PERSPECTIVES ON MANAGEMENT OF PESTIFEROUS CHIRONOMIDAE (DIPTERA), AN EMERGING GLOBAL PROBLEM

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ABSTRACT. In recent years, adult Chironomidae emerging from some urban natural or man-made habitats have increasingly posed a variety of nuisance and economic problems, and in some situations medical problems to humans in different parts of the world. Although there are an estimated 4,000 or more species of chironomid midges worldwide, less than 100 species have been reported to be pestiferous. Among midge control methods, numerous laboratory and field studies have been conducted on the use of organochlorines, organophosphates (OPs), pyrethroids and insect growth regulators (IGRs). Field use of OP insecticides such as chlorpyrifos, temephos and others in the USA and Japan has generally resulted in larval control for 2–5 wk or longer with application rates below 0.56 kg AI/ha (USA) and <1–5 ppm (Japan). Frequent use of some OP insecticides in the USA and Japan has caused their increased tolerance in several midge species. The IGRs, diflubenzuron and methoprene, provide alternate means for midge control. These IGRs in some situations suppressed adult midge emergence by >90% at rates <0.3 kg AI/ha. A number of parasites and pathogens have been reported from midges in different parts of the world. *Bacillus thuringiensis* serovar. *israelensis* is effective against some midge species, but at rates at least 10× or higher established for mosquito larvicidal activity. The flatworm, *Dugesia dorotocephala*, and some fish species offer a good potential for midge control in some situations. In large habitats covering hundreds or thousands of ha, information on the basic ecology of larval midges and adult behavior is essential for formulating midge control criteria. More research is needed on the biological and physical and cultural control of these pestiferous insects.

INTRODUCTION

Nonbiting midge flies of the dipteran family Chironomidae commonly occur in most inland natural or man-made aquatic ecosystems of diverse natures. They inhabit shallow and fast flowing headwaters of streams and rivers as well as deep and slow moving waters in lagoons. Midges occur in stagnant waters in small and shallow temporary or permanent ditches and ponds and in large shallow or deep lakes. Chironomid larvae exhibit a very wide range of tolerance to environmental conditions as indicated by their presence in "clean" waters saturated with dissolved oxygen, as well as in "polluted" waters very low in oxygen. The occurrence of certain species of midges in polluted waters is indicative of the type of pollution in their habitat. Due to their adaptive nature, some midge species survive even in brackish, estuarine or marine environments. Although most chironomids are aquatic, a few species occur in decaying organic matter, under bark, or in moist soil.

In recent years, large populations of midge larvae have been reported in different countries (e.g., USA, Japan, Italy, Sudan and others). Some central Florida lakes support midge larval densities of 10,000–40,000/m^2 or higher, resulting in heavy emergence of adult midges from these lakes (Ali and Baggs 1982, Callahan and Morris 1987, Patterson 1964). Similar larval densities of midges are encountered in some rivers and lakes of Japan (Moriya 1977, Ohno and Shimizu 1982, Tabaru 1975, Tabaru et al. 1978), in the lagoon surrounding the city of Venice, Italy (Ali et al. 1985b), in man-made urban and suburban aquatic environments, such as shallow and open wastewater channels (Ali and Mulla 1976a), water spreading basins (Ali and Mulla 1978a), sewage oxidation and settling ponds and overflow gutters (Edwards et al. 1964, Spiller 1965,Tabaru 1985b), and residential-recreational lakes (Ali and Mulla 1977b, Ali et al. 1978).

Generally, water bodies in urban and suburban areas exposed to intensive human use (residential, recreational, agricultural, etc.) and also receiving discharges from point and nonpoint sources are becoming increasingly eutrophic. As a consequence, macrofaunal species diversity in these habitats is gradually decreasing and results in the survival and profuse breeding of more pollution-tolerant organisms, such as some species of Chironomidae that constitute a major component of the macroinvertebrates. It should be understood that generally chironomid larvae play a beneficial role as an important source of food for the predatory fish and some other invertebrates in the food web of aquatic ecosystems. The larvae also keep the aquatic environment clean by consuming and recycling organic debris; hence, they are considered highly desirable organisms in the ecosystem. However, the adult midges from some densely populated habitats frequently emerge in large numbers, causing a variety of nuisance, economic and in some situations medical problems for humans residing or working near their breeding sources. The ever increasing importance of chironomids as a pest and the somewhat scattered literature on their chemical, biological, physical and cultural control necessitated compilation of this review.

NUISANCE, ECONOMIC AND MEDICAL PROBLEMS

Dense swarms of midges often limit outdoor human activity since the adults can be inhaled or fly into the mouth, eyes and ears of an individual. They are liable to cause asphyxia in cattle. During summer, midges seek cool and shady places in the daytime leaving behind stained stucco, paint and other wall finishes on which they rest. They also soil automobiles, and cover the headlights and windshields, causing traffic accidents. At night, the adults are attracted to light, swarming around indoor and outdoor fixtures. Adults of some small-sized species pass through standard screens on doors and windows and thus create nuisance and economic problems indoors, such as staining laundry, walls, ceilings, draperies and other furnishings as well as causing discomfort for the residents. Adult midges cause a considerable economic loss to the hotel and tourism industry (Ali 1980b). Accumulations of dead midges and the unsightly spider webs in which midges are trapped require frequent washing and maintenance of properties. They clog automobile radiators and air-conditioning wall units and are a problem for some paint, pharmaceutical and food processing industries where hordes of adults fly into the final products. The dead midges produce an unpleasant odor similar to rotting fish. This odor persists in damp weather for several days, even after the adults have been removed. At times, the dead adults accumulate on roads in such quantities that they make the roads slippery, causing traffic hazards. At the Marco Polo Airport near Venice, Italy, there is a great concern for the potential of airplanes skidding over massive accumulations of dead midges on the runways, and also, of economic loss due to the adults flying into delicate equipment (gauges) mounted on the planes (E. Tsuroplis, personal communication). Midge swarms pose severe nuisance problems to passengers and crews of cargo vessels and other boats moving through the lagoon of Venice, thus adversely affecting human activity in that historically touristic area.

Adult midges are not vectors of any disease organism although they are considered to be mechanical carriers of some microorganisms when emerging from polluted waters (Lysenko 1957, Steinhaus and Brinley 1957). They are, however, associated with human allergic reactions such as asthma and rhinitis in Africa (Cranston et al. 1981, Gad-El-Rab and Kay 1980), Europe (Giacomin and Tassi 1988) and Asia (Ito et al. 1986). It is believed that midges are a potential cause of allergies worldwide (Cranston et al. 1983). Adult midges may even cause anaphylactic shock in some individuals (M. Sasa, personal communication).

Chironomid larvae, too, can produce certain undesirable effects. When inhabiting storage and distribution systems for potable water, larvae may pass through taps causing concern to householders. There are numerous reports of midges infesting water systems in various parts of the world (e.g., Hafiz 1939, Flentje 1945a, Wilhelmi 1925, Williams 1974). Larvae of several midge species also have been implicated as agricultural pests. For example, there are several reports of damage to rice seeds and plants by chironomid larvae (Darby 1962, Ishihara 1972, Risbec 1951); members of the subfamily Orthocladiinae injure roots of Japanese horseradish (Yokogi and Ueno 1971); and *Stenochironomus nelumbus* feeds on floating leaves of lotus (*Nelumbo nucifera*) (Tokunaga and Kuroda 1936).

PREDOMINANT NUISANCE SPECIES

There are probably more than 2,500 species of Chironomidae in North America (Coffman and Ferrington 1984). It is estimated that there are 4,000 or more species of midges worldwide (A. Soponis, personal communication). A summary of ecological and distributional data on Chironomidae was given by Coffman and Ferrington (1984). Of the 7 subfamilies of Chironomidae, species most commonly encountered in heavy midge producing urban and suburban habitats are in the genera *Chironomus*, *Cryptochironomus*, *Goeldichironomus*, *Glyptotendipes*, *Dicrotendipes*, *Paralauterborniella*, *Polypedilum*, *Tanytarsus*, *Cladotanytarsus*, *Rheotanytarsus*, *Tokunagayusurika*, *Cricotopus*, *Procladius*, *Coelotanypus*, *Tanypus* and *Pentaneura*. Species of a few other quantitatively less important genera may also occur in some locations.

In general, *Chironomus decorus*, *C. frommeri*, *Dicrotendipes californicus*, *Cricotopus bicinctus*, *C. sylvestris*, *Procladius freemani* and a few species of *Tanytarsus* are most widely distributed in California and are potentially pestiferous (Ali and Mulla 1979b). Specifically, in 1–2 m deep man-made lakes, water spreading basins and flood control channels in southern California, *Tanytarsus*, *Chironomus* and *Procladius* are most common (Ali and Mulla 1975, 1976b; Ali et al. 1978), while *Cricotopus* predominates in storm drains (Ali and Mulla 1979c, Ali et al. 1977). In 2–4 m deep recreational lakes in California, *Chironomus* and *Procladius* are most abundant and emerge at nuisance levels (Ali and Mulla 1977b, Mulla et al. 1975, 1976). The species composition of adult midges in some southern California problem situations was compiled by Grodhaus (1968) and Ali and Mulla (1979b).

In Florida, *Glyptotendipes paripes*, *Chironomus crassicaudatus* and *C. decorus* are the major pest species of midges (Ali and Baggs 1982, Ali and Fowler 1985). Beck and Beck (1969) also provided a list of nuisance species of chironomids in Florida. In Illinois, *Chironomus riparius* causes annoyance (Polls et al. 1975), *C. decorus* was a problem in New York (Jamnback 1956) and *C. plumosus* in Wisconsin (Hilsenhoff 1959). There may be several more unreported pestiferous species of chironomids in the United States. Outside of the United States in recent years, *Cladotanytarsus lewisi* in Sudan (Cranston et al. 1981), *Chironomus salinarius* in Italy (Ali et al. 1985b), and *Tokunagayusurika akamusi*, *Chironomus yoshimatsui* and *C. plumosus* in Japan (Tabaru et al. 1987) have been reported to be pestiferous and/or a cause of allergies.

Identification of larval and adult chironomids to the species level is somewhat difficult due to the lack of proper taxonomic keys; however, generic identification is feasible under most circumstances. In combination, the keys provided by Beck and Beck (1969), Coffman and Ferrington (1984), Darby (1962), Mason (1973), Oliver et al. (1978), Roback (1971), Sublette (1960, 1964), Sublette and Sublette (1971) and Wirth and Stone (1956) are useful. For taxonomic purposes and other laboratory investigations, some midge species can be reared and/or colonized by using the techniques of Biever (1965, 1971).

CONTROL METHODS

A variety of control methods have been investigated in the past several decades. Most of these studies were focused on chemical control. Some work has been conducted on biological control of this pest through the use of predators. A number of parasites and pathogens have been reported from midges, but very few of these microbial organisms have been subjected to mass culturing and inoculation of natural breeding sources, or studied in a quantitative manner. Physical and cultural control methodologies of chironomids also remain the least explored.

In some situations, satisfactory but temporary control of chironomids may be achieved by employing physical and cultural, biological or chemical means, depending upon the nature of the breeding source. Usually, in small habitats (<200 ha) one or more control techniques are effective. However, an integrated approach combining the various control methodologies is desirable and should produce better results. In lakes and lagoons covering several thousand ha, such as in central Florida or around Venice, Italy, midge control by the use of insecticides as larvicides is not economically feasible because of the large volumes of water to be treated. Chemical displacement, adverse effects on aquatic nontarget organisms and other environmental concerns also severely restrict or prevent the use of insecticides as larvicides. In such habitats, an understanding of the ecology and manipulation of the larval environment and the adult behavior, combined with the use of natural enemies, may provide some solution to the problem.

Physical and cultural: Midge control methods through environmental management are poorly developed, primarily because a precise understanding of the ecological bases for midge production in various problem habitats is lacking. Among the methods used to reduce larval densities, the mechanical removal of sludge and egg masses of chironomids from the sides of rivers, and disturbing the riverbeds by dredging and mixing the substrate materials (Shimizu 1978) were ineffective in producing control. In semipermanent habitats, such as water spreading basins, some reductions in midge populations may be achieved by rotational flooding and drying of partial areas of breeding sources (Anderson et al. 1964). However, more frequent drying, dredging and reflooding of such habitats may be conducive to higher midge productivity and midge nuisance problems (Ali and Mulla 1978a). Increase in depth of some temporary or permanent habitats also reduced some midge populations (Ali and Mulla 1976c). In concrete-lined storm drains, removal of substrate materials by mechanical means, or by natural factors such as rainfall, reduced populations of midge larvae (Ali et al. 1976b, 1977). Proper designing of reservoirs and lakes in some situations would be helpful in keeping midge populations at lower levels (Magy 1968). Information related to nutrient cycles and availability, and the influence of nutrients on primary and secondary productivity, which in turn have an impact on the abundance of nuisance chironomids in some man-made habitats, is desirable (Johnson and Mulla 1984). Understanding the role of macrophytes as physical barriers or as sources of release of biologically active chemicals that interfere with midge survival and development in some habitats is useful for the ecological manipulation of midge production (Johnson and Mulla 1982b, 1983).

Exploration of midge control by physical and cultural control techniques is highly desirable in huge breeding sources, such as the lakes in central Florida and the lagoon of Venice, Italy. In such situations, knowledge of the physicochemical environment of the nuisance species, i.e., the physical and chemical composition of the substrate materials and chemistry of the overlying water in relation to the spatial and seasonal abundance and distribution of larvae of the pest species, may provide a clue to their ecological basis of production. Their proliferation could then be discouraged by manipulating the nutrients (pollutants) and/or other factors conducive to their breeding and rapid propagation. Recently, chemistry of sediments, water chemistry and midge populations in a central Florida lake, Lake Monroe, were monitored by Ali (1989). These studies revealed that larval densities of *G. paripes* and *C. crassicaudatus* were inversely related with water depth, and that populations of the former species were inversely associated with total phosphorus (TP), Kjeldahl nitrogen (kj-N), organic carbon and some micronutrients while the latter species was distributed irrespective of the concentrations of these chemical parameters.

Thus, environmental requirements of midge species may differ from species to species. Both *G. paripes* and *C. crassicaudatus*, however, showed significant (0.01 level) positive correlations with electrical conductivity, concentrations of chlorophyll *a*, and the standing crop of Cyanobacteria (="blue-green algae") and total phytoplankton. Since larvae of *C. crassicaudatus* (Ali 1990) and *G. paripes* (Provost and Branch 1959) feed on phytoplankton, particularly Cyanobacteria, and the abundance of these species is directly related to the phytoplankton abundance, it was concluded that the occurrence of high densities of *C. crassicaudatus* and *G. paripes* was a function of phytoplankton abundance in water. However, many other interrelated biological and chemical parameters may also play some role in the population fluctuations of these midges. Since Lake Monroe is a part of the St. Johns River system, it may be possible to artificially increase the water flow through the lake at times of midge larval abundance to displace phytoplankton populations and, in turn, reduce midge densities. Thus, it appears that in some large habitats, physical and cultural control of midges may be practical through knowledge of the basic ecology of the nuisance species. The ecology should be investigated in habitats such as the lagoon of Venice and in other locations because each habitat possesses its own characteristics in terms of midge and other invertebrate fauna. Information gathered in one habitat may not be applicable to another with similar problems.

