FIELD EFFICACY AND NONTARGET EFFECTS OF THE MOSQUITO
LARVICIDES TEMEPHOS, METHOPRENE, AND BACILLUS
THURINGIENSIS VAR. ISRAELENSIS IN FLORIDA
MANGROVE SWAMPS

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ABSTRACT. We compared the efficacy and nontarget effects of temephos, Bacillus thuringiensis var. israelensis (B.t.i.), and methoprene applied by helicopter to control mosquito larvae in mangrove swamps on Sanibel Island, FL, in May 1997. Three sites per treatment and 3 untreated sites were used. Temephos (Abate®) was applied at 37 ml/ha (43% active ingredient [AI]), B.t.i. granules (Vectobac G®) were applied at 5,606 kg/ha (200 International Toxic Units/mg), and methoprene (Altosid® ALL) was applied at 213 ml/ha (5% AI). Efficacy was quantified by monitoring the survival of sentinel nontarget amphipods (Talitridae) at all sites, monitored the effect of temephos on flying arthropods using light traps, and collected dead insects in tarps suspended under mangroves in areas treated with either temephos or methoprene. Each pesticide showed good overall efficacy but occasional failures occurred. No detectable mortality of amphipods or flying insects attributable to pesticides was found. The inconsistent field efficacies of the pesticides indicate a need for reinspection of treated sites in this habitat.

KEY WORDS B.t.i., Abate®, Altosid®, mosquito control, Aedes taeniorhynchus

INTRODUCTION

Coastal marshes and mangrove swamps are often managed for mosquito control because salt-marsh mosquitoes can emerge in numbers that threaten the health of humans and livestock. The salt-marsh mosquito Aedes taeniorhynchus (Wiedemann) can make our study area, Sanibel Island, FL, nearly uninhabitable, and it can harm livestock (Addison and Ritchie 1993). Aedes taeniorhynchus can fly long distances to obtain blood meals (Ritchie and Montague 1995), so one of the best methods of controlling this species is to kill the larvae in local breeding sites before they disperse as adults. Aedes taeniorhynchus larvae develop in temporary pools that form in depressions above the upper intertidal zone in mangrove swamps and salt marshes. They often occur in such large numbers that emergence of even a small percentage of the population can create problems for residents. Because salt marshes and mangrove swamps are productive habitats that sustain a variety of wildlife (review, Mitsch and Gosselink 1993), environmentally sound mosquito management is a conservation priority. We conducted a large-scale field study on 3 larvicides, temephos, Bacillus thuringiensis var. israelensis (de Barjac) (B.t.i.), and methoprene, to assess whether these larvicides could control mosquitoes in mangrove areas without causing substantial mortality of nontarget amphipods and canopy insects.

The 3 pesticides have different modes of action and expected nontarget effects. All are relatively safe for vertebrates at levels used in mosquito control, but vary in risk to invertebrates. Temephos is an organophosphate pesticide that acts by inhibiting cholinesterase, and it is toxic to insects and some other nontarget invertebrates (Smith 1987, Brown et al. 1996). The bacterium B.t.i. is a microbial insecticide. It controls mosquitoes with toxins whose action is specific to nematoceran dipterans (e.g., mosquitoes and black flies), and is expected to have little effect on other macroinvertebrates (Back et al. 1985, Federici 1995). Methoprene is similar in structure to insect juvenile hormone, and it causes mortality in mosquitoes by interfering with metamorphosis. Although the action of methoprene is not specific to mosquitoes, many insects are insensitive to the levels of methoprene used in mosquito control (Hershey et al. 1995, but see Gelbic et al. 1994). Methoprene is not expected to affect adult insects. Methoprene and B.t.i. were recently reported to have negative indirect effects on predatory insects (Hershey et al. 1998). However, declines of predators occurred only after 2–3 years of frequent application of the materials at maximum label rates, and no such effects have been documented during normal use of these materials.

This study offers a side-by-side comparison of the field efficacy of the pesticides when applied by aircraft to swamps composed of mangroves and grasses. To compare the nontarget effects of the pesticides, we monitored the survival of a common amphipod (Talitridae) in treated and control sites. We also tested whether temephos would kill invertebrates inhabiting the mangrove canopy. Nontarget insects in the mangrove canopy could be affected by aerial applications of temephos because it is a contact poison.

