	1985–1988
Africa	1	1	0	0	2	2	0
Asia	2	1	3	0	1	1	2
Australia	0	0	0	0	0	3	2
Europe	2	4	2	1	1	4	2
North America	20	20	25	12	12	13	16
Pacific region	2	3	6	0	2	3	3
Tropical America	0	1	1	1	1	2	1
Unknown	4	7	3	6	6	1	0
Totals	31	37	40	20	25	29	26

Table 7. Status of eradication programs (1955–1988).

Target	Year started	Year ended	Status
Aleurothrixus floccosus	1966	1971	failed
Anastrepha suspensa	1984	1984	successful
Anthonomus grandis	1984	to present	in progress
Aphis mellifera (Africanized)	1985	1986	successful
Ceratitis capitata	1975[1]	1976	successful
Dacus correctus	1986	1987	successful
Dacus cucurbitae	1956[1]	1957	successful
Dacus dorsalis	1960[1]	1961	successful
Dacus zonatus	1985[1]	1986	successful
Endothenia albolineana	1957	1970	failed
Lymantria dispar	1976[1]	1979	successful
Megastigmus pistaciae	1967	1970	failed
Pseudococcus comstocki	1967	1976	failed
Pectinophora gossypiella	1965	1970	failed
Popillia japonica	1961[1]	1965	successful
Rhagoletis pomonella	1983	1986	failed

[1] First introduction for each pest. Subsequent infestations not included in our analysis.

Since few other political entities attempt to eradicate new infestations of exotic pests, it is difficult to evaluate how California compares with other states or countries. British Columbia, Canada, attempted to eradicate 2 of 43 accidentally introduced Lepidoptera (4.7%) (Gillespie and Gillespie, 1982). California's rate is nearly three-fold higher.

The greatest number of eradication targets came from North America with roughly equal numbers from Asia, the Pacific Region, and Tropical America. However, new introductions from these areas became the objects of CDFA eradication programs 3 to 4 times more often than those from North America (Table 3). A χ^2 analysis shows that new invaders from Asia are targeted for eradication significantly more often than expected based upon their proportion of all introductions ($\chi^2 = 5.67$, $P < 0.02$). A similar analysis shows that Diptera are targeted for eradication significantly more frequently than expected ($\chi^2 = 22.2$, $P < 0.001$). Not surprisingly most of the new immigrants from Asia have been fruit infesting Diptera (Tables 1, 4).

Although the average number of eradication programs per 5-yr period has risen consistently since 1970–1974, there is no significant difference in the number of programs started per 5-yr period ($\chi^2 = 5.33$, df = 6, $P > 0.05$).

Since 1955, CDFA has not successfully eradicated any Homopteran. The success rate against Lepidoptera is 33.3% while those for Hymenoptera and Diptera were 50% and 86%, respectively. All completed programs against Coleoptera have been successful, with one program in progress.

Hawaii deserves special mention as the origin of exotic invertebrates coming to California. A total of 14 invaders originated in Hawaii (Table 1) which is equal to or greater than all other regions except North America and Europe (Table 3). Over 73% of all Pacific Region invaders came from Hawaii. These included three fruit flies targeted for eradication (Tables 1, 7). Each of these has invaded and been eradicated from California 2–17 times (Dowell, pers. comm.). In many respects Hawaii acts as a staging area that collects exotic invertebrates from which they then "jump" to California.

Effect on California

Introduced invertebrates have a long history of causing extensive crop damage in California. Before the widespread use of resistant rootstocks, the grape phylloxera, *Daktulosphaira vitifoliae,* destroyed over 46,000,000 grapevines (Dowell and Krass, 1988). As late as 1978, this pest was credited with over $8,000,000 damage to California grapes (Papp, 1979). The codling moth and Oriental fruit moth caused $6,365,000 and $7,782,000 in crop losses, respectively, in 1978 (Papp, 1979). The pink bollworm (*Pectinophora gossypiella*) increased azinphosmethyl use on California cotton 11-fold within 12 yr of its discovery to 93,440 kg of active ingredient (AI) in 1977. Dowell (1983, 1985, unpubl. data) estimated that the fruit flies listed in Table 7 could cause crop losses in excess of $694,000,000 per year should they become established in the state. These are losses after appropriate pesticides have been used.