Another possibility of cultural control of midges is through the understanding and manipulation of their adult behavior. For example, studies in the laboratory (Ali et al. 1984) and field (Ali et al. 1986) in central Florida on the attraction of *G. paripes*, *C. crassicaudatus*, *G. holoprasinus*, *P. halterale* and other species revealed that among a combination of white (incandescent and fluorescent), yellow, orange, blue, green and red lamps of the same wattage, these species were generally attracted the most to white light (highest intensity) and the least to blue, green or red light (lowest intensity). This behavior of adult midges is in contrast to adult mosquito behavior; a majority of mosquitoes respond to a specific color or wavelength in the electromagnetic spectrum (Ali et al. 1989b), while midge species respond more to the quantity (power or intensity) of light (Ali et al. 1984). Such information is of practical significance in controlling midges. Fifty or so species of chironomids and 3 of *Chaoborus* were collectively responsible for the "lakefly nuisance" at Entebbe, Uganda; this nuisance was being ameliorated in 1962 by the use of UV mercury-vapor lamps faced away from occupied buildings, combined with window-screening, the elimination of hedges in the lakeward side of dwellings, and the planting of hedges on the landward side to direct the flies beyond houses and their gardens (M. Laird, personal communication). Many habitats producing midges at nuisance levels in Florida, Italy (Venice lagoon) and perhaps elsewhere are surrounded by a high density of homes and businesses interspersed with less densely inhabited areas. If dimmer lights could be used in the densely inhabited areas and high intensity (brighter) lights installed in and around the less densely inhabited areas, adult midges would be drawn to the latter areas where suitable control measures could be implemented. Along the lines of midge adult behavioral studies for control purpose, information on adult dispersal (Ali and Fowler 1983), patterns of abundance (Ali et al. 1983, 1985a) and diel eclosion periodicity (Ali 1980a, Ali and Mulla 1979a, Ferrarese and Ceretti 1989) should be useful in reducing the cost of adulticiding. Applications of insecticides could be synchronized with the emergence of adults, thereby reducing the area to be treated and the amount of material needed.

In some situations, relief from adult midges is achieved by using electrocutor traps. However, the attraction of huge numbers of adults in most situations cause the traps to malfunction as their body fragments stick and completely cover the grid in the trap. Intensive research is presently being conducted to improve the efficiency of electrocutor traps for midge control (W. Adkins, personal communication).

Biological: parasites and pathogens: Many biotic control agents regulate populations of chironomids in nature. Viruses, rickettsiae, protozoans, nematodes and fungi have been reported in the literature.

Among aquatic insects, only chironomid midges are reported to be hosts of entomopoxviruses (Anthony 1975). Weiser (1969), Huger et al. (1970), Stoltz and Summers (1971), Federici et al. (1974), Harkrider and Hall (1975) and Majori et al. (1986) have reported entomopoxviruses in *Camptochironomus tentans, Chironomus luridus, C. attenuatus* (a junior synonym of *C. decorus*) and *C. plumosus, Goeldichironomus holoprasinus, C. decorus* and *C. salinarius*, respectively.

Entomopoxviruses have been shown to play a significant role in the natural regulation of nuisance midge populations (Harkrider and Hall 1978). In laboratory studies, Harkrider and Hall (1979) demonstrated the important role of high midge population density in the precipitation of an epizootic of entomopoxvirus. However, the reported larval mortalities of field populations of chironomid species infected by poxviruses in different habitats range from <1 to 100% (Anthony 1975, Huger et al. 1970, Majori et al. 1986, Weiser 1948). In addition to the poxviruses, a cytoplasmic polyhedrosis virus (CPV) in chironomids collected from Florida was detected by Federici et al. (1973), and another virus closely related to iridoviruses was found in *C. plumosus* in Wisconsin (Stoltz et al. 1968).

Among fungi, the genus *Coelomomyces* is a pathogen of chironomids. Rasin (1929) reported *Coelomomyces chironomi* in midge larvae. Later, this fungus was also found in *C. paraplumosus* in Czechoslovakia (Weiser 1976, Weiser and Vávra 1964). Weiser and McCauley (1971) discovered 2 *Coelomomyces* infections of Chironomidae in Marion Lake, British Columbia, Canada, but their *C. beirnei* is now "highly suspect" as a member of this genus and thought to be a protozoan (Couch and Bland 1985). The same authors also reported a new fungal species, *Bertramia marionensis*, parasitizing midge larvae (Weiser and McCauley 1974).

The occurrence of rickettsiae in midges is rare. *Rickettsiella chironomi* in *C. decorus* (Götz 1972) and a *Rickettsiella*-like organism in *C. frommeri* (Federici et al. 1976) have been reported.

The protozoan parasites of midge larvae are represented by microsporidia and ciliophores. Weiser (1961) discovered 16 species of microsporidia in chironomids. Hilsenhoff and Lovett (1966) found *Thelohania* in a chironomid in Lake Winnebago, WI. They reported that the incidence of disease ranged from 0.9 to 9.5% in field populations with no viable adults maturing from the infected larvae. This agreed with an earlier report of Weiser (1963). Microsporidia can play an important role in the regulation of aquatic insect populations. A good example of the potential value of microsporidian infection is the annihilation of midges in 3 semipermanent ponds 3 wk after initial detection of the diseased larvae (Hunter 1968).

Most reports of ciliates parasitizing insects concern the genus *Tetrahymena*. The systematics and parasitism of this genus was reviewed by Corliss (1960), who reported a fatal attack of *T. chironomi* and *T. pyriformis* on *C. plumosus*. These ciliates were found in up to 11.8% of *C. plumosus* larvae in 8 samples and the incidence was greater in larger larvae; 43.2% of third instar larvae in one sample were parasitized. Barthelmes (1960) found another species, *T. parasitica*, in *C. plumosus*. However, no epizootics of ciliates controlling midge populations have been reported.

A number of nematode parasites of midge larvae have been reported in the literature (e.g., Götz 1964, Karanukaran 1966, McCauley 1973). Johnson (1963, 1965) reported *Octomyomermis itascensis* in *C. plumosus* and *Hydromermis itascensis* in *Glyptotendipes lobiferus* in the central United States. Parenti (1966) found *Paramermis contorta* in *C. tentans* in France. Poinar (1964) reported a new nematode, *Orthomermis oedobranchus*, parasitizing *Smittia* sp. larvae in England, a new species of *Gastromermis* parasitizing *Tanytarsus* larvae in California (Poinar and Ecke 1967), and another mermithid, *Hydromermis conophaga*, in *Tanytarsus* larvae in California (Poinar 1968). There are several other reports indicating that many mermithids have a variety of host chironomids in various parts of the world (Lewis 1957, McCauley 1973, Wülker 1958, 1961, 1963, 1965; Welch and Poinar 1965). Welch and Poinar (1965), Poinar (1981) and Petersen (1985) have discussed the role and use of nematodes in the regulation and control of insects of medical importance.

In the USA, a monthly infection rate of *Hydromermis contorta* in *C. plumosus* ranged from 0 to 24.8% throughout the year (Johnson 1955[1]), while in Germany, natural mermithid infections in *Tanytarsus* midges at certain times of the year were as high as 100% (Wülker 1958, 1961). More recent investigations concerning mermi-

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[1] Johnson, A. A. 1955. Life history studies on *Hydromermis contorta* (Kohn), a nematode parasite of *Chironomus plumosus* (L.). Ph.D. thesis, Univ. Illinois, Urbana.

thids of chironomids are those of Chapman and Ecke (1969) in percolation ponds in California, where the incidence of *H. conophaga* infection in *Tanytarsus* reached 45% in a spring season. The authors concluded that the parasite controlled the midge populations for nearly 2 years after the ponds were first flooded. Such incidences, however, are rarely observed in nature.

Two microbial agents, *Bacillus thuringiensis* serovar. *israelensis* (*B.t.i.*) and *Bacillus sphaericus*, have great larvicidal potential against some Diptera of medical importance (Ali and Nayar 1986, Ali et al. 1981, 1989a; Lacey et al. 1984, Mulla et al. 1982, 1988). Of the 2 spore-forming bacteria, different *B.t.i.* formulations are currently being used as larvicide of mosquitoes and blackflies in various parts of the world (Kurtak et al. 1987, Majori et al. 1987, Merritt et al. 1989, Mulla et al. 1985, World Health Organization 1982). *Bacillus sphaericus*, shown to be highly effective primarily against *Culex* mosquitoes (Ali and Nayar 1986, Ali et al. 1989a, Mulla et al. 1988, World Health Organization 1985), is presently being investigated and developed for commercial use in mosquito control programs. The potential for the 2 biocides in chironomid control has also been investigated (Ali 1981a, Ali and Majori 1984, Ali and Nayar 1986, Ali et al. 1981, 1985b; Rodcharoen et al. 1991). In laboratory bioassays, the LC_{90} values of *G. paripes*, *C. crassicaudatus*, *C. decorus* and *Tanytarsus* midges ranged from 4.56 to 47.02 ppm with different wettable powders (WP) and a flowable concentrate (FC) of *B.t.i.*, including IPS-78 (WP), R-153-78 (WP), ABG-6108 (WP) and SAN-402-WDC (FC), which had potencies of 1,000–3,500 international units of toxicity (ITU)/mg (Ali et al. 1981). The same formulations of *B.t.i.* against *Aedes aegypti* and *Culex quinquefasciatus* larvae were highly active (LC_{90} = 0.13–0.88 ppm), revealing that chironomid midges, in general, are relatively less susceptible to *B.t.i.* than mosquitoes. In other laboratory studies (Ali and Majori 1984, Ali et al. 1985b), Bactimos® (WP), Vectobac® (WP) and Teknar® (FC) containing 1,500–3,500 ITU/mg tested against *C. salinarius* were shown to have LC_{90} values ranged between 5.07 and 38.26 ppm. These results were comparable to those of Ali et al. (1981).

Field tests were conducted in experimental ponds (each 24 m^2 at surface and 0.5 m deep) and in a golf course pond (1 ha at surface and 0.6 m deep) in Florida with a WP formulation of *B.t.i.*, ABG-6108, containing 1,000 ITU/mg (Ali 1981a). At 1, 2, 3, 4 and 10 kg/ha, ABG-6108 gave 18–88% larval reductions of Chironomini and Tanytarsini midges in the experimental ponds. As expected, the highest rate of application (10 kg/ha or 2.5 ppm) gave the highest level of control (88%) after 2 wk of treatment. In the golf course pond, the rate of 3 kg/ha (0.5 ppm) yielded 30–67% reduction of Chironomini, but Tanypodinae midges remained generally unaffected.

More recently, Rodcharoen et al. (1991) conducted a number of field studies with *B.t.i.* for midge control in California. In ponds (each 30 m^2 at surface and 0.3 m deep), Vectobac® 6AS (aqueous suspension containing 600 ITU/mg) at rates of 11.2 and 22.4 kg/ha, yielded a maximum of 37 and 57% reduction, respectively, of *C. decorus*, *C. fulvipillus* and *Paralauterborniella elachistus* midges during the 2-wk evaluation period. In 3 separate man-made lakes (Woodward Lake, Woodbridge North Lake and Lake Calabasas), ranging from 8.4 to 21.6 ha at surface and 1.8 to 2.1 m in depth, different formulations of *B.t.i.* at various rates were evaluated against midges. In Woodward Lake, ABG-6253 (corngrit granules containing 200 ITU/mg) was evaluated at rates of 13.5, 28 and 56 kg/ha in 1.4- to 2-ha separate sections (fingers) of the lake. These rates yielded 22, 83 and 96% control, respectively, of *C. decorus* midges at 2 wk posttreatment. Species of Tanypodinae (*Procladius maculatus* and *Tanypus grodhausi*) remained unaffected. In Woodbridge North Lake, a technical powder (TP) of *B.t.i.*, ABG-6164 (containing 12,430 ITU/mg), was tested at rates of 1.4 and 2.8 kg/ha. These treatments yielded 73 and 87% control, respectively, of *Chironomus* sp. at 2–3 wk posttreatment. In Lake Calabasas, Vectobac® TP containing 5,000 ITU/mg was evaluated at rates of 2.2, 4.5 and 6.7 kg/ha. These treatments resulted in a maximum control of 66, 90 and 100%, respectively, of *Chironomus* midges at 2–3 wk posttreatment.

The laboratory and field evaluations of *B.t.i.* have shown that this biocide is effective mostly against Chironomine midges, although rather high rates of treatment (at least 10× or higher the rates established for mosquito larvicidal activity) are required to achieve satisfactory larval control of midges in some situations (Rodcharoen et al. 1991). The use of such elevated rates of *B.t.i.* in midge control programs may be possible in habitats ranging up to 50 or 100 ha, but would not be economical or practical in large lakes, such as Lake Monroe in Florida or in the lagoon of Venice, Italy. Thus, there is a need to discover new more toxic strain(s) of this biocide to be economically effective against chironomid larvae.

Studies on *B. sphaericus* against chironomids (Ali and Nayar 1986, Sinegre et al. 1990, Rodcharoen et al. 1991) have shown that this bacterium remains ineffective against midge larvae at mosquito control rates or even at very high rates of treatment (11.2 and 22.4 kg/ha). The LC_{50} values of *G. paripes* and *C. crassicaudatus* in the laboratory were >50 ppm for primary powders of strains 1593 and 2362 of *B. sphaericus* (Ali and Nayar 1986). Thus, strains 1593 and 2362 of *B. sphaericus* known to be highly toxic to some mosquito larvae (Ali and Nayar 1986), do not offer any potential for midge control.

Macroinvertebrate predators: Many macroinvertebrates in various phyla are predaceous on midge larvae and pupae in nature. For example, there are several reports of leeches (Bay 1964, Bennike 1943, Elliott 1973, Mann 1957), dragonfly nymphs (Prichard 1964), and dytiscid beetles and *Coelotanypus* midges (Bay 1964) being predaceous on chironomids. Schuytema (1977), in his review of biological control of aquatic nuisances, included predators of chironomids. Bay (1974) reviewed the subject of midge predation by invertebrates and discussed the predator-prey relationships of aquatic insects. So far, however, most accounts in the literature concerning midge predators are qualitative laboratory or field observations where predation by certain invertebrates on midges was noted. Very few of these predators were subjected to quantitative experimentation against midges.

The flatworm, *Dugesia dorotocephala*, is the most studied invertebrate predator of chironomid larvae. Under laboratory and semifield experimental conditions, this planarian was shown to be quite effective in reducing midges (Legner et al. 1975b). Ali and Mulla (1983) evaluated *D. dorotocephala* against chironomids in experimental ponds during 3 consecutive summers. Of the different rates (10, 25, 50 and 100 planaria/m^2) used, the rate of 50 planaria/m^2 reduced midge populations by 32–61% during the 3rd to the 8th wk post-introduction of the predator. In these evaluations, the highest rate (100 planaria/m^2) did not produce the maximum reduction of midge larvae. This was perhaps because the abundance of the flatworm after a certain level was checked and regulated by higher predators in the food chain in these ponds. Since mass rearing of *D. dorotocephala* seems feasible (Tsai and Legner 1977), this predator warrants further development for the biological control of midges. Also, *D. tigrina* should be evaluated as a predator of midge larvae since its production and maintenance of large numbers are possible (Callahan and Morris 1989).