MATERIALS AND METHODS

Study sites: The study was conducted in May 1997, during the 1st larviciding operations of that
We established 11 study sites on Sanibel Island plus one on nearby Fisherman's Key (Fig. 1). Sites ranged in size from 3.2 to 27.6 ha. The dominant species in all areas were red mangrove (*Rhizophora mangle* (L.)) and black mangrove (*Avicennia germinans* (L.)), with a few areas of grasses or white mangroves (*Laguncularia racemosa* (Gaertn)) in some sites. These sites typically flood during high-tide cycles that coincide with onshore winds, and the water usually disappears within several days (G. Wichterman, personal communication). All sites flooded with rain and tide waters during a storm on May 12, 1997, and 1st-stage *Ae. taeniorhynchus* appeared the next day. Each larvicide was applied to 3 sites and 3 control sites were not treated. Control sites flooded simultaneously with treated sites but produced few mosquitoes. It was unable to assign control sites at random with respect to the presence of mosquitoes, because even small untreated areas can produce enormous numbers of mosquitoes that attack nearby residents.

We sampled study sites on the day before pesticide application and on the subsequent 6 days. At all sites, we monitored survival of caged mosquito larvae and amphipods, and sampled uncaged mosquitoes in treated sites using dippers. We evaluated whether temephos would affect terrestrial insects by comparing insect collections from sites treated with temephos to sites that were either untreated or treated with methoprene. Details are given below.

**Pesticide application:** Lee County Mosquito Control District personnel applied all pesticides by helicopter, and cleaned application gear between applications of different materials. The *B.t.i.* granules (Vectobac G®, Abbott Laboratories, North Chicago, IL) were applied on May 14, 1997, at a rate of 5.606 kg/ha (200 International Toxic Units per mg; 5 lb/acre). Temephos and methoprene were applied on May 15, 1997, except for 1 application of temephos to Fisherman’s Key on May 16, 1997. Temephos (Abate®, Clarke Mosquito Control Products, Roselle, IL) was applied at 37 ml/ha (43% active ingredient [AI]; 0.5 fl oz/acre). Methoprene (Altosid® ALL, Wellmark International, Bensonville, IL) was applied at 213 ml/ha (5% AI, 3 oz/acre). One *B.t.i.* site was retreated with temephos after 2 days to prevent emergence of mosquitoes that survived the *B.t.i.* application.

**Sentinels:** We used field-collected *Ae. taeniorhynchus* larvae and amphipods in the family Taliprotile.
tridas as sentinels to monitor insecticide activity. *Aedes taeniorhynchus* and the amphipods were the only aquatic macroinvertebrates consistently present in study sites after flooding, probably because the habitat is ephemeral. Other aquatic macroinvertebrates occasionally observed during field work were fiddler crabs, water boatmen (Corixidae), and dytiscid beetles. Sentinels were held in floating predator-exclusion cages. Cages were 1.9-liter plastic buckets that were suspended in the water by a ring of styrofoam and attached to a stake by string. Cages had 2 screened windows measuring 5 × 10.5 cm, and had screened lids that were removed during insecticide applications. Before pesticide application on May 14, 25 2nd-stage mosquito larvae were placed in each of 2 cages per site, and 25 amphipods were placed in each of 2 cages per site. We recorded sentinel organism survival each day.

**Dip samples:** We monitored pesticide efficacy using 3 transects of 15 mosquito-dipper samples per site (45 dips of 350 ml each). We used a random dipping pattern at all sites except for 1 site treated with methoprene. This site contained large numbers of mosquitoes that formed dense aggregations, and random sampling underestimated their abundance. Beginning on May 18, we targeted aggregations in our dip transects to check for mosquitoes dying as mature 4th instars or pupae, as is typical of methoprene. On this date we also put 10 4th-stage larvae into each of 3 additional sentinel cages, to see what proportion of previously uncaged mosquitoes would metamorphose. Aggregations did not pose sampling problems at other sites because mosquitoes either were dead by the time aggregations formed or were too sparse to form aggregations.