Application costs for these pesticides are estimated at $108,525,000 per year. Most alarmingly, it is estimated that annual commercial pesticide use could increase by 1,095,000 kg AI per year with annual residential pesticide use increasing by over 4,500,000 kg AI against these fruit flies.

In addition to these costs, the presence of many of these pests could greatly interfere with current efforts to develop non-insecticidal controls for existing pests. Presence of the apple maggot could end efforts to develop pheromone confusion tactics for the codling moth. Sprays needed to control the apple maggot would overlap with the flight period of the codling moth. Since apple maggot insecticides are effective against codling moth and since they must be applied for the maggot, there is little to no incentive to develop alternate control technologies for the codling moth. Presence of the boll weevil could eliminate the use of pheromone confusion to control the pink bollworm. Use of pheromone confusion and good management practices have reduced pesticide use against this pest by 92% since 1977. These insects share the same flight period and host. As with the apple maggot/codling moth situation, pesticides applied to control the boll weevil will also control the pink bollworm.

The problems posed by these exotic pests are not confined to agricultural plantings. The eucalyptus borer (*Phoracantha semipunctata*) poses a serious threat to the extensive eucalyptus plantings in California. Large scale deaths of these trees can significantly increase the fire hazard in many areas. The fuchsia mite, *Aculops fuchsiae*; woolly and cloudywinged whiteflies, *Aleurothrixus floccosus* and *Dialeurodes citrifolii*; southern green stinkbug, *Nezara viridula*; oak scale, *Kuwania quercus*; and pepper tree psyllid, *Calophya schini* all pose significant problems to ornamental plants.

The roaches, *Periplaneta brunnea* and *P. fuliginosa,* and the hornet, *Vespula germanica,* will become pests of our houses and persons. The Africanized honey bee has the potential of becoming a major public health problem. Each of these organisms has already caused or has the potential to cause measurable increases in pesticide use by homeowners.

Conclusions

Exotic plants and animals have already altered the California landscape. Eucalyptus trees, annual grasses, yellow starthistle, English sparrows, starlings, honey bees, cabbage butterflies, brown garden snails, house flies, German cockroaches, and Norway rats are examples of exotic organisms with which Californians deal on a daily basis. Most commercial crops including citrus, cotton, English walnut, alfalfa, and stone fruits were brought to California. As our data show, this flow of exotic immigrants poses serious threats to current efforts to reduce both agricultural and homeowner pesticide use, efforts to reestablish native plant communities (see Vitousek et al., 1987, for an example), and to develop sustainable, low input agriculture. Based upon this situation we conclude the following: (1) The immigration of exotic organisms cannot be stopped but we can prepare for their arrival. Such preparation includes developing data bases on the biology and control tactics for potential invaders. (2) An active biological control program is needed to seek, import, and establish natural enemies of these invaders. California has been extremely successful with this tactic. (3) Good pest management programs are needed to enhance naturally occurring predators, and plant breeding programs are needed to develop pest resistant plant cultivars. Through such efforts California can and will continue to meet the challenges posed by the immigration of exotic plant and animal pests.

Literature Cited

Arzone, A., C. Vidano, and A. Alma. 1987. Auchenorrhyncha introduced in Europe from the Nearctic region: taxonomic and phytopathological problems. Pp. 3–17 *in* M. R. Wilson and L. R. Nault (eds.), Proc. 2nd Int. Cong. Leafhoppers and Planthoppers Econ. Import. CIE, London.

Beardsley, J. W. 1962. On accidental immigration and establishment of terrestrial arthropods in Hawaii during recent years. Proc. Hawaiian Entomol. Soc., 18:99–109.