Predatory fish: There are numerous reports of predation by fish on chironomid midges (Bay and Anderson 1965, 1966; Ceretti et al. 1987, Cook 1962, 1964; Cook et al. 1964, Guziur 1976, Kajak et al. 1972, Kimball 1968, Kugler and Chen 1968, Legner et al. 1975a, Mezger 1967, Zur 1980). These studies have shown that chironomid larvae and pupae form a significant part of the diet of fish, including several sunfish, catfish, desert pupfish, young bass, carp, mosquito fish, *Tilapia* and even gilthead seabream. Only the carp appears to have been successful in causing appreciable reductions of midges in field trials (Bay and Anderson 1965, Mezger 1967). Bottom-feeding fish, such as catfish, may also consume considerable numbers of midge larvae, but do not produce significant reductions of midge nuisance in situations of large midge populations where food supply of fish tends to be continuously replaced as it is consumed (Hayne and Ball 1956).

The chironomid component in the diet of fish inhabiting a man-made reservoir in central Florida was recently studied (A. Ali, unpublished). Foregut contents of 14 species of fish taken from the reservoir were examined. Of these, 3 species of sunfish, *Lepomis macrochirus* (bluegill), *L. megalotis* (longear), and *L. microlophus* (redear), and one species of catfish, *Ictaluris* sp., had consumed appreciable numbers of chironomid larvae and pupae. In the foregut of these 4 species, midge larvae and pupae comprised 42–67% by volume, and 42–78% by wet weight, of the total food contents. The total number of midge larvae and pupae in the foregut of these 10–25 cm long fish ranged from 4 to 45. Thus, predatory pressure by the use of these fish could be increased for the possible reduction of midges in some habitats in Florida and elsewhere.

Quantitative evaluations of fish in water spreading basins in the USA have shown that carp, *Cyprinus carpio*, and goldfish, *Carassius auratus*, were effective in reducing midge populations for a short time when stocked at 165–550 kg of fish/ha (Bay and Anderson 1965). Over the long term, however, factors such as pond siltation, filamentous algae and natural enemies tended to maintain larval populations at the same level as did the 2 fish species. When the fish were removed from the basins, midge larval populations increased only temporarily until other controls interceded. The authors concluded that carp are less valuable for midge control in large lakes and temporarily disrupted habitats than in smaller sources of chironomid nuisance. Carp have also been used for the biological control of midge larvae in Japan (Anonymous 1974), but no quantitative data on their effectiveness are available. It should be understood that carp are prolific and aggressive fish. When introduced for midge control, they could outcompete the desirable species of fish and become a pest, inducing permanent and drastic alterations, similar to those produced by the mosquito fish (*Gambusia affinis*) in pond ecosystems (Hurlbert et al. 1972). Introduction of *G. affinis* had resulted in marked reduction of zooplankton populations that fed upon phytoplankton, thereby changing the water quality, as heavy algal blooms resulted due to the absence of zooplankton. The possibility of indiscriminate or preferential feeding of the introduced fish on macroinvertebrate predators (midge predators), which are more efficient than the fish in having access to protective niches where midge larvae prevail, may also disrupt the trophic structure in the aquatic habitat. However, in the presence of predatory fish, such as bass, the number of carp or other midge-predatory fish may be regulated, thus diminishing the undesirable effects produced by the latter.

The possible use of mosquito fish for midge control was studied by Bay and Anderson (1966). They reported that although these fish fed upon chironomid larvae and emerging adults, no reduction in midge populations occurred even when the predator biomass reached more than 276 kg/ha. Cook et al. (1964) studied the impact of the fishery upon the midge population of Clear Lake, CA, and found that chironomid larvae and adults comprised the bulk of the summer diet of mosquito fish, but suggested that these fish feed on chironomid larvae when under food stress, concluding that mosquito fish are of little or no value in chironomid midge control.

Legner and Medved (1973) and Murray (1976) studied the use of exotic fish, such as *Tilapia* spp. for midge control and found them to be highly predaceous on midge larvae. However, *Tilapia* cannot withstand temperatures below 10–12°C and would die each winter, requiring removal of large numbers of dead fish from the midge breeding habitat, and their restocking during summer. Additionally, there is a great environmental risk involved with the introduction of exotic fishes. They interact and compete with native fish and depauperate fish fauna, a problem of great concern to fish and wildlife biologists and conservation agencies. In several instances, introduction of mosquito fish into Nevada (western United States) had adverse effects on the native fish populations (Deacon et al. 1964). Mosquito fish generally compete effectively and may displace native species of fish by consuming food and occupying their niches (Deacon and Bunnel 1970). These considerations, thus, warrant great caution in exercising the introduction and stocking of exotic fishes that offer potential for control of pest insects.

In general, the biological control of midges through the use of midge predatory fish would be partially effective in small (<1–20 ha) and closed habitats. However, for satisfactory midge control in some situations, other possibilities of control in the integrated approach would be required. Control of midges through the use of fish in large and open habitats, such as Lake Monroe, FL, and the lagoon of Venice, Italy, would be relatively less effective because of the possibility of fish displacement, due to their free movement and migration.

Chemical: The chemical control of midges by larviciding or adulticiding has primarily been attempted in the USA and Japan (Ali 1980b, Tabaru et al. 1987). A few scattered and limited midge control studies (laboratory or field) have been made in other countries, such as the United Kingdom (Edwards et al. 1964), Egypt (Abul-Nasr et al. 1970, Brown et al. 1961), France (Sinegre et al. 1990), Italy (Ali and Majori 1984, Ali et al. 1985b) and others. A bibliography of chemical control of chironomids was provided by Grodhaus (1975).

In the past 3–4 decades, the majority of chemical control work on midges in the USA has been conducted in Florida (Patterson 1964, 1965; Patterson and von Windeguth 1964a, 1964b; Patterson and Wilson 1966, Patterson et al. 1966, Ali 1981b, Ali and Chaudhuri 1988, Ali and Lord 1980, Ali and Nayar 1985, 1987; Ali and Stanley 1981, Ali et al. 1987), Wisconsin (Hilsenhoff 1959, 1960, 1962) and California (Ali and Mulla 1976b, 1977a, 1977b, 1978b; Ali et al. 1978, Anderson et al. 1964, 1965; Johnson and Mulla 1980, 1981, 1982a; McFarland et al. 1962, Mulla and Darwazeh 1975, Mulla and Khasawinah 1969, Mulla et al. 1971, 1973, 1974, 1975, 1976; Norland and Mulla 1975, Norland et al. 1974, Pelsue and McFarland 1971, Pelsue et al. 1974). Occasional reports on chironomid control from other states, such as New York (Jamnback 1954, 1956), Maryland (Bickley and Ludlam 1968), Illinois (Polls et al. 1975) and others also exist in the literature.

Numerous laboratory and field studies on midge control were conducted in the past 2–3 decades in Japan (Inoue and Mihara 1975, Kamei et al. 1982, Kudamatsu 1969, Ohno and Shimizu 1982, Sato and Yasuno 1979, Tabaru 1975, 1985a, 1985b, 1985c, 1985d; Tabaru et al. 1978, Tsumuraya et al. 1982a, 1982b; Yasuno et al. 1982, 1985).

Insecticides against chironomids were first evaluated against midge larvae half a century ago when Fellton (1940) used pyrethrins and rotenone. These costly botanicals were used only for a very short time because of the introduction of organochlorines, orthodichlorobenzene and trichlorobenzene compounds, which yielded satisfactory control of *Chironomus* and *Procladius* midges (Fellton 1941). Subsequently, several other organochlorines, such as DDT, DDD and dieldrin, afforded excellent control of midge larvae (Anderson and Ingram 1960, Anderson et al. 1964, Edwards et al. 1964, Flentje 1945b). However, the problem of toxicity of organochlorines to fish and other invertebrates in the food chain (Hunt and Bischoff 1960), and the development of resistance in midge larvae (Lieux and Mulrennan 1956), diverted the focus of midge control to the use of organophosphate (OP) insecticides. Several of these compounds were evaluated by Hilsenhoff (1959), who reported dichlorvos, trichlorfon, EPN, fenthion, malathion and phosdrin to be highly toxic to *C. plumosus* larvae. Granular malathion was considered a suitable insecticide to control this species (Hilsenhoff 1960, 1962).

In the early 1950s and 1960s in Florida, more than 100 chemical compounds were evaluated in the laboratory and/or field as potential larvicides of *G. paripes*. Benzene hexachloride and the organophosphorus insecticide EPN were the most extensively used for midge control, but their use was generally discontinued by 1955, due to the development of resistance by midge larvae (Patterson 1964, 1965). Control measures had to be substituted by the use of fenthion and temephos, and by adulticiding with thermal aerosol fogs (Patterson and von Windeguth 1964b, Patterson et al. 1966). Fenthion as 1% granular (G) applied at 0.22–0.28 kg AI/ha controlled *G. paripes* for 3–10 wk, depending upon the time of the year; the duration of control was minimum in summer (Patterson and Wilson 1966). Temephos (1% G) applied at 0.06 kg AI/ha yielded excellent control of *G. paripes*. In the last decade, several laboratory and semifield (experimental ponds) studies on the evaluation of organophosphates, pyrethroids and insect growth regulators (IGRs) (including chitin synthesis inhibitors and juvenile hormone analogs) have been conducted (Ali 1981b, Ali and Chaudhuri 1988, Ali and Lord 1980, Ali and Nayar 1987, Ali and Stanley 1981, Ali et al. 1987). The activity of an avermectin insecticide, abamectin, has also been tested in the laboratory against *C. crassicaudatus* and *G. paripes* (Ali and Nayar 1985). However, these studies remain of academic interest because no large-scale field trials using OPs, pyrethroids or IGRs in actual midge problem habitats have been conducted in Florida in the past 2 decades.

Laboratory evaluations: Organophosphorus larvicides. Mulla and Khasawinah (1969) developed a useful laboratory method for larvicide screening and establishing susceptibility levels of field-collected or laboratory-colonized midge populations to the candidate compounds prior to their large-scale use in the field. This method was used to evaluate the OP insecticides chlorpyrifos, temephos, fenthion, malathion, phenthoate, ethyl parathion and methyl parathion against field-collected larvae from various habitats in southern California (Ali and Mulla 1976b, 1977b, 1978b, 1980; Pelsue and McFarland 1971). These studies showed that different midge species manifested different degrees of susceptibility to the compounds tested. For example, larval populations of *C. decorus* and *Tanytarsus* spp. drawn from the Santa Ana River spreading grounds were highly susceptible to chlorpyrifos and temephos (LC_{90} = 1.5 and 4.6 ppb, and 2.0 and 4.6 ppb, respectively), but *Cricotopus* spp. in the same habitat were tolerant to all the OPs tested (LC_{90} = 0.12–2.1 ppm) (Ali and Mulla 1976b). Chlorpyrifos, temephos and phenthoate were also very effective against *Chironomus utahensis* taken from Silver Lakes with LC_{90} values of 7.8, 4.7 and 8.1 ppb, respectively. This species, however, was tolerant to methyl parathion and fenthion (LC_{90} = 0.47 and 1.16 ppm, respectively) (Ali and Mulla 1977b). *Chironomus decorus* was most susceptible to chlorpyrifos among all the OPs tested, but showed 5–74× tolerance to chlorpyrifos, temephos and malathion when compared with the susceptibility of *C. utahensis* to these compounds. Larvae of *Procladius* spp. in Silver Lakes were the least susceptible to temephos and the most to chlorpyrifos and phenthoate, while *Cricotopus* spp. were most susceptible to phenthoate and least to methyl parathion (Ali and Mulla 1977b). Against larval populations from another residential-recreational lake in southern California (Ali et al. 1978), chlorpyrifos was highly toxic to *Tanytarsus* spp. (LC_{90} = 3.1 ppb) and *C. decorus* (LC_{90} = 1.4 ppb). Temephos and fenthion were also considerably active against *Tanytarsus* spp. (LC_{90} = 7.2 and 8.8 ppb, respectively), but against *P. freemani*, temephos was totally ineffective, as indicated by the LC_{90} value of >5 ppm. In the same study, fenthion showed poor activity against *C. decorus* as well as against *P. freemani*, and malathion was also only slightly toxic to *P. freemani*. In contrast to the midge susceptibility results from the Santa Ana River spreading grounds and the residential-recreational lakes, chironomid fauna (mostly *C. decorus*, *D. californicus* and *Cricotopus* spp.) inhabiting flood control channels, such as the Coyote Creek system draining Orange and Los Angeles counties, CA (Ali et al. 1976a), were resistant to most OPs, including chlorpyrifos, temephos, fenthion and malathion (LC_{90} = 0.16–42.14 ppm) (Ali and Mulla 1980). Similar findings were reported by Pelsue and McFarland (1971) studying the midge problem earlier in the same channel system.

More recently in Florida, chlorpyrifos, temephos, fenthion and malathion were evaluated against field-collected larvae of *G. paripes* and *C. crassicaudatus* from Lake Monroe, and against *C. decorus* collected from 2 sewage oxidation ponds in Sanford, FL (Ali 1981b). In these evaluations, *G. paripes* exhibited the most susceptibility to malathion (LC_{90} = 0.0079 ppm) and the least to temephos (LC_{90} = 0.022 ppm); *C. crassicaudatus* was generally tolerant to these OP insecticides with LC_{90} values ranging from 0.14 ppm (chlorpyrifos) to 0.48 ppm (fenthion). *Chironomus decorus* was also relatively resistant to these compounds (LC_{90} = 0.1–0.38 ppm).

In Italy, the laboratory activity of chlorpyrifos, temephos, malathion and fenthion was determined for field-collected *C. salinarius* larvae from the saltwater lakes of Orbetello (Ali and Majori 1984) and from the lagoon of Venice (Ali et al. 1985b). Among the OPs used, temephos was the most active [(LC_{90} = 0.021 ppm (lakes) and 0.027 ppm (lagoon)], but the range of activity of all the OPs tested was narrow (LC_{90} = 0.021–0.091 ppm), indicating that *C. salinarius* populations in the lakes and in the lagoon were susceptible to these compounds.

From Japan, Kudamatsu (1969) had reported on the larvicidal activity of some OP insecticides against field-collected *C. plumosus*. Sato and Yasuno (1979) evaluated several insecticides against larvae of *C. yoshimatsui*, *Polypedilum nubifer*, *Paratanytarsus parthenogeneticus*, *Psectrocladius* sp. and *Procladius* sp. These midges, except for *Procladius* sp., were susceptible to temephos with LC_{50} values ranging from 0.0003 to 0.015 ppm. Tabaru (1985a) studied the laboratory activity of chlorphoxim, chlorpyrifos, chlorpyrifos methyl and temephos against *C. yoshimatsui*. The same author also developed and described a unique criterion for determining midge larval mortality by observing the tube-building inability of intoxicated larvae provided with 0.1-mm glass beads.