We used analysis of variance (ANOVA) to compare the abundance of mosquitoes before vs. after treatment in treated sites. Abundances were transformed as ln(n + 1) to normalize their distribution. Data were the mean of the number per dip averaged over 2 pretreatment dates for temephos (May 14, 15), compared to the mean abundance of 2 posttreatment dates (May 18, 19). Only 1 pretreatment date was available for the *B.t.i.* sites (May 14), and we used May 15 as the posttreatment date because 1 site had to be retreated with temephos after May 15. Natural mortality cannot be factored out of the data set, but the data allow a comparison of the relative proportion of mosquitoes emerging from each treatment. Analysis of the sentinel data from controls showed whether mortality could be attributed to pesticides. Unfortunately, we could not perform a statistical test for uncaged mosquitoes exposed to methoprene because we had suitable data from only 1 site. The 2nd site dried, and larval aggregation at the 3rd caused an apparent rise in sample numbers after treatment. However, sentinel data were available for statistical tests of the effect of methoprene.

**Canopy insects:** Preliminary sampling showed that insects were too sparse in the mangrove canopy for effective sampling by sweep net (15 canopy sweeps typically yielded fewer than 4 insects). Therefore, we tested whether temephos affected flying insect abundance by collecting insects with Centers for Disease Control light traps (CDC traps) and ultraviolet light traps (UV traps) in 2 sites treated with temephos (Wulfert’s Point and West Impoundment Swale), and in 2 sites that are not larvicated (Pole Line and Tarpon Bay). We placed 2 CDC traps and 1 UV trap in each site, at least 20 m apart. The vegetation was thick in these areas and so it is unlikely that the traps attracted insects from outside the designated sites. We could not see from 1 trap to the next and had to follow flagged trails to find them. However, insects were free to fly in and out of sites during the study. We collected insects on the night before temephos was applied, and on the subsequent 4 nights. We used ANOVA to determine whether treated areas showed greater differences in abundance than controls after the pesticide application date. Data points were transformed as ln(abundance) − ln(controls), where the pretreatment data were collected May 14 p.m. to May 15 a.m. and the posttreatment data were collected May 16 p.m. to May 17 a.m. The posttreatment collection occurred on the night after the highest mortality was seen in larval mosquitoes.

**RESULTS**

**Sentinel organisms**

All 3 materials killed sentinel mosquitoes. Heavy mortality occurred in treated sites but survival was high in controls (Fig. 2A). Ninety-five percent of sentinel mosquitoes died in 2 of 3 sites treated with temephos, but all survived in the 3rd site, Fisherman’s Key. This site was treated 1 day later, and contained older 4th-stage larvae that may have been less susceptible to temephos (G. Wichterman, personal communication). The effect of temephos was significant when we eliminated this site from sta-
Dynamics of sentinel organisms

Analysis of the sentinel data showed significant decreases in mosquito populations in treated sites (Fig. 3B), although 1 site could not exhibit much of a decrease because very few larvae were present initially. An ANOVA indicated a strong trend toward an effect of B.t.i. on mosquito abundance whether or not this site was included (all sites, df 1,4, F = 4.9, P < 0.09; 1 site excluded, df 1,3, F = 13.0, P < 0.07).

Methoprene killed nearly all mosquitoes at metamorphosis in 1 of the 2 sites that remained wet until mosquitoes emerged (Fig. 3C). At the 2nd site, the final dip sample consisted of 35% shed pupal skins and 65% dead pupae or larvae and many biting adults were present, showing that methoprene did not yield adequate control. This was the same site that showed emergence of 5% of the original caged sentinels and 10% of field-exposed mosquitoes that were caged on day 5. Dip samples at both sites contained many dead pupae, 4th-stage larvae, and partially emerged adults, as is typical of the action of methoprene.

Canopy insects: Analysis of light trap data did not indicate any consistent loss of insects from treated sites (Fig. 4). No significant decreases occurred in the abundance of flying insects captured in CDC traps in sites treated with temephos (ANOVA, df 1,2, F = 4.3, P = 0.17). Results from UV light traps were similar. Unfortunately, 2 of the UV traps failed during the pretreatment night, 1 from a treated site and the other in a control. Therefore, instead of analyzing pre- vs. posttreatment differences for UV traps, we compared the posttreatment abundance of insects in controls vs. treated areas.
Fig. 3. Numbers of *Aedes taeniorhynchus* mosquito larvae per dip in 3 transects of 15 mosquito-dipper samples per site, per date, in Florida mangrove areas treated with (A) temephos, (B) *Bacillus thuringiensis* var. *israelensis*, or (C) methoprene. Each line represents a separate site. The arrow on the x axis indicates the date of pesticide application.

on May 17, the 1st night when all traps ran properly. No effect of temephos (ANOVA, df 1, 2, F = 2.1, P = 0.28) was detected. Most of the insects captured in light traps were small flies in the families Psychodidae and Ceratopogonidae. Other common taxa included mosquitoes, crane flies, moths, beetles, and Hymenoptera.