———. 1979. New immigrant insects in Hawaii 1962 through 1976. Proc. Hawaiian Entomol. Soc., 23:35–44.

Belskaya, N. M., and L. G. Popova. 1978. Injurious insects in cargoes from India. Zashchita Rastenii 2:42–43 (in Russian).

Borror, D. J., D. M. DeLong, and C. A. Triplehorn. 1981. An introduction to the study of insects. Saunders College Pub., Philadelphia. 928 pp.

Brown, F. G. 1986. Bark beetles and ambrosia beetles (Coleoptera: Scolytidae and Platypodidae) intercepted at Japanese ports with descriptions of new species, XV. Kontyu (Tokyo), 54:661–671.

Cochrane, S. 1985. Why rare species. Outdoor Calif. Sept./Oct. 1985: 20–23.

Dowell, R. V. 1983. The medfly in California: the threat. Hortsci., 18:40–44.

———. 1985. Surveillance and control of exotic insect pests in California. Bull. Soc. Vector Ecol., 10:52–59.

———. 1988. Exclusion, detection, and eradication of exotic fruit flies in California. *In* M. T. Ali Niazee (ed.), Ecology and management of economically important fruit flies. Agric. Exp. Stn. Ore. St. Univ. Special Rpt., 830:98–112.

———, and C. J. Krass. 1989. Quarantines and grape pest management. *In* L. T. Wilson (ed.), Grape pest management. U.C. Press, In press.

Gillespie, D. R., and B. I. Gillespie. 1982. A list of plant-feeding Lepidoptera introduced into British Columbia. J. Entomol. Soc. Brit. Columbia, 79:37–54.

Hamilton, K. G. A. 1983. Introduced and native leafhoppers common to the Old and New Worlds (Rynchota: Homoptera: Cicadellidae). Can. Ent., 115:473–511.

———, and D. W. Langor. 1987. Leafhopper fauna of Newfoundland and Cape Breton Islands (Rynchota: Homoptera: Cicadellidae). Can. Ent., 119:663–695.

Hoebeke, E. R., and A. G. Wheeler. 1983. Exotic insects reported new to Northeastern United States and Eastern Canada since 1970. J. N.Y. Entomol. Soc., 91:193–222.

Moran, V. C. 1983. The phytophagous insects and mites of cultivated plants in South Africa: patterns and pest status. J. Appl. Ecol., 20:439–450.

Papp, C. S. 1979. Estimated damage and crop loss caused by insects and mites 1978. California Dept. Food and Agric. Pub., 28 pp.

Pemberton, R. W. 1988. The use of the Thai giant waterbug, *Lethocerus indicus* (Hemiptera: Belostomatidae), as human food in California. Pan-Pac. Entomol., 64:81–82.

Sailer, R. I. 1978. Our immigrant insect fauna. Bull. Entomol. Soc. Amer., 24:3–11.

———. 1983. History of insect introductions. Pp. 15–38 *in* C. L. Wilson and C. L. Graham (eds.), Exotic plant pests and North American agriculture. Academic Press, New York.

Stephanova, N. E. 1981. Invasion of the entomofauna of the Krasnodar Region by foreign species. Vsesoyuznoe Entomol. Obshchestvo, 1981:160–162 (in Russian).

Sturgeon, R. K. 1971. *Achatina fulica* infestation in North Miami, Florida. The Biologist, 53:93–103.

Turnbull, A. L. 1979. Recent changes to the insect fauna of Canada. Mem. Ent. Soc. Can., 108:180–194.

———. 1980. Man and insects: the influence of human settlement on the insect fauna of Canada. Can. Ent., 112:1177–1184.

Vitousek, P. M., L. R. Walker, L. D. Whitaker, D. Mueller-Dombois, and P. A. Matson. 1987. Biological invasion by *Myrica faya* alters ecosystem development in Hawaii. Science, 238:802–804.