Pyrethroids: Several pyrethroids have been evaluated in the laboratory against midge larvae drawn from different habitats in California (Ali and Mulla 1978b, 1980; Ali et al. 1978), Florida (Ali 1981b) and Venice, Italy (Ali et al. 1985b). Evaluations made in California have shown that decamethrin (FMC-45498) and its chloro analogue FMC-45497 were highly active against *C. utahensis*, *P. freemani* and *P. sublettei* larvae drawn from Silver Lakes, with LC_{90} values ranging from 0.13 to 0.77 ppb. Other pyrethroids, FMC-35171 and Pydrin® (SD-43775), were relatively less active against these species (Ali and Mulla 1978b). Against *Tanytarsus* midges inhabiting Village Grove Lake, CA, all 4 pyrethroids were extremely toxic (LC_{90} = 0.025–0.058 ppb) (Ali et al. 1978). Decamethrin and its analogue were also highly active against *C. decorus* and *P. freemani* (LC_{90} = 0.76 and 0.5 ppb, and 0.11 and 0.36 ppb, respectively). The pyrethroid FMC 35171 was also very effective against *C. decorus* and *P. freemani* inhabiting Village Grove Lake, but Pydrin was moderately active against *C. decorus* (LC_{90} = 17 ppb) and *P. freemani* (LC_{90} = 47 ppb). Midge fauna (mostly *C. decorus*, *D. californicus*, *Cricotopus* spp. and *T. grodhausi*) of flood control channels, such as the Coyote Creek system and San Jose Creek, CA, were also highly susceptible to decamethrin and its analogue, FMC-45497 (LC_{90} = 0.13–12.0 ppb), but these midges showed lesser sensitivity to Pydrin (LC_{90} = 33.0–420.0 ppb) (Ali and Mulla 1980).

In Florida, several new experimental pyrethroids (e.g., FMC-30980, FMC-33297, FMC-35171, FMC-45497, FMC-45499 and FMC-52703) were evaluated in the laboratory against field-collected *G. paripes*, *C. crassicaudatus* and *C. decorus* larvae (Ali 1981b). These pyrethroids showed a very high level of activity against the 3 midge species, with LC_{90} values ranging from 0.26 to 13 ppb. Of the 3 species, *G. paripes* was the most susceptible (LC_{90} = 1.3–9.8 ppb), followed by *C. decorus* (LC_{90} = 2.1–13.0 ppb). Among the pyrethroids tested, FMC-45499 and FMC-52703 were the 2 most toxic to the midge larvae.

Evaluations of the pyrethroids cypermethrin, permethrin and deltamethrin against *C. salinarius* larvae collected from the lagoon of Venice, Italy, indicated the superior activity of cypermethrin (LC_{90} = 0.34 ppb) and permethrin (LC_{90} = 0.3 ppb) against this saltwater midge. Deltamethrin was 13–14× less toxic to *C. salinarius* (LC_{90} = 4.3 ppb) when compared with cypermethrin and permethrin (Ali et al. 1985b).

Although most pyrethroids have proven to be far superior to OP compounds in activity against chironomid larvae, the pyrethroids at mosquito and midge larvicidal rates have a relatively low index of safety to nontarget invertebrates and fish (Mulla et al. 1978a, 1978b). Therefore, the field use of pyrethroids as midge larvicides would be limited to midge problem habitats such as sewage ponds and wastewater channels where nontarget invertebrates and fish would be of minimal or no concern.

Insect growth regulators: With the advent of insect juvenile hormone analogue and chitin synthesis inhibitory insect growth regulators (IGRs) such as methoprene and diflubenzuron, respectively, additional materials for midge control have become available. Mulla et al. (1974)

evaluated several juvenile hormone analogue IGRs, Altosid® (ZR-515 or methoprene), R-20458, RO-20-3600 and RO-8-5497 against OP-resistant and OP-susceptible populations of *Chironomus* sp. larvae and found ZR-515 to be the most effective. The same IGR at 0.05 ppm induced complete inhibition of adult emergence in *Chironomus stigmaterus* and *T. grodhausi* collected from sewage oxidation ponds and exposed in the laboratory. Ali and Lord (1980) described a laboratory bioassay technique for these IGRs (having delayed effects) against midges, and evaluated the chitin synthesis inhibitors diflubenzuron, Bay SIR-8514 and Stauffer MV-678, and the JHA Stauffer R-20458 against 2 nuisance midge species of Florida. In this study, diflubenzuron and SIR-8514 caused 90% mortality of *C. decorus* and *G. paripes* at 4–22 ppb, the LC_{90} of MV-678 for the 2 species ranged from 50 to 69 ppb, and R-20458 was the least active with LC_{90} values of 0.24–0.7 ppm. In other laboratory studies in Florida, several new benzoylphenylurea IGRs (similar to diflubenzuron) were tested for activity against *G. paripes* and *C. decorus* (Ali and Stanley 1981), and *G. paripes* and *C. crassicaudatus* (Ali and Nayar 1987, Ali et al. 1987). The studies of Ali and Stanley (1981) revealed that the IGR UC-62644 was slightly more active than diflubenzuron against *G. paripes* and *C. decorus* (LC_{90} values of 3.1 ppb, *G. paripes*, and 5.7 ppb, *C. decorus*). The respective LC_{90} values with diflubenzuron for these species were 4.1 and 6.0 ppb. More recently, another IGR, UC-84572, was shown to be even more toxic in the laboratory to *G. paripes* (LC_{90} = 0.58 ppb) and *C. crassicaudatus* (LC_{90} = 1.99 ppb) than diflubenzuron or UC-62644 (Ali and Nayar 1987). Four other benzoylphenylurea IGRs, UC-75118, UC-75150, UC-76721 and UC-76724, showed an LC_{90} range of 4.5–25.3 ppb against *C. crassicaudatus* and 3.1–34.2 ppb against *G. paripes*. Among these, UC-76724, was the most active against *G. paripes* (LC_{90} = 3.1 ppb) as well as *C. crassicaudatus* (LC_{90} = 4.5 ppb) (Ali et al. 1987).

In addition to the IGRs, Ali and Nayar (1985) have evaluated the laboratory activity of an avermectin microbial pesticide, abamectin, against field-collected *C. crassicaudatus* and *G. paripes* larvae. Since avermectins exhibit delayed toxicological effects (Wright 1984), the activity of abamectin was compared with that of diflubenzuron, tested simultaneously as a standard. A comparison of the LC_{50} values revealed that abamectin was slightly superior in activity to diflubenzuron against *C. crassicaudatus* (LC_{50} = 1.63 ppb, abamectin, and 1.94 ppb, diflubenzuron) as well as *G. paripes* (LC_{50} = 1.52 ppb, abamectin, and 1.82 ppb, diflubenzuron) (Ali and Nayar 1985).

In Japan, the IGRs methoprene and diflubenzuron were tested against *C. yoshimatsui* (Kamei et al. 1982, Tabaru 1985d). Both IGRs proved highly effective at concentrations of <0.001 ppm, but diflubenzuron showed superior activity over methoprene (Tabaru 1985d). Currently, these IGRs are being evaluated in the laboratory in Italy, against field-collected *C. salinarius* from the Venice lagoon (S. Della Sala, personal communication).

It is obvious from the laboratory studies that the levels of susceptibility of various midge species or genera to different insecticides vary considerably. Even the same species in different geographical locations may show different levels of susceptibility to a chemical. The existing variation of species composition between habitats further complicates the problem. Thus, each habitat requires an independent approach for the chemical control of midges.

Field studies: Adult control. In the 1950s and 1960s, adulticiding was the principal means of midge control in Florida. Malathion and malathion-Lethane or naled were used as thermal aerosol fogs. Application of these materials was made from trucks, boats and airplanes. Low volume aerial sprays of malathion at 0.14–0.27 kg AI/ha were very effective. At the higher rate, malathion controlled *G. paripes* within 3 h and the control lasted for 4 days (Patterson et al. 1966). Although midge adulticiding proved effective, fogging has its limitations for controlling these insects. Presently, no specific insecticide is registered by the United States Environmental Protection Agency for adulticiding midges. However, some OP compounds, pyrethroids and other insecticides labeled for adult mosquito control in the USA (Rathburn 1988) probably reduce some adult midge populations when used by mosquito control agencies for the control of adult mosquitoes in some situations. Rathburn (1988) provided comprehensive information on label recommendations of 16–20 insecticides for use as ultralow volume (ULV), low volume sprays, ground applications, thermal aerosols in ground applications and mists in ground applications in adult mosquito control programs. The label requirements for droplet size of ULV and nonthermal aerosols for adult mosquito control were also provided. Because of the rapidly escalating problem of midge nuisance in the USA, federal and/or state registration of some insecticides as midge adulticides is needed.

Insecticides as midge adulticides are used on a very limited basis in Japan (Y. Tabaru, personal communication). However, in Italy, aerial applications of deltamethrin and malathion are the only means of control of adult *C. salinarius* in and around Venice (F. D'Andrea, personal communication).

Larval control: Organophosphorus larvicides. A number of OP insecticides in different formulations were evaluated in several residential-recreational lakes and in the Santa Ana River spreading system in California by Ali and Mulla (1976b, 1977a, 1977b, 1978b), and Mulla et al. (1971, 1973, 1975). Chlorpyrifos at rates ranging from 0.11 to 0.28 kg AI/ha gave excellent control of tanypodine and chironomine midges in Lake Calabasas and Westlake (Mulla et al. 1971, 1973), Spring Valley Lake (Mulla et al. 1975) and Silver Lakes (Ali and Mulla 1977b). The duration of control varied from 1 to 5 months, depending upon the rate of treatment and nature of the habitat. In 4–5 m deep Spring Valley Lake, when applied at 0.28 kg AI/ha, control lasted for over 1 month (Mulla et al. 1975); while in 1–2 m deep Lake Calabasas, chlorpyrifos at 0.22 kg AI/ha provided midge control for at least 4 months (Mulla et al. 1971). The granular formulation gave better (magnitude) and longer-lasting control than the emulsifiable concentrate formulation (Mulla et al. 1971, 1975). Chlorpyrifos was also reported to provide satisfactory control of *C. raparius* in sewage channels in Chicago, IL (Polls et al. 1975).

Field evaluations of temephos indicated that this OP insecticide was effective against some midge species in residential-recreational lakes and other midge habitats in California, but yielded control for shorter durations than chlorpyrifos, even though the rates of application were much higher than those employed for chlorpyrifos. In water percolation basins, temephos at 0.27–0.38 kg AI/ha gave a maximum of 78% control of midges (mixture of *Tanytarsus*, *Chironomus* and *Procladius*) for 1 wk posttreatment (Johnson and Mulla 1980). At higher rates (0.56–0.84 kg AI/ha) temephos controlled midges for 4–5 wk in Lake Calabasas and Spring Valley Lake (Mulla et al. 1971, 1975), while at lower rates (0.17–0.28 kg AI/ha) in the Santa Ana River basin and in Silver Lakes, it produced similar results (Ali and Mulla 1976b, 1977b). Later treatments of Silver Lakes with temephos at 0.28 kg AI/ha produced complete control of *Tanytarsus* spp. for 2 wk, but *Procladius* spp. and *C. decorus* remained unaffected. Even higher rates of temephos (0.33 and 0.56 kg AI/ha) failed to produce satisfactory control of *C. decorus* and *Procladius* spp. in the lake (Johnson and Mulla 1981). In Westlake, CA, temephos was also not effective at 0.56 kg AI/ha (Mulla et al. 1971). Generally, temephos was effective against Chironomini in most situations, but caused only slight or no mortality in Tanypodini (mostly *Procladius* spp.). Temephos, in granular formulations, is the sole insecticide registered by the United States Environmental Protection Agency for use as a larvicide against nuisance midges, and only in standing water situations.

Among other OPs, fenthion at 0.56 kg AI/ha provided satisfactory midge control for >7 wk in Lake Calabasas, and for 4 wk in Spring Valley Lake, but remained ineffective in Westlake at 0.56 kg AI/ha (Mulla et al. 1971, 1975). Malathion and phenthoate applied at 0.56 kg AI/ha, yielded good control of midges for 2–3 wk in Spring Valley Lake; methyl parathion at the same rate of application produced marginal midge control (Mulla et al. 1975).

In Japan, in outdoor model streams, temephos and chlorphoxim applied at 2 and 5 ppm, respectively, caused drastic larval reductions of *Thienemanniella majuscula*, *Paratrichocladius rufiventris* and *Chironomus flaviplumus*, but these species recovered within 2–3 wk posttreatment (Yasuno et al. 1985). In wastewater, temephos has been successfully used at 2 ppm maintained for 20 min in the gutters to control *C. yoshimatsui* (Inoue and Mihara 1975). The same rate of temephos and chlorpyrifos methyl maintained for 30 min in the gutters, disinfectant tanks and effluent discharge channels of sewage treatment plants gave excellent control of *C. yoshimatsui* (Tabaru 1985b). Tabaru (1975) and Tabaru et al. (1978) reported satisfactory control of *C. yoshimatsui* for 3 wk in polluted rivers by using temephos at rates of 0.69–1 ppm maintained for 60 min; the insecticide was carried up to 3,000 m downstream from the application site. *Chironomus yoshimatsui* in another river was successfully controlled at rates of 0.9–2.0 ppm of temephos maintained for 60 min (Ohno and Shimizu 1982). In other studies, temephos applied at rates of 0.05–1 ppm provided excellent control of *Polypedilum nubifer*, *Cricotopus bicinctus*, *Chironomus kiiensis* and *Chironomus tainanus* inhabiting eel culturing ponds (Ohkura and Tabaru 1975, Yasuno et al. 1982).

Overall, the field studies on OP insecticides against midges in the USA and Japan have indicated that chlorpyrifos, chlorpyrifos methyl, temephos, chlorphoxim and a few other OP compounds were effective against most nuisance species of midges, suppressing the larval populations for 2–5 wk or longer at application rates below 0.56 kg AI/ha (USA) and <1–5 ppm (Japan). These studies were not intended to eradicate midge larvae, but were implemented to reduce and maintain midge populations below the levels at which they pose pest problems. Also, the repeated and prolonged use of insecticides may result in buildup of resistance in midge larvae, as occurred in Florida due to the prolonged use of EPN and BHC (Lieux and Mulrennan 1956). In some storm drains and flood control channels in California, most OPs, including chlorpyrifos and temephos, have become ineffective against midge larvae even at 1.1 kg AI/ha rate of treatment (Pelsue and McFarland 1971). In the Chicago area, *C. raparius* has developed resistance to chlorpyrifos due to the repeated use of this OP insecticide (I. Polls, personal communication). In Silver Lakes, CA, a considerable decline in the effectiveness of chlorpyrifos and temephos was noted after repeated use of these compounds against *C. utahensis*, *C. decorus*, *P. freemani* and *P. sublettei* (Ali and Mulla 1978b). Resistance levels in these species to some other OPs not used in the field also increased, indicating the phenomenon of cross-resistance within the OP group.