Table 1. Numbers of insects caught in 3.8-m² tarps hung below mangrove canopy sprayed with either methoprene or temephos, during 2 days after pesticide application.

<table>
<thead>
<tr>
<th></th>
<th>Ants</th>
<th>Wasps</th>
<th>Beetles</th>
<th>Moths</th>
<th>Spiders</th>
<th>Flies</th>
<th>Bugs</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temephos</td>
<td>91</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>6</td>
<td>0</td>
<td>3</td>
<td>108</td>
</tr>
<tr>
<td>Methoprene</td>
<td>17</td>
<td>3</td>
<td>19</td>
<td>1</td>
<td>6</td>
<td>2</td>
<td>9</td>
<td>4</td>
<td>61</td>
</tr>
</tbody>
</table>

**DISCUSSION**

All 3 pesticides caused significant mortality of sentinel mosquito larvae in treated sites compared to controls, demonstrating that the pesticides (rather than predation or other natural sources of mortality) were responsible for reducing mosquito populations. The mortality of sentinel mosquitoes paralleled decreases in natural populations in treated sites. However, sentinel mosquitoes sometimes showed greater or lesser declines after pesticide application.
plication than natural populations. These differenc-
es could result from uneven distribution of pesti-
cides over the sites or different levels of exposure
due to the cages.

Larvicides were often effective in killing un-
caged *Ae. taeniorhynchus* larvae underneath the
mangrove canopy, yielding average control levels
of 80–90%. This is a good level of control for this
habitat, which is difficult to treat because the can-
opy can interfere with delivery of the materials and
the water is often hidden from view. However, in
at least 1 site per material, the larvicides failed to
yield the high level of control necessary for salt-
marsh mosquitoes.

Temephos failed to control mosquitoes adequate-
ly at 2 sites, including 1 complete failure. This may
have been due to a 1-day delay in treating the site,
because older *Ae. taeniorhynchus* larvae that are
approaching pupation are less susceptible to teme-
phos (G. Wicherteman, personal communication).

The *B.t.i.* reduced dip-counts of mosquitoes to 0
at 2 sites but a 3rd site had to be retreated with
temephos to further reduce emergence from 14% to
nearly 0. Mosquitoes were more abundant at this
site than at any of the others (Fig. 3), and *B.t.i.*
sometimes fails to control dense populations of mosqui-
toes if they deplete the toxin from the water
before all obtain a lethal dose (e.g., Mulla et al.

Finally, methoprene yielded 1 success and 1 par-
tial failure. Dame et al. (1998) recently demonstrat-
ed resistance to methoprene for a population of *Ae.
taeniorhynchus* on Captiva Island that had been ex-
posed to extended-release, 150-day Altosid briquets
over a period of 6 years. Captiva and Sanibel is-
lands are part of the same land mass, and it is pos-
sible that the population of *Ae. taeniorhynchus*
is also the same. This could explain the emergence of
mosquitoes from our methoprene-treated sites, al-
though uneven application of materials is also a
possibility.

The occasional failures of the 3 larvicides demon-
strate that re-inspection and retreatment of breeding
sites are very important in ensuring an effective
mosquito control program. However, a 2nd appli-
cation of larvicide is only feasible for sites treated
with *B.t.i.* early in larval development, or before
the late 4th stage with temephos. Methoprene does
not afford this opportunity because it kills mosqui-
toes during pupation and emergence, when it is too
late to re-treat with a larvicide.

Pesticides did not cause detectable mortality of
amphipods. The amphipods had been collected in
aquatic samples from the sites and were sometimes
seen swimming in the water; however, they often
climbed up the screens of the sentinel buckets and
rested above the waterline. This could have reduced
their exposure to pesticides. Most Talitridae are
semiaquatic species, which explains their abun-
dance in the intermittently flooded high marsh.