The frequent and extensive use of temephos, and to an extent fenthion, has caused the development of resistance in *C. yoshimatsui* in the Kanda River, Tokyo (Ohno and Okamoto 1980). Tabaru (1985c) has also indicated a widespread acquired resistance to fenthion in *C. yoshimatsui* collected from 10 different rivers in Japan. However, larvae from all of these rivers were susceptible to chlorpyrifos methyl, and temephos was still considered to be economically effective against *C. yoshimatsui* in about 50% of the habitats exposed to the OP insecticide.

Insect growth regulators: Pioneering field studies on the use of IGRs for midge control are those of Mulla and Darwazeh (1975) and Mulla et al. (1974, 1976) who reported on the activity of methoprene and diflubenzuron against midges. These two IGRs, in different formulations, were evaluated in California in residential-recreational lakes (Ali and Mulla 1977b, Ali et al. 1978, Mulla et al. 1974, 1975, 1976), and in the Santa Ana River basin (Ali and Mulla 1977a). In these studies, methoprene at 0.28 kg AI/ha controlled midges for 1–2 wk by inhibiting adult emergence (Mulla et al. 1974, 1976), while diflubenzuron at 0.11–0.28 kg AI/ha induced midge control for 4–8 wk at the highest rate of treatment (Mulla et al. 1976). In one study in residential-recreational lakes in California, diflubenzuron at 0.11 and 0.28 kg AI/ha completely suppressed emergence of *Tanytarsus* and *Procladius* midges for 2 wk posttreatment, but was not as effective against *C. decorus* (Johnson and Mulla 1981). The same study indicated that SIR-8514 applied at the same rates of diflubenzuron gave similar results. The authors suggested that higher rates of application of the two IGRs may produce satisfactory control of *C. decorus* in the lakes. Johnson and Mulla (1982a) evaluated 2 formulations (25 WP and 0.5% G) of SIR-8514 in ponds on a golf course in California. These ponds ranged from 0.25 to 2.5 ha in surface area and <1 to 2.5 m in depth. The WP, applied at 0.11 and 0.28 kg AI/ha, inhibited adult emergence of *Tanytarsus*, *Chironomus* and *Procladius* midges for 2 wk, while the granular formulation at the same rates effectively suppressed adult eclosion of these chironomids for up to 4 wk after treatment. The duration of control resulting from the lower rate of treatment of each formulation was almost the same as produced by the higher rate.

Under semifield conditions in shallow experimental ponds in Florida, a 25% WP and a 1% granular formulation of SIR-8514 at 56 and 112 g AI/ha gave excellent overall control of *Tanytarsus* spp., *G. holoprasinus* and *C. decorus* midges for ca. 3 wk. Diflubenzuron 25 WP at 28 and 56 g AI/ha was slightly more effective than SIR-8514 and far more than MV-678 applied at comparable rates (Ali and Lord 1980). These authors also showed that SIR-8514 at 70 g AI/ha completely suppressed adult emergence of midges in a sewage pond for at least 10 days after treatment. In another study in the same ponds, a 25 WP formulation of the benzoylphenylurea IGR, UC-62644, was tested against midges at 25, 50 and 100 g AI/ha (Ali and Stanley 1981). All 3 treatment rates produced excellent control of midges for more than 4 wk. Even the lowest rate (25 g AI/ha) induced 94–99% inhibition of midge emergence during the 4 wk of the evaluation period. The WP of UC-62644 was also applied at 100 g AI/ha in a golf course pond in Florida, and gave good control (53–98%) of the predominant midge species, *Chironomus carus*, in the ponds during the 4 wk of evaluation (Ali and Stanley 1981). Less than 6 years ago another benzoylphenylurea IGR, UC-84572, became available for testing against midges. A 10 EC formulation of this IGR was evaluated at 1, 5 and 10 ppb AI in the experimental ponds in Florida. Diflubenzuron (Dimilin 25 WP) at 10 ppb AI was simultaneously tested as a standard in ponds because of its large data base. Emergence of adult *C. decorus*, *C. stigmaterus*, *G. holoprasinus* and Tanytarsini was inhibited by UC-84572 as well as diflubenzuron (Ali and Chaudhuri 1988). Even at 1 ppb, UC-84572 caused a maximum of 90% inhibition of emergence of *C. decorus*, 66% each of *C. stigmaterus* and *G. holoprasinus*, and 53% of Tanytarsini, 2 days after treatment. However, the overall reduction of total adult midges at 1 ppb ranged from 0 to 67% during the 28 days of posttreatment evaluation. The rate of 5 ppb gave complete control of *G. holoprasinus*, a maximum 99% reduction of *C. decorus* and 94% reduction each of *C. stigmaterus* and Tanytarsini, with an overall 96% control of total chironomids. At 10 ppb, UC-84572 caused complete inhibition of adult emergence within 2 days posttreatment, lasting for 2 wk for *C. stigmaterus*, 1 wk for *C. decorus* and <1 wk for *G. holoprasinus* and Tanytarsini. Diflubenzuron at 10 ppb also induced complete inhibition of adult midge emergence, but it lasted for <1 wk for all midge species except for *C. stigmaterus*, which was controlled for >1 wk. A comparison of the activity of UC-84572 with that of diflubenzuron applied at the same rate, 10 ppb, revealed that UC-84572 generally produced slightly longer lasting control of *C. decorus*, *C. stigmaterus* and *G. holoprasinus* than diflubenzuron. Emergence of Tanytarsini, however, remained suppressed for longer periods of time in the ponds that were treated with diflubenzuron.

In 1990, four formulations, liquid (Altosid Liquid Larvicide or A.L.L.), granular (SAN 810 I 1.3 GR), Altosid pellet and Altosid XR (extended residual) briquet of the juvenile hormone analogue IGR methoprene were evaluated for efficacy against midges including *C. decorus*, *C. stigmaterus*, *G. holoprasinus*, *Polypedilum* spp. and Tanytarsini in experimental ponds (each pond 24 m^2 containing 0.5 m deep water) in Florida (A. Ali, unpublished). In this study, A.L.L. at 2 rates 0.293 and 5.86 liters/ha, granules at 13.0 kg/ha, pellets at 5.6 kg/ha and briquets at the rate of 3/pond were each applied to 3 separate ponds. Three ponds were left untreated as controls. The A.L.L., granular, pellet and briquet formulations contained 5.0, 1.3, 4.0 and 1.8% of (S)-methropene, respectively. This study indicated that A.L.L. at 0.293 liters/ha remained ineffective, but at 5.86 liters/ha, it reduced emergence of midges by 74–99% for 2 wk posttreatment. Midge emergence returned to pretreatment or higher levels in the 3rd wk after treatment. The granular formulation reduced emergence of midges from 61–87% in the 2 wk after treatment. The effectiveness of the granular formulation was totally lost in the 4th wk posttreatment. The pellet and the briquet formulations produced greater control of midges for a longer duration as compared with the liquid and the granular formulations. The pellet formulation gave a maximum of 98% control at 3 days after treatment, with the level of control gradually declining and fluctuating between 64 and 90% for the 1–7 wk posttreatment. The briquet formulation gave 66–96% control of midges during 35 days posttreatment, with emergence of adult midges reducing by 98% after 7 days posttreatment. Generally, the pellet formulation provided control equal or better than the XR briquets with almost 1/4th the active ingredient.

The IGRs, diflubenzuron and methoprene, have been used in Japan for controlling *C. yoshimatsui*. Treatments of 2 rivers with the former IGR at 1 ppm maintained for 60 min resulted in excellent control of *C. yoshimatsui* for 3 wk. Methoprene at the same dosage proved less effective than diflubenzuron in the same river (Tabaru 1985d). In the gutters and discharge channels of sewage treatment plants, methoprene was applied at the rates of 0.13 and 4 ppm, but was effective against *C. yoshimatsui* only at the higher rate (Tsumuraya et al. 1982b).

The laboratory and field studies on IGRs against midges have shown that many of these compounds are highly effective against most chironomid species. These compounds are different from insecticides, such as OP larvicides, in that they inhibit larval or pupal development to the adult stage without reducing larval populations to the extent and magnitude of some OP insecticides, such as chlorpyrifos and temephos (Ali and Mulla 1977a, 1977b). Therefore, these compounds may have less of a decimating effect on an important component of the food chain. The IGRs also offer a good potential as additional tools for control of midge species resistant to OP insecticides. It has been documented that several of these IGRs, as well as OP larvicides, may have temporary or chronic effects on nontarget aquatic biota coexisting with midge larvae (Ali and Mulla 1978c, 1978d). Mulla et al. (1979) provided an excellent review of some 200 published papers covering the effects of predators, biocides, insecticides, and insect juvenile hormone analogue and chitin synthesis inhibitor growth regulators on nontarget biota associated with a variety of mosquito habitats. However, the severe nuisance and economic problems posed by adult midges and their recently discovered association with problems of allergy in humans, warrant availability of new tools, such as diflubenzuron and methoprene (particularly the pellet formulation), for midge control in selected habitats. These IGRs should be useful especially in polluted habitats where impact on nontarget organisms and the ecological balance of the habitat would be of minimal concern. In some situations, only partial areas of a habitat that support heavy populations of larval midges need to be treated (Ali and Mulla 1977b). This practice would not only reduce some midge nuisance, but would also help in quicker restoration of the lost nontarget invertebrates from the untreated areas. The toxic effects of the chemical used in these habitats would also diminish sooner due to dilution.

Presently, diflubenzuron has a state registration (24c) for use against midges by the California Department of Food and Agriculture. Such a registration of diflubenzuron should also be considered in other states. Also, methoprene warrants a similar registration.

SUMMARY

In many parts of the world, water bodies in urban and suburban areas exposed to intensive human use have become increasingly eutrophic and favorable for the profuse breeding of chironomid midges. Some of these habitats support larval densities in excess of 40,000/m^2, resulting in massive emergences of adult midges that pose a variety of nuisance, economic and occasionally medical problems for the nearby residents. In the past 2–3 decades, numerous habitats supporting primarily Chironomini species in the USA, Italy and Japan have been the focus of control studies.

A variety of chironomid control methods have been investigated in the past 2–3 decades, with a majority dealing with chemical control. A number of parasites and pathogens, such as viruses, rickettsiae, protozoans, nematodes and fungi have been reported from midges in different parts of the world but very few of these microbial organisms have been subjected to mass culturing and inoculating of natural breeding sources for quantitative biological control assessments. Physical and cultural control methodologies of chironomids are also the least explored.

A large number of organochlorines, organophosphates (OPs), pyrethroids and insect growth regulators (IGRs) including juvenile hormone analogues (e.g., methoprene) and chitin synthesis inhibitors (e.g., diflubenzuron) have been evaluated in the laboratory and/or in the field against nuisance species of midges in the USA and Japan. Among the OP compounds tested, chlorpyrifos and temephos were generally toxic to field-collected larvae of *Chironomus decorus* and *C. utahensis* (California), *Glyptotendipes paripes* (Florida), *C. yoshimatsui* and *C. plumosus* (Japan) and *C. salinarius* (Italy), but some of these and a few other species of midges in some situations in the USA and Japan were tolerant to temephos. There is also evidence of cross-resistance in chironomid larvae to the OP group. Presently, temephos is the only registered midge larvicide in the USA. Field studies on OP insecticides against midges in the USA and Japan have indicated that chlorpyrifos, chlorpyrifos methyl, temephos, chlorphoxim and a few other OP compounds caused appreciable larval reductions for 2–5 wk or longer at rate below 0.56 kg AI/ha (USA) and <1–5 ppm (Japan). Numerous pyrethroids have exhibited far superior activity than OP insecticides against chironomid larvae, but most pyrethroids at mosquito and midge larvicidal rates would have a relatively low index of safety to nontarget aquatic invertebrates and fish.

The IGRs, methoprene, diflubenzuron and several benzoylphenylurea compounds (similar to diflubenzuron), have shown superior activity against a variety of midge species in Japan and the USA. Some species exhibited an LC_{90} value <1 ppb to experimental benzoylphenylureas, such as UC-84572. In the field, methoprene, diflubenzuron, Bay SIR-8514 and several other benzoylphenylureas were highly effective, yielding midge control for several weeks at rates <0.3 kg AI/ha. A new pellet formulation of methoprene at 0.22 kg AI/ha suppressed emergence of adult midges by 64–98% in experimental ponds for 7 wk posttreatment. Generally, diflubenzuron showed superior activity over methoprene in several field studies. The 2 IGRs are excellent candidates for controlling midges, particularly the OP-resistant species, and warrant registration in the USA. Diflubenzuron and methoprene are presently being used in Japan for midge control.

Among biological control agents, *Bacillus thuringiensis* serovar. *israelensis* (*B.t.i.*) reduced midge larvae to various degrees in some ponds and lakes. However, the application rates of *B.t.i.*, needed for the satisfactory control (90% or higher) of midges, were at least 10× or higher the rates established for mosquito control; therefore, *B.t.i.* may have limited scope for use in midge control programs. The flatworm, *Dugesia dorotocephala* and some fish (e.g., carp, sunfish, catfish, *Tilapia* and others) have been reported to be effective in reducing midge larvae in some situations. Fish, as predators of midge larvae, however, are considered to be partially effective and only in small (20 ha or smaller) and closed habitats. These predators would be less effective in midge habitats covering several hundred or thousands of ha, particularly those that are connected to river systems where they may be displaced due to their free movement and migration. More research on the development and quantitative field assessments of promising parasites, pathogens and predators of midge larvae, and the environmental implications and impact on trophic structure of these biological control agents in the aquatic environment is needed.

Midge habitats that spread over several hundred or thousands of ha demand exploration of physical and cultural control methods. In such habitats, the physical and chemical composition of substrate materials and chemistry of the overlying water in relation to spatial and seasonal distribution of midge larval populations may provide a clue to the conditions conducive to their proliferation, and the ecological basis of midge production. Their proliferation could then be discouraged by manipulating their environment. Information related to adult dispersal behavior, patterns of abundance, diel periodicity of eclosion and attraction to light could also be manipulated in some situations to reduce midge nuisance more economically. Thusfar, very few studies on the larval ecology and adult behavior of pestiferous Chironomidae have been undertaken.

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REFERENCES CITED

Abul-Nasr, S., A. L. Isa and A. M. El-Tantawy. 1970. Control measures of the bloodworms, *Chironomus* sp., in rice nurseries. Bull. Entomol. Soc. Egypt, Econ. Ser. 4:127–33.

Ali, A. 1980a. Diel adult eclosion periodicity of nuisance chironomid midges of central Florida. Environ. Entomol. 9:365–370.

Ali, A. 1980b. Nuisance chironomids and their control: a review. Bull. Entomol. Soc. Am. 26:3–16.

Ali, A. 1981a. *Bacillus thuringiensis* serovar. *israelensis* (ABG-6108) against chironomids and some nontarget aquatic invertebrates. J. Invertebr. Pathol. 38:264–272.

Ali, A. 1981b. Laboratory evaluation of organophosphate and new synthetic pyrethroid insecticides against pestiferous midges of central Florida. Mosq. News 41:157–161.

Ali, A. 1989. Chironomids, algae, and chemical nutrients in a lentic system in central Florida, USA. Acta Biol. Debr. Oecol. Hung. 3:15–27.

Ali, A. 1990. Seasonal changes of larval food and feeding of *Chironomus crassicaudatus* Malloch (Diptera: Chironomidae) in a subtropical lake. J. Am. Mosq. Control Assoc. 6:84–88.

Ali, A. and R. D. Baggs. 1982. Seasonal changes of chironomid populations in a shallow natural lake and in a man-made water cooling reservoir in central Florida. Mosq. News 42:76–85.

Ali, A. and P. K. Chaudhuri. 1988. Evaluation of a new benzoylphenylurea insect growth regulator (UC-84572) against chironomid midges in experimental ponds. J. Am. Mosq. Control Assoc. 4:542–544.

Ali, A. and R. C. Fowler. 1983. Prevalence and dispersal of pestiferous Chironomidae in a lakefront city of central Florida. Mosq. News 43:55–59.

Ali, A. and R. C. Fowler. 1985. A natural decline of pestiferous Chironomidae (Diptera) populations from 1979 to 1984 in an urban area of central Florida. Fla. Entomol. 68:304–311.

Ali, A. and J. Lord. 1980. Experimental insect growth regulators against some nuisance chironomid midges of central Florida. J. Econ. Entomol. 73:243–249.

Ali, A. and G. Majori. 1984. A short-term investigation of chironomid midge (Diptera: Chironomidae) problem in saltwater lakes of Orbetello, Grosseto, Italy. Mosq. News 44:17–21.

Ali, A. and M. S. Mulla. 1975. Chironomid midge problem in water spreading basins and flood control channel in the Santa Ana River, Orange County, California. Proc. Pap. Calif. Mosq. Control Assoc. 43:116–117.

Ali, A. and M. S. Mulla. 1976a. Substrate type as a factor influencing spatial distribution of chironomid midges in an urban flood control channel system. Environ. Entomol. 5:631–636.

Ali, A. and M. S. Mulla. 1976b. Insecticidal control of chironomid midges in the Santa Ana River water spreading system, Orange County, California. J. Econ. Entomol. 69:509–513.

Ali, A. and M. S. Mulla. 1976c. Chironomid larval density at various depths in a southern California water-percolation reservoir. Environ. Entomol. 5:1071–1074.

Ali, A. and M. S. Mulla. 1977a. Chemical control of nuisance midges in the Santa Ana River Basin, southern California. J. Econ. Entomol. 70:191–195.

Ali, A. and M. S. Mulla. 1977b. The IGR diflubenzuron and organophosphorus insecticides against nuisance midges in man-made residential-recreational lakes. J. Econ. Entomol. 70:571–577.

Ali, A. and M. S. Mulla. 1978a. Chironomid population changes in an intermittent water spreading system. Mosq. News 38:386–392.

Ali, A. and M. S. Mulla. 1978b. Declining field efficacy of chlorpyrifos against chironomid midges and laboratory evaluation of substitute larvicides. J. Econ. Entomol. 71:778–782.

Ali, A. and M. S. Mulla. 1978c. Effects of chironomid larvicides and diflubenzuron on nontarget invertebrates in residential-recreational lakes. Environ. Entomol. 7:21–27.

Ali, A. and M. S. Mulla. 1978d. Impact of the IGR diflubenzuron on invertebrates in a residential-recreational lake. Arch. Environ. Contam. Toxicol. 7:483–491.

Ali, A. and M. S. Mulla. 1979a. Diel periodicity of eclosion of adult chironomid midges in a residential-recreational lake. Mosq. News 39:360–364.

Ali, A. and M. S. Mulla. 1979b. Nuisance midge problem in southern California: chemical control strategies. Bull. Soc. Vector Ecol. 5:44–53.

Ali, A. and M. S. Mulla. 1979c. Diel periodicity of chironomid larval and pupal drift in an urban flood control channel system. Environ. Entomol. 8:902–907.

Ali, A. and M. S. Mulla. 1980. Activity of organophosphate and synthetic pyrethroid insecticides against pestiferous midges in some southern California flood control channels. Mosq. News 40:593–597.

Ali, A. and M. S. Mulla. 1983. Evaluation of the planarian, *Dugesia dorotocephala*, as a predator of chironomid midges and mosquitoes in experimental ponds. Mosq. News 43:46–49.

Ali, A. and J. K. Nayar. 1985. Activity of an avermectin insecticide, abamectin (MK-936), against mosquitoes and chironomid midges in the laboratory. J. Am. Mosq. Control Assoc. 1:384–386.

Ali, A. and J. K. Nayar. 1986. Efficacy of *Bacillus sphaericus* Neide against larval mosquitoes (Diptera: Culicidae) and midges (Diptera: Chironomidae) in the laboratory. Fla. Entomol. 69:685–690.

Ali, A. and J. K. Nayar. 1987. Laboratory toxicity of a new benzoylphenylurea insect growth regulator (UC-84572) against mosquitoes and chironomid midges. J. Am. Mosq. Control Assoc. 3:309–311.

Ali, A. and B. H. Stanley. 1981. Effects of a new insect growth regulator, UC-62644, on target Chironomidae and some nontarget aquatic invertebrates. Mosq. News 41:640–649.

Ali, A., R. D. Baggs and J. P. Stewart. 1981. Susceptibility of some Florida chironomids and mosquitoes to various formulations of *Bacillus thuringiensis* serovar. *israelensis*. J. Econ. Entomol. 74:672–677.

Ali, A., M. S. Mulla and F. W. Pelsue. 1976a. Chironomid midge investigations in a concrete-lined drainage system in southern California. Proc. Pap. Calif. Mosq. Control Assoc. 44:136–138.

Ali, A., M. S. Mulla and F. W. Pelsue. 1976b. Removal of substrate for the control of chironomid midges in concrete-lined flood control channels. Environ. Entomol. 5:755–758.

Ali, A., J. K. Nayar and M. L. Kok-Yokomi. 1987. Evaluation of new experimental insect growth regulators against mosquitoes (Diptera: Culicidae) and midges (Diptera: Chironomidae) in the laboratory. Proc. Calif. Mosq. Vector Control Assoc. 55:81–86.

Ali, A., S. R. Stafford and R. C. Fowler. 1984. Attraction of adult Chironomidae (Diptera) to incandescent light under laboratory conditions. Environ. Entomol. 13:1004–1009.

Ali, A., B. H. Stanley and P. K. Chaudhuri. 1986. Attraction of some adult midges (Diptera: Chironomidae) of Florida to artificial light in the field. Fla. Entomol. 69:644–650.

Ali, A., B. H. Stanley and S. R. Stafford. 1983. Short-term daily emergence of adult Chironomidae from a natural lake and a man-made reservoir. Environ. Entomol. 12:765–767.

Ali, A., M. S. Mulla, B. A. Federici and F. W. Pelsue. 1977. Seasonal changes in chironomid fauna and rainfall reducing chironomids in urban flood control channels. Environ. Entomol. 6:619–622.

Ali, A., M. S. Mulla, A. R. Pfuntner and L. L. Luna. 1978. Pestiferous midges and their control in a shallow residential-recreational lake in southern California. Mosq. News 38:528–535.

Ali, A., M. S. Weaver and E. Cotsenmoyer. 1989a. Effectiveness of *Bacillus thuringiensis* serovar. *israelensis* (Vectobac 12 AS) and *Bacillus sphaericus* (ABG-6232) against *Culex* spp. mosquitoes in a dairy lagoon in central Florida. Fla. Entomol. 72:585–591.

Ali, A., J. K. Nayar, J. W. Knight and B. H. Stanley. 1989b. Attraction of Florida mosquitoes (Diptera: Culicidae) to artificial light in the field. Proc. Calif. Mosq. Vector Control Assoc. 57:82–88.

Ali, A., B. H. Stanley and G. Majori. 1985a. Daily abundance patterns of pestiferous Chironomidae (Diptera) in an urban lake front in central Florida. Environ. Entomol. 14:780–784.

Ali, A., G. Majori, G. Ceretti, F. D'Andrea, M. Scattolin and U. Ferrarese. 1985b. A chironomid (Diptera: Chironomidae) midge population study and laboratory evaluation of larvicides against midges inhabiting the lagoon of Venice, Italy. J. Am. Mosq. Control Assoc. 1:66–71.

Anderson, L. D. and A. A. Ingram. 1960. Preliminary report on the chironomid midge project at the Los Angeles County Flood Control District water spreading grounds on the Rio Hondo and San Gabriel River near Whittier, California. Proc. Pap. Calif. Mosq. Control Assoc. 28:99–103.

Anderson, L. D., E. C. Bay and A. A. Ingram. 1964. Studies on chironomid midge control in water spreading basins near Montebello, California, Calif. Vector Views 11:13–20.

Anderson, L. D., E. C. Bay and M. S. Mulla. 1965. Aquatic midge investigations in southern California. Proc. Pap. Calif. Mosq. Control Assoc. 33:31–33.

Anonymous. 1974. A report on midge in the Kanda River. Rep. Dept. Sewer Syst., Metropolitan Tokyo, Tokyo. (In Japanese).

Anthony, D. W. 1975. Use of viruses for control of aquatic insect pests. Environ. Prot. Agency, EPA-600/3-75-100.

Barthelmes, D. 1960. *Tetrahymena parasitica* (Penard 1922) Corliss 1952 als Parasit in Larven vom *Chironomus plumosus*. Typ. z. F. Fischerei der. Hilfswiss 9 N.F:273–280.

Bay, E. C. 1964. An analysis of the "Sayule" (Diptera: Chironomidae) nuisance at San Carlos, Nicaragua, and recommendations for its alleviation. W.H.O. document, WHO/EBL/20.

Bay, E. C. 1974. Predator-prey relationships among aquatic insects. Annu. Rev. Entomol. 19:441–453.

Bay, E. C. and L. D. Anderson. 1965. Chironomid control by carp and goldfish. Mosq. News 25:310–316.

Bay, E. C. and L. D. Anderson. 1966. Studies with the mosquito fish, *Gambusia affinis*, as a chironomid control. Ann. Entomol. Soc. Am. 59:150–153.

Beck, E. C. and W. M. Beck, Jr. 1969. Chironomidae of Florida. II. The nuisance species. Fla. Entomol. 52:1–11.

Bennike, S. A. B. 1943. Contributions to the ecology and biology of the Danish freshwater leeches (Hirudinea). Folia Limnol. Scand. 2:1–109.

Bickley, W. E. and K. W. Ludlam. 1968. Insecticidal control of *Glyptotendipes paripes* in two Maryland sewage lagoons. J. Econ. Entomol. 61:1454.

Biever, K. D. 1965. A rearing technique for the colonization of chironomid midges. Ann. Entomol. Soc. Am. 58:135–136.

Biever, K. D. 1971. Effect of diet and competition in laboratory rearing of chironomid midges. Ann. Entomol. Soc. Am. 64:1116–1119.

Brown, A. W. A., D. J. McKinley, H. W. Bedford and M. Qutubuddin. 1961. Insecticidal operations against chironomid midges along the Blue Nile. Bull. Entomol. Res. 51:789–801.

Callahan, J. L. and C. D. Morris. 1987. Survey of 13 Polk County, Florida, lakes for mosquito (Diptera: Culicidae) and midge (Diptera: Chironomidae) production. Fla. Entomol. 70:471-478.

Callahan, J. L. and C. D. Morris. 1989. Production and maintenance of large numbers of *Dugesia tigrina* (Turbellaria: Trachladida) for the control of mosquitoes in the field. J. Am. Mosq. Control Assoc. 5:10-14.

Ceretti, G., U. Ferrarese, A. Francesion and A. Barbaro. 1987. Chironomids (Diptera: Chironomidae) in the natural diet of gilthead seabream (*Sparus aurata* L.) farmed in the Venice lagoon. Entomol. Scand. Suppl. 29:289-292.

Chapman, J. and D. H. Ecke. 1969. Study of a population of chironomid midges (*Tanytarsus*) parasitized by mermithid nematodes in Santa Clara County, California. Calif. Vector Views 16:83-88.

Coffman, W. P. and L. C. Ferrington, Jr. 1984. Chironomidae. pp. 551-652. *In:* R. W. Merritt and K. W. Cummins (eds.). An introduction to the aquatic insects of North America. 2nd Edition. Kendall/Hunt Publ. Co., Iowa.

Cook, S. F., Jr. 1962. Feeding studies of the aeneus catfish, *Corydoras aeneus* on aquatic midges. J. Econ. Entomol. 55:155-157.

Cook, S. F., Jr. 1964. The potential of two native California fish in the control of chironomid midges. Mosq. News 24:332-333.

Cook, S. F., Jr., J. D. Conners and R. L. Moore. 1964. The impact of the fishery upon the midge populations of Clear Lake, Lake County, California. Ann. Entomol. Soc. Am. 57:701-707.

Corliss, J. O. 1960. *Tetrahymena chironomi* sp. nov., a ciliate from midge larvae and the current status of facultative parasitism in the genus *Tetrahymena.* Parasitology 50:111-153.

Couch, J. N. and C. E. Bland. 1985. Taxonomy. pp. 81-29. *In:* J. N. Couch and C. E. Bland (eds.). The genus *Coelomomyces.* Academic Press, Orlando, FL.

Cranston, P. S., M. O. Gad-El-Rab and A. B. Kay. 1981. Chironomid midges as a cause of allergy in the Sudan. Trans. R. Soc. Trop. Med. Hyg. 75:1-4.

Cranston, P. S., R. D. Tee, P. F. Credland and A. B. Kay. 1983. Chironomid haemoglobins: their detection and role in allergy to midges in the Sudan and elsewhere. Mem. Am. Entomol. Soc. 34:71-87.

Darby, R. E. 1962. Midges associated with California rice fields, with special reference to their ecology (Diptera: Chironomidae). Hilgardia 32. 206 p.

Deacon, J. E. and S. Bunnel. 1970. Man and pupfish. *In:* Pupfish of the Death Valley region, a task force report. Cry Calif. 5:14.

Deacon, J. E., C. Hubbs and B. J. Zahuranec. 1964. Some effects of introduced fishes on the native fish fauna of southern Nevada. Copeia 1964:384.

Edwards, R. W., H. Egan, M. A. Learner and P. J. Maris. 1964. The control of chironomid larvae in ponds, using TDE(DDD). J. Appl. Ecol. 1:97-119.

Elliott, J. M. 1973. The diet activity pattern, drifting, and food of the leech (*Erpobdella octoculata*) in a Lake District stream. J. Anim. Ecol. 42:449-459.

Federici, B. A., E. I. Hazard and D. W. Anthony. 1973. A new cytoplasmic polyhedrosis virus from Chironomidae collected in Florida. J. Invertebr. Pathol. 22:136-138.

Federici, B. A., W. L. Kramer and M. S. Mulla. 1976. A disease in *Chironomus frommeri* caused by a *Rickettsiella*-like organism. Proc. Pap. Calif. Mosq. Control Assoc. 44:123.