Comparatively few other studies have been pub-
lished of the nontarget effects of these pesticides
on salt marshes or mangrove swamp fauna with
which to compare our results, but we review those
available below. We found few aquatic nontarget
organisms in our ephemeral sites; however, we re-
port studies of macroinvertebrates or fish that may
enter the high marsh during more extended periods
of flooding. As a caveat in interpreting these stud-
ies, all but the 1st 2 presented were conducted in
laboratories. Laboratory studies often result in
greater exposure of organisms to toxins because of
clean water conditions and the inability of organ-
isms to behaviorally avoid contaminants.

In a field study, the granular formulation of te-
memphos was reported to cause behavioral changes
in fiddler crabs. The fiddler crabs actively collected
and ingested the granules, which were applied at 63
g Al/ha (Ward and Busch 1976, Ward et al. 1976).
Crabs may have been attracted by the celatom in
the granules. This effect is not expected with the
liquid temephos used in our study area because the
liquid is applied at a lower rate and the crabs cannot
collect it. The 2nd field study was performed by
Pierce et al. (1989), who quantified the effects of
liquid temephos on 2 species of shrimp, juvenile
snook, and sheephead minnows. Temephos was
applied at twice the application rate used in our
study. Although temephos was safe for the fish, re-
results for the shrimp were unclear because 32% mor-
tality occurred at 1 of their 3 treated sites. However,
this mortality was not correlated with the amount of
temephos in the water.

Roberts (1995) found that *B.t.i.* had no effec-
on either a salt-marsh gammarid amphipod or a
shrimp. McKenney and Celestial (1996) found that
methoprene killed a marine mysid shrimp exposed
to 125 μg/liter over 4 days, with sublethal effects
occurring at levels as low as 2 μg/liter. In a com-
parative study, Lee and Scott (1989) used the mum-
michog fish (*Fundulus heteroclitus*) to compare the
acute toxicities of *B.t.i.*, methoprene, and temephos.
Temephos was more toxic than the other larvicides,
but all 3 were safe for the fish at the expected water
concentration for mosquito control. Brown et al.
(1996) compared the toxicity of *B.t.i.*, methoprene,
and temephos to an Australian estuarine shrimp
(*Leander tenuicornis*). Methoprene and *B.t.i.* were
not toxic at levels used in mosquito control. The
median lethal concentration of temephos was 0.01
ppm, and concentrations of temephos this high may
occur under operational conditions in Florida man-
groves. The expected concentration of temephos
applied at 14 g (0.5 oz) of 43% Al temephos/acre
(as in our study) is 0.026 ppm, with realized con-
centrations of 0.12–0.0045 ppm temephos found in
surface and midwater samples, respectively (Pierce
et al. 1996). However, whether laboratory studies
on an Australian shrimp can predict toxicity for
southeastern North America intertidal fauna under
field conditions is not known. In conclusion, al-
though temephos had some documented toxic ef-
fects, little field evidence exists that it causes mor-
tality of nontarget macroinvertebrates or fish when
applied at rates used in mosquito control. Relatively
low potential exists for mortality of aquatic nontar-
gets in our study area because few species utilize
the high marsh during the brief period that it is
flooded, and the more species-rich low marsh is
rarely treated because regular tidal flooding reduces
or prevents mosquito breeding.

This is the 1st study of whether temephos affects
mangrove canopy arthropods. We did not find sig-
nificant decreases in nocturnal flying insects in sites
treated with temephos compared with controls. We
also compared the number of insects collected in
tarps under canopy treated with temephos vs. meth-
ophrene, and found a similarly low number of dead
insects (an average of 10/tarp/day). In conclusion,
temephos, B.t.i., and methoprene effectively con-
trolled Ae. taeniorynchus without observable mor-
tality of the nontarget amphipods, and temephos did
not cause detectable changes in the abundance of
flying insects.

ACKNOWLEDGMENTS

We thank S. Stenquist, J. O’Neal, L. Hinds, L.
Hamilton, and J. Coppen of the U.S. Fish and Wild-
life Service for their assistance in planning and fa-
cilitating this project, and we also thank J. Coppen,
E. Jensen, and several Youth Conservation Corps
volunteers for help with field work. We are grateful
to the Lee County Mosquito Control District for
their generous help with many aspects of the work,
with particular thanks to W. Opp and T. Stewart.
We are indebted to R. K. Washino for help in or-
ganizing the study. The comments of 2 anonymous
reviewers improved the paper. This project was
funded by the U.S. Department of the Interior and
the U.S. Fish and Wildlife Service Cooperative
Agreement 14-48-0001-94582, Mosquito Manage-
ment on National Wildlife Refuges.