Federici, B. A., R. R. Granados, D. W. Anthony and E. I. Hazard. 1974. An entomopoxvirus and nonoccluded virus-like particles in larvae of the chironomid *Goeldichironomus holoprasinus.* J. Invertebr. Pathol. 23:117-120.

Fellton, H. L. 1940. Control of aquatic midges with notes on the biology of certain species. J. Econ. Entomol. 33:252-264.

Fellton, H. L. 1941. The use of chlorinated benzenes for the control of aquatic midges. J. Econ. Entomol. 34:192-194.

Ferrarese, U. and G. Ceretti. 1989. Diel emergence of *Chironomus salinarius* (Diptera: Chironomidae) in a Venice lagoon. Acta Biol. Debr. Oecol. Hung. 2:189-194.

Flentje, M. E. 1945a. Control and elimination of pest infestations in public water supplies. J. Am. Water Works Assoc. 37:1194-1203.

Flentje, M. E. 1945b. Elimination of midge fly larvae with DDT. J. Am. Water Works Assoc. 37:1053.

Gad-El-Rab, M. O. and A. B. Kay. 1980. Widespread IgE-mediated hypersensitivity in the Sudan in the "green nimitti" midge *Cladotanytarsus lewisi* (Diptera: Chironomidae). I. Diagnosis by radioallergosorbent test. J. Allergy Clin. Immunol. 66:190-195.

Giacomin, C. and G. C. Tassi. 1988. Hypersensitivity to chironomid *Chironomus salinarius* (non-biting midge living in the lagoon of Venice) in a child with serious skin and respiratory symptoms. Boll. Ist Sieroter. Milan 67:72-76.

Götz, P. 1964. Der Einfluss Unterschiedlicher Befallsbedingungen auf die Mermithogene Intersexualität von *Chironomus* (Dipt.). Z. Parasitenkd. 24:484-545.

Götz, P. 1972. *Rickettsiella chironomi*: an unusual bacterial pathogen which reproduces by multiple cell division. J. Invertebr. Pathol. 20:22-30.

Grodhaus, G. 1968. Considerations in controlling chironomids. Proc. Pap. Calif. Mosq. Control Assoc. 36:37-39.

Grodhaus, G. 1975. Bibliography of chironomid midge nuisance and control. Calif. Vector Views 22:71-81.

Guziur, J. 1976. The feeding of two year old carp (*Cyprinus carpio*) in Vendeace Lake Klaws. Ekol. Polska 24:211-235.

Hafiz, H. A. 1939. Observations on the bionomics of the midge *Chironomus* (*Limnochironomus*) *tenueiforceps* K., occurring on the filter beds of the Calcutta corporation at Pulta, near Calcutta. Rec. Ind. Mus. 41:225-231.

Harkrider, J. R. and I. M. Hall. 1975. The occurrence of an entomopoxvirus in a field population of *Chironomus* sp. Proc. Pap. Calif. Mosq. Control Assoc. 43:103-106.

Harkrider, J. R. and I. M. Hall. 1978. The dynamics of an entomopoxvirus in a field population of larval midges of the *Chironomus decorus* complex. Environ. Entomol. 7:858-862.

Harkrider, J. R. and I. M. Hall. 1979. The effect of an entomopoxvirus on larval populations of an undescribed midge species in the *Chironomus decorus* complex under laboratory conditions. Environ. Entomol. 8:631-635.

Hayne, D. W. and R. C. Ball. 1956. Benthic productivity as influenced by fish predation. Limnol. Oceanog. 1:162–175.

Hilsenhoff, W. L. 1959. The evaluation of insecticides for the control of *Tendipes plumosus* (Linnaeus). J. Econ. Entomol. 52:331–332.

Hilsenhoff, W. L. 1960. Treating water areas with granular insecticides. Mosq. News 20:187–188.

Hilsenhoff, W. L. 1962. Granulated malathion as a possible control for *Tendipes plumosus* (Diptera: Tendipedidae). J. Econ. Entomol. 55:71–78.

Hilsenhoff, W. L. and O. L. Lovett. 1966. Infection of *Chironomus plumosus* (Dipt.:Chir.) by a microsporidian (*Thelohania* sp.) in Lake Winnebago, Wisconsin. J. Invertebr. Pathol. 8:512–519.

Huger, A. M., A. Kreig, P. Emschermann and P. Götz. 1970. Further studies on *Polypoxvirus chironomi*, an insect virus of the pox group isolated from the midge *Chironomus luridus*. J. Invertebr. Pathol. 15:253–261.

Hunt, E. G. and A. I. Bischoff. 1960. Inimical effects on wildlife of periodic DDD applications to Clear Lake. Calif. Fish Game 46:91–106.

Hunter, K. D. 1968. Response of populations of *Chironomus californicus* to a microspordian (*Gurleya* sp.). J. Invertebr. Pathol. 10:387–389.

Hurlbert, S. H., J. Fedler and D. Fairbanks. 1972. Ecosystem alternation by mosquito fish (*Gambusia affinis*) predation. Science 175:639.

Inoue, Y. and M. Mihara. 1975. Studies on the Japanese chironomid midges as a nuisance. I. Larvicidal effects of some organophosphorus insecticides against the last instar larvae of *Chironomus yoshimatsui* Martin and Sublette. Jap. J. Sanit. Zool. 26:135–138. (In Japanese).

Ishihara, T. 1972. An introduction to the study of agricultural insects of Japan, Yokendo, Tokyo. (In Japanese).

Ito, K., T. Miyamoto, T. Shibuya, K. Kamei, K. Mano, T. Taniai and M. Sasa. 1986. Skin test and radioallergosorbent test with extracts of larval and adult midges of *Tokunagayusurika akamusi* Tokunaga (Diptera: Chironomidae) in asthmatic patients of the metropolitan area of Tokyo. Ann. Allergy 57:199–204.

Jamnback, H. 1954. The biology and control of the midge *Tendipes decorus* (Joh.) in Moriches Bay (Preliminary Report). N.Y. State Sci. Serv. Rep. 6.

Jamnback, H. 1956. Continued studies of fuzzbill, *Tendipes decorus* (Joh.) control on Long Island. Proc. 43rd Annu. Meet. N. J. Mosq. Exterm. Assoc. 162:167.

Johnson, A. A. 1963. *Octomyomermis itascensis* gen. et sp. nov. a parasite of *Chironomus plumosus* (L.). Trans Am. Microsc. Soc. 82:237-241.

Johnson, A. A. 1965. *Hydromermis itascensis* sp. n. (Nematoda: Mermithidae) a parasite of *Glyptotendipes lobiferus* (Say) (Diptera: Chironomidae) and the taxonomic status of *Gastromermis*. J. Parasitol. 51:53–56.

Johnson, G. D. and M. S. Mulla. 1980. Investigations on nuisance midges in water percolation basins, Montclair, California. Proc. Calif. Mosq. Vector Control Assoc. 48:118–120.

Johnson, G. D. and M. S. Mulla. 1981. Chemical control of aquatic nuisance midges in residential-recreational lakes. Mosq. News 41:495–501.

Johnson, G. D. and M. S. Mulla. 1982a. Suppression of nuisance aquatic midges with a urea insect growth regulator. J. Econ. Entomol. 75:297–300.

Johnson, G. D. and M. S. Mulla. 1982b. Evaluation of emergence traps in assessing the impact of a macrophyte on the production of chironomid midges. Mosq. News 42:260–264.

Johnson, G. D. and M. S. Mulla. 1983. An aquatic macrophyte affecting nuisance chironomid midges in a warm-water lake. Environ. Entomol. 12:226–269.

Johnson, G. D. and M. S. Mulla. 1984. Physical and chemical properties of water and bottom sediments in Silver Lakes, a residential-recreational community in southern California. Bull. Soc. Vector Ecol. 9:37–50.

Kamei, M., H. Shimada, S. Ohokubo and T. Ishii. 1982. Effects of Altosid 10F on the chironomid midge, *Chironomus yoshimatsui* Martin et Sublette (Diptera: Chironomidae) of Tokushima City. Jap. J. Sanit. Zool. 33:207-212. (In Japanese).

Karanukaran, L. 1966. Parasitism of *Chironomus costatus* Joh. (Dipt., Nematocera) by a mermithid. Nematologia, Leiden 12:172–174.

Kimball, J. H. 1968. Carp for chironomid midge control. Mosq. News 28:147–148.

Kudamatsu, A. 1969. Larvicidal activity of some insecticides against *Chironomus plumosus*. Jap. J. Sanit. Zool. 20:129–130. (In Japanese).

Kugler, J. and H. Chen. 1968. Distribution of chironomid larvae in Lake Tiberias and their occurrence in the food of fish in the lake. Israel J. Zool. 17:95–115.

Kurtak, D., H. Jamnback, R. Meyer, M. Ocran and P. Renaud. 1987. Evaluation of larvicides for the control of *Simulium damnosum* s. 1. (Diptera: Simuliidae) in West Africa. J. Am. Mosq. Control Assoc. 3:201-206.

Kajak, Z., K. Dusoge, A. Hillbricht-ilkowska, E. Pieczynsi, G. Preis, I. Spodniewska and T. Weglenska. 1972. Influence of the artificially increased fish stock on the lake biocoenosis. Verh. Int. Verein. Limnol. 18:228-235.

Lacey, L. A., M. A. Urbina and C. M. Heitzman. 1984. Sustained release formulations of *Bacillus sphaericus* and *Bacillus thuringiensis* (H-14) for the control of container-breeding *Culex quinquefasciatus*. Mosq. News 44:26–32.

Legner, E. F. and R. A. Medved. 1973. Predation of mosquitoes and chironomid midges in ponds by *Tilapia zillii* (Gervais) and *T mossambica* (Peters) (Teleosteii: Cichlidae). Proc. Calif. Mosq. Control Assoc. 41:119–121.

Legner, E. F., R. A. Medved and W. J. Hauser. 1975a. Predation of the desert pupfish, *Cyprinodon macularius*, on *Culex* mosquitoes and benthic chironomid midges. Entomophaga 20:23–30.

Legner, E. F., H. S. Yu, R. A. Medved and M. E. Badgley. 1975b. Mosquito and chironomid midge control by planaria. Calif. Agric. 29:3–6.

Lieux, D. B. and J. A. Mulrennan. 1956. Investigations of the biology and control of midges in Florida

(Diptera: Tendipedidae). A progress report. Mosq. News 16:201–204.

Lewis, D. J. 1957. Observations on Chironomidae at Khartoum. Bull. Entomol. Res. 48:155–184.

Lysenko, O. 1957. The possibility of bacterial transfer during the metamorphosis of the midge *Chironomus plumosus*. Ceskoslovenenska Microbiol. 2:248–250. (In Czech).

Magy, H. I. 1968. Vector and nuisance problem emanating from man-made recreational lakes. Proc. Pap. Calif. Mosq. Control Assoc. 36:36–37.

Majori, G., A. Ali and G. Sabatinelli. 1987. Laboratory and field efficacy of *Bacillus thuringiensis* serovar. *israelensis* and *Bacillus sphaericus* against *Anopheles gambiae* s.l. and *Culex quinquefasciatus* in Ouagadougou, Burkina Faso. J. Am. Mosq. Control Assoc. 3:20–25.

Majori, G., A. Ali, G. Donelli, F. Tangucci and J. R. Harkrider. 1986. The occurrence of a virus of the pox group in a field population of *Chironomus salinarius* Kieffer in Italy. Fla. Entomol. 69:418–421.

Mann, K. H. 1957. The breeding, growth, and age structure of a population of the leech, *Helobdella stagnalis* (L.). J. Anim. Ecol. 26:171–177.

Mason, Jr., W. T. 1973. An introduction to the identification of chironomid larvae. Div. Pollution Surveillance, Federal Water Pollution Control Assoc., U.S. Dept. of the Interior, Cincinnati, Ohio.

McCauley, V. J. E. 1973. Mermithid (nematode) parasites of Chironomidae (Diptera) in Marion Lake, British Columbia. J. Invertebr. Pathol. 22:454–463.

McFarland, G. C., F. C. Cherry and E. L. Geushausen. 1962. Chironomid control with malathion granules. Proc. Pap. Calif. Mosq. Control Assoc. 30:86.

Merritt, R. W., E. D. Walker, M. A. Wilzbach, K. W. Cummins and W. T. Morgan. 1989. A broad evaluation of *B.t.i.* for blackfly (Diptera: Simuliidae) control in a Michigan river: efficacy, carry, and nontarget effects on invertebrates and fish. J. Am. Mosq. Control Assoc. 5:397–415.

Mezger, E. G. 1967. Insecticidal and naturalistic control of chironomid larvae in Lake Dalwigk, Vallejo, California. Proc. Pap. Calif. Mosq. Control Assoc. 35:125–128.

Moriya, K. 1977. Seasonal prevalence of *Chironomus yoshimatsui*. Jap. J. Sanit. Zool. 28:63. (In Japanese).

Mulla, M. S. and H. A. Darwazeh. 1975. Evaluation of insect growth regulators against chironomids in experimental ponds. Proc. Pap. Calif. Mosq. Control Assoc. 43:164–168.

Mulla, M. S. and A. M. Khasawinah. 1969. Laboratory and field evaluations of larvicides against chironomid midges. J. Econ. Entomol. 62:37–41.

Mulla, M. S., D. R. Barnard and R. L. Norland. 1975. Chironomid midges and their control in Spring Valley Lake, California. Mosq. News 35:389–395.

Mulla, M. S., B. A. Federici and H. A. Darwazeh. 1982. Larvicidal efficacy of *Bacillus thuringiensis* serotype H-14 against stagnant water mosquitoes and its effect on nontarget organisms. Environ. Entomol. 11:788–795.

Mulla, M. S., W. L. Kramer and D. R. Barnard. 1976. Insect growth regulators for the control of chironomid midges in residential-recreational lakes. J. Econ. Entomol. 69:285–291.

Mulla, M. S., G. Majori and A. A. Arata. 1979. Impact of biological and chemical mosquito control agents on nontarget biota in aquatic ecosystems. Residue Reviews 71:121–173.

Mulla, M. S., H. A. Navvab-Gojrati and H. A. Darwazeh. 1978a. Biological activity and longevity of synthetic pyrethroids against mosquitoes and some nontarget insects. Mosq. News 38:90–96.

Mulla, M. S., H. A. Navvab-Gojrati and H. A. Darwazeh. 1978b. Biological activity and longevity of four species of freshwater fishes. Environ. Entomol. 7:428–430.

Mulla, M. S., H. Axelrod, H. A. Darwazeh and B. A. Matanmi. 1988. Efficacy and longevity of *Bacillus sphaericus* 2362 formulations for control of mosquito larvae in dairy wastewater lagoons. J. Am. Mosq. Control Assoc. 4:448–452.

Mulla, M. S., R. L. Norland, T. Ikeshoji and W. L. Kramer. 1974. Insect growth regulators for the control of aquatic midges. J. Econ. Entomol. 67:167–170.