REFERENCES CITED

from prolonged exposure to Aedes taeniorhynchus

Back, C., J. Boisvert, J. O. Lacoursiere and G. Charpen-
tier. 1985. High-dosage treatment of a Quebec stream
with Bacillus thuringiensis serovar. israelensis: efficacy
against black fly larvae (Diptera: Simuliidae) and im-
 pact on non-target insects. Can. Entomol. 117:1523-
1534.

Becker, N., M. Zgomba, M. Ludwig, D. Petric and F. Ret-
tich. 1992. Factors influencing the activity of Bacillus
thuringiensis var. israelensis treatments. J. Am. Mosq.
Control Assoc. 8:285-289.

Brown, M. D., D. Thomas, K. Watson, J. G. Greenwood
and B. H. Kay. 1996. Acute toxicity of selected pesti-
cides to the estuarine shrimp Leander tenuicornis (De-
12:721-724.

Mosquito (Aedes taeniorhynchus) resistance to metho-
phrene in an isolated habitat. J. Am. Mosq. Control As-
oc. 14:200-203.

Federici, B. A. 1995. The future of microbial insecticides

Gelbic, I., M. Papacek and J. Pokuta. 1994. The effects
of methophrene 5 on the aquatic bug Ilyocoris cimicoides
(Heteroptera, Naucauridiae). Ecotoxicology 3:89-93.

1998. Effects of Bacillus thuringiensis israelensis (B.t.i.)
and methoprene on nontarget macroinvertebrates in

Hershey, A. E., L. Shannon, R. Axler, C. Ernst and P.
Mickelson. 1995. Effects of methophrene and Bti (Ba-
cillus thuringiensis var. israelensis) on non-target in-

memphos, fenoxycarb, diflubenzuron, and methoprene
and Bacillus thuringiensis var. israelensis to the mum-
michog (Fundulus heteroclitus). Bull. Environ. Contam.
Toxicol. 43:827-832.

McKenney, C. L., Jr. and D. M. Celestial. 1996. Modified
survival, growth and reproduction in an estuarine mysid
(Mysidopsis bahia) exposed to a juvenile hormone an-
aloge through a complete life cycle. Aquat. Toxicol.
35:11-20.

Nostrand Reinhold, New York.

Effect of some environmental factors on the efficacy of
Bacillus sphaericus 2362 and Bacillus thuringiensis (H-
14) against mosquitoes. Bull. Soc. Vector Ecol. 15:166-
175.

Pierce, R. H., R. C. Brown, K. R. Hardman, M. S. Henry,
Fate and toxicity of temephos applied to an intertidal
mangrove community. J. Am. Mosq. Control Assoc. 5:
569-578.

Pierce, R., M. Henry, D. Kelly, P. Sherblom, W. Kozlows-
ky, G. Wichterman and T. W. Miller. 1996. Temephos
distribution and persistence in a southwest Florida salt
marsh community. J. Am. Mosq. Control Assoc. 12:
637-646.

Ritchie, S. A. and C. L. Montague. 1995. Simulated pop-
ulations of the black salt marsh mosquito (Aedes tae-
niorynchus) in a Florida mangrove forest. Ecol. Mod-
el. 77:123-141.

Roberts, G. M. 1995. Salt-marsh crustaceans, Gammarus
duebeni and Palaemonetes varians as predators of mos-
quito larvae and their reaction to Bacillus thuringiensis

Smith, G. J. 1987. Pesticide use and toxicology in relation
to wildlife: organophosphorus and carbamate com-
pounds. Resource Publication 170. U.S. Department of
the Interior, Fish and Wildlife Service, Washington, DC.

Ward, D. V. and D. A. Busch. 1976. Effects of temefos,
an organophosphorus insecticide, on survival and es-
cape behaviour of the marsh fiddler crab Uca pugnax.
Oikos 27:331-335.

Ward, D. V., B. L. Howes and D. F. Ludwid. 1976. Inter-
active effects of predation pressure and insecticide (Te-
memos) toxicity on populations of the marsh fiddler crab