Mulla, M. S., H. A. Darwazeh, L. Ede, B. Kennedy and H. T. Dulmage. 1985. Efficacy and field evaluation of *Bacillus thuringiensis* (H-14) and *B. sphaericus* against floodwater mosquitoes in California. J. Am. Mosq. Control Assoc. 1:310–315.

Mulla, M. S., R. L. Norland, D. M. Fanara, H. A. Darwazeh and D. W. McKean. 1971. Control of chironomid midges in recreational lakes. J. Econ. Entomol. 64:300–307.

Mulla, M. S., R. L. Norland, W. E. Westlake, B. Dell and J. St. Amant. 1973. Aquatic midge larvicides, their efficacy and residues in water, soil and fish in a warm water lake. Environ. Entomol. 2:58–65.

Murray, D. W. 1976. *Tilapia* fish for midge control in a sewage treatment pond. Proc. Pap. Calif. Mosq. Control Assoc. 44:122.

Norland, R. L. and M. S. Mulla. 1975. Impact of Altosid on selected members of an aquatic ecosystem. Environ. Entomol. 4:145–152.

Norland, R. L., M. S. Mulla, F. W. Pelsue and T. Ikeshoji. 1974. Conventional and new insecticides for the control of chironomid midges. Proc. Pap. Calif. Mosq. Control Assoc. 42:181–183.

Ohkura, T. and Y. Tabaru. 1975. Control of chironomids breeding in eel culture ponds. Suisan Zoshoku 23:1–7. (In Japanese).

Ohno, M. and H. Okamoto. 1980. Test on the susceptibility of the last instar larvae of *Chironomus yoshimatsui* Martin and Sublette (Diptera: Chironomidae) collected at the Kanda River to two organophosphorus insecticides. Annu. Rep. Tokyo Metropolitan Pub. Health Res. Lab. 31:261–264. (In Japanese).

Ohno, M. and K. Shimizu. 1982. On changes in numbers of larvae and imagos of *Chironomus yoshimatsui* Martin and Sublette (Diptera: Chironomidae), and drift of larvae after applications of temephos in the Kanda River. Annu. Rep. Tokyo Metropolitan Public Health Res. Lab. 33:314–321. (In Japanese).

Oliver, D. R., D. McClymont and M. E. Roussel. 1978. A key to some larvae of Chironomidae (Diptera) from the Mackenzie and Porcupine River watersheds. Fishers and Marine Serv. Tech. Rep. 791.

Parenti, U. 1966. Facteurs de l'environnement dans le rapport sexes de *Paramermis contorta* de *Chirono-*

mus tentans. Proc. 1st Int. Congr. Parasitol., Rome. 1964:584–585.

Patterson, R. S. 1964. Recent investigations on the use of BHC and EPN to control chironomid midges in central Florida. Mosq. News 24:292–299.

Patterson, R. S. 1965. Control of chironomid midges in Florida. Fla. Anti-Mosq. Assoc. Annu. Rept. 36:35–39.

Patterson, R. S. and D. L. von Windeguth. 1964a. The effects of Baytex on some aquatic organisms. Mosq. News 24:46–49.

Patterson, R. S. and D. L. von Windeguth. 1964b. The use of Baytex as a midge larvicide. Mosq. News 24:393–396.

Patterson, R. S. and F. L. Wilson. 1966. Fogging and granule applications are teamed to control chironomid midges on Florida lake fronts. Pest Control 34:29–31.

Patterson, R. S., D. L. von Windeguth, B. M. Glancy and F. L. Wilson. 1966. Control of the midge *Glyptotendipes paripes* with low-volume aerial sprays of malathion. J. Econ. Entomol. 59:864–866.

Pelsue, F. W. and G. C. McFarland. 1971. Laboratory and field studies on a new chironomid species in the Southeast Mosquito Abatement District. Proc. Pap. Calif. Mosq. Control Assoc. 39:74–79.

Pelsue, F. W., G. C. McFarland and C. Beesley. 1974. Field evaluation of two insect growth regulators against chironomid midges in water spreading basins. Proc. Pap. Calif. Mosq. Control Assoc. 42:157–163.

Petersen, J. J. 1985. Nematode parasites, pp. 110–122. *In:* H. C. Chapman (ed). Biological control of mosquitoes. Am. Mosq. Control Assoc. Bull. 6.

Poinar, G. O., Jr. 1964. A new nematode, *Orthomermis oedobranchus* gen.n.sp.n. (Mermithidae) parasitizing *Smittia* larvae (Chironomidae) in England. Nematologica 10:501–506.

Poinar, G. O., Jr. 1968. *Hydromermis conophaga* n. sp., parasitizing midges (Chironomidae) in California, Ann. Entomol. Soc. Am. 61:593–598.

Poinar, G. O., Jr. 1981. Mermethid nematodes of blackflies. pp. 159–170. *In:* M. Laird (ed.). Blackflies: the future for biological methods in integrated control. Academic Press, London.

Poinar, G. O., Jr. and D. H. Ecke. 1967. Studies on a new species of *Gastromermis* (Mermithidae) parasitizing *Tanytarsus* larvae (Chironomidae) in California. WHO/VBC/67.

Polls, I., B. Greenberg and C. Lue-Hing. 1975. Control of nuisance midges in a channel receiving treated municipal sewage. Mosq. News 35:533–537.

Prichard, G. 1964. The prey of dragonfly larvae (Odonata: Anisoptera) in ponds in northern Alberta. Can. J. Zool. 42:785–800.

Provost, M. W. and N. Branch. 1959. Food of chironomid larvae in Polk County lakes. Fla. Entomol. 42:49–62.

Rasin, K. 1929. *Coelomomyces chironomi* n. sp., houba cizopasici v dutine telni larer *Chironoma*. Biol. Spis. Vys. Sk. Zverolek 8:1–13.

Rathburn, C. B. 1988. Insecticides labeled for the control of adult and larval mosquitoes by ground and aerial application methods. J. Fla. Anti-Mosq. Assoc. 59:27–36.

Risbec, J. 1951. Les Diptères nuisibles au riz de Camargue au début de son développment. Rev. Pathol. Veg. Entomol. Agric. Fr. 30:211–227.

Roback, S. S. 1971. The adults of the subfamily Tanypodinae (=Pelpoiinae) in North America (Diptera: Chironomidae). Mon. Acad. Nat. Sci. Philadelphia No. 17.

Rodcharoen, J., M. S. Mulla and J. D. Chaney. 1991. Microbial larvicides for the control of nuisance aquatic midges breeding in mesocosms and manmade lakes in California. J. Am. Mosq. Control Assoc. (In press).

Sato, H. and M. Yasuno. 1979. Tests on Chironomidae larvae susceptibility to various insecticides. Jap. J. Sanit. Zool. 30:361–366. (In Japanese).

Schuytema, G. S. 1977. Biological control of aquatic nuisances—a review. Ecological Research Series, EPA-600/3-77-084.

Shimizu, K. 1978. On the nuisance midge in Kanda river. Seikatsu to Kankyo 23:25–38. (In Japanese).

Sinegre, G., M. Babinot, G. Vigo and J. N. Tourenq. 1990. Sensibilité de trois espèces de *Chironomus* (Diptera) à huit insecticides utilisés en démoustication. Ann. Limnol. 26:65–71.

Spiller, D. 1965. Methods used for chironomid larva surveys of sewage oxidation ponds and natural waters at Auckland, New Zealand. Calif. Vector Views 12:9–15.

Steinhaus, E. A. and F. J. Brinley. 1957. Some relationships between bacteria and certain sewage-inhabiting insects. Mosq. News 17:299–302.

Stoltz, D. B. and M. D. Summers. 1971. Observations on the morphogenesis and structure of a hemocytic poxvirus in the midge *Chironomus attenuatus*. J. Ultrastr. Res. 40:581–598.

Stoltz, D. B., W. L. Hilsenhoff and H. F. Stitch. 1968. A virus disease of *Chironomus plumosus*. J. Invertebr. Pathol. 12:118–128.

Sublette, J. E. 1960. Chironomid midges of California. I. Chironominae, exclusive of Tanytarsini (=Calopsectrini). Proc. U.S. Nat. Mus. 112:197–226.

Sublette, J. E. 1964. Chironomid midges of California. II. Tanypodinae, Podonominae, and Diamesinae. Proc. U.S. Nat. Mus. 112:85–136.

Sublette, J. E. and M. S. Sublette. 1971. The Orthocladiinae (Chironomidae: Diptera) of California. I. The *Cricotopus infuscatus* group. Entomol. News 82:85–102.

Tabaru, Y. 1975. Outbreak of chironomid midge in a polluted river and chemical control of the larvae. Jap. J. Sanit. Zool. 26:247–251. (In Japanese).

Tabaru, Y. 1985a. Studies on chemical control of a nuisance chironomid midge (Diptera: Chironomidae). 1. Larvicidal activity of organophosphorus insecticides against *Chironomus yoshimatsui*. Jap. J. Sanit. Zool. 36:285–290. (In Japanese).

Tabaru, Y. 1985b. Studies on chemical control of nuisance chironomid midge (Diptera: Chironomidae). 2. Chemical control of the midge larvae in a sewage treatment plant by dripping technique and effects of the chemicals on microorganisms in activated sludge. Jap. J. Sanit. Zool. 36:291–298. (In Japanese).

Tabaru, Y. 1985c. Studies on chemical control of a nuisance chironomid midge (Diptera: Chironomidae). 3. Susceptibility of *Chironomus yoshimatsui* collected from various rivers to the three kinds of organophosphorus larvicides and larval control trials with chlorpyrifos methyl in the field. Jap. J. Sanit. Zool. 36:299–304. (In Japanese).

Tabaru, Y. 1985d. Studies on chemical control of a nuisance chironomid midge (Diptera: Chironomidae). 4. Efficacy of two insect growth regulators to *Chironomus yoshimatsui* in laboratory and field. Jap. J. Sanit. Zool. 36:305–309. (In Japanese).

Tabaru, Y., H. Matsunaga and A. Sato. 1978. Chemical control of the chironomid larvae (Diptera: Chironomidae) in the polluted river in reference to the controlled area and the mortality of the intoxicated larvae carried by the stream. Jap. J. Sanit. Zool. 29:87–91. (In Japanese).

Tabaru, Y., K. Moriya and A. Ali. 1987. Nuisance midges and their control in Japan. J. Am. Mosq. Control Assoc. 3:45–49.

Tokunaga, M. and M. Kuroda. 1936. *Stenochironomus* midge from Japan (Diptera), with notes on controlling methods of a leaf mining midge. Trans. Kansai Entomol. Soc. 7:1–6.

Tsai, S. C. and E. F. Legner. 1977. Exponential growth in culture of the planarian mosquito predator, *Dugesia dorotocephala* (Woodworth). Mosq. News 37:474–478.

Tsumuraya, T., T. Mori and T. Matsumoto. 1982a. The ecology and control of *Chironomus yoshimatsui* in the sewage water treatment plant. Yosui to Haisui 24:331–335. (In Japanese).

Tsumuraya, T., K. Moriya, T. Matsumoto and T. Mori. 1982b. The ecology and control of *Chironomus yoshimatsui* in the sewage water treatment plant. Yosui to Haisui 24:1356–1362. (In Japanese).

Weiser, J. 1948. Zwei neuartige Erkrankungen bei Insekten. Experientia (Basel) 4:317–318.

Weiser, J. 1961. Die Mikrosporidien als Parasiten der Insekten. Monogr. Angew. Entomol. 17.

Weiser, J. 1963. Zür Kenntnis der Mikrosporidien aus Chironomiden-Larven III. Zool. Anz. 170:226–230.

Weiser, J. 1969. A poxlike virus in the midge *Camptochironomus tentans*. Acta Virol. 13:549–553.

Weiser, J. 1976. The intermediary host for the fungus *Coelomomyces chironomi*. J. Invertebr. Pathol. 28:273–274.

Weiser, J. and V. J. E. McCauley. 1971. Two *Coelomomyces* infections of Chironomidae (Diptera) larvae in Marion Lake, British Columbia. Can. J. Zool. 49:65–68.

Weiser, J. and V. J. E. McCauley. 1974. *Bertramia marionensis* n.sp., a fungal parasite of Chironomidae (Diptera) larvae. Z. Parasitenkd. 43:299–304.

Weiser, J. and J. Vávra. 1964. Zür Verbrietung der *Coelomomyces*. Pilze in europäischen Insekten. Z. Tropenmed. Parasitol. 15:38–42.

Welch, H. E. and G. O. Poinar, Jr. 1965. The role and use of nematodes in the regulation and control of insects of medical importance. Proc. XII Int. Congr. Entomol. Lond. July 1964:732.

Wilhelmi, J. 1925. Zuckmückenlarven im Hochbehalter einer Wasserversorgungsanlage. Kl. Mitt. Mitgl. Ver. Wasserversorgung Abwasserbes. 1:119–120.

Williams, D. A. 1974. An infestation by a parthenogenetic chironomid. Water Treat. Exam. 23:215–229.

Wirth, W. W. and A. Stone. 1956. Aquatic Diptera. pp. 372–482. *In:* R. L. Usinger (ed.). Aquatic insects of California. Univ. Calif. Press, Berkeley and Los Angeles.

World Health Organization. 1982. Data sheet on the biological control agent *Bacillus thuringiensis* serotype H-14 (de Barjac 1978). WHO/VBC/79.750 Rev. 1.

World Health Organization. 1985. Informal consultation on the development of *Bacillus sphaericus* as a microbial larvicide. WHO/TDR/BCV/SPHAERICUS 85.3.

Wright, J. E. 1984. Biological activity of Avermectin B_1 against the boll weevil (Coleoptera: Curculionidae). J. Econ. Entomol. 77:1029–1032.

Wülker, W. 1958. Parasitäre Intersexualität bei Chironomiden des Schluchsees. Gew. Abwässer 20:62–67.

Wülker, W. 1961. Untersuchungen über die Intersexualität der Chironomiden (Dipt.) nach *Paramermis* - Infektion. Arch. Hydrobiol. Suppl. 25:127–181.

Wülker, W. 1963. Prospects for biological control of pest Chironomidae in the Sudan. WHO/EBL/11.

Wülker, W. 1965. Der Mechanismus des Eindringens parasitärer Mermithiden (Nematoda) in *Chironomus*-Larven (Diptera: Chironomidae) Z. Parasitenkd. 26:29–49.

Yasuno, M., Y. Sugaya and T. Iwakuma. 1985. Effects of insecticides on benthic community in a model stream. Environ. Pollut. 38:31–43.

Yasuno, M., J. Hasegawa, T. Iwakuma, N. Imamura and Y. Sugaya. 1982. Effects of temephos on chironomid and plankton populations in eel culture ponds. Jap. J. Sanit. Zool. 33:207–212. (In Japanese).

Yokogi, K. and R. Ueno. 1971. Wasabi (Japanese horseradish, *Wasabia japonica*). Nohson-Gyoson Bunka Kyoukai, Tokyo. 136 p. (In Japanese).

Zur, O. 1980. The importance of chironomid larvae as natural feed and as biological indicator of soil condition in ponds containing common carp (*Cyprinus carpio*) and *Tilapia* (*Sarotherodon aureus*). Bamidgeh 32:66–77.