Control of the Tadpole Shrimp, *Triops longicaudatus*, in California Rice Fields[1]

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Abstract

The tadpole shrimp is a common pest in most of the northern rice-growing counties of the Central Valley of California. It causes damage of two types: a chewing of roots and leaves, and a dislodging of rice seedlings by the chewing and by burrowing on the bottom. Field and laboratory tests conducted in 1954, 1957, 1958, and 1959 confirm that 2 pounds of DDT gives control when applied as granules with the seed, or application as granules or sprays after seeding. Copper sulfate "resistance" was associated with the rate of solubility of the bluestone crystals, for solutions were effective but crystals were not. Of the newer materials tried for shrimp control, Diazinon® (*O,O*-diethyl *O*-(2-isopropyl-4-methyl-6-pyrimidinyl) phosphorothioate), malathion, and Sevin® (1-naphthyl methylcarbamate) were all effective at 2 pounds actual toxicant per acre as postflooding sprays.

Branchiopod crustaceans, of the order Notostraca, are common inhabitants of temporary pools of fresh or brackish water. California rice culture creates such a freshwater habitat. Rosenberg (1947) reported *Triops longicaudatus* (Le Conte) (under the names *Apus oryzaphagus* and *Apus biggsi*) to be damaging rice seedlings in Butte and Sutter Counties. Such damage has since been found in most of the northern rice-growing counties of the Central Valley of this state. Longhurst (1955), in a taxonomic review of this order, recorded the range of *T. longicaudatus* as Western North America south of 50° N., through Central and South America, West Indies, Galapagos Islands, Hawaii, Japan, and New Caledonia. It is also a pest of rice in Japan. Longhurst listed *T. cancriformis* (Bosc.) as a rice field pest in Northern Italy, Spain, and France; and Walton & Kemp (1911) reported the same species damaging rice in India.

T. longicaudatus is commonly called the "tadpole shrimp" by California rice growers because of its similarity to the true tadpole in color, size, and swimming activity (fig. 1). It is olive-gray, the anterior portion of the body is covered with a shield-like carapace, and the nearly cylindrical abdomen extends from beneath this carapace and terminates in two cercopods. Overall length may reach 2 to 2½ inches. The crustacean has two large compound eyes and a median ocellus. The first and second pairs of appendages are respectively the antennules and antennae, and the third pair forms two strong toothed structures called the mandibles, which may be compared to those of a chewing insect. Numerous appendages bearing leaf-like gills attach to the abdomen.

In late April and May the shrimp are easily observed within 8 to 12 days after infested rice fields are flooded. Rosenberg (1947) reported on the following phases of shrimp biology. Dried eggs from the previous year hatched 72 hours after water submergence. The metanauplii and succeeding stages passed through a series of moults until they became adults. Reddish-orange egg-sacks appeared along the sides of the abdomen near the carapace in about 8 to 10 days. The number of generations was not determined but was believed to be more than one because eggs taken from the egg-sacks and kept in water hatched in a minimum of 5 days. Longhurst (1955) reported that species of this genus occur only in waters that dry out regularly. He was able to induce hatching of nondried eggs in 12 to 14 days by reducing the osmotic pressure of the water, a condition not likely to occur at the bottom of a pool, where the eggs are laid. He reported that reproduction in *T. longicaudatus* is bisexual and hermaphroditic, the latter only in California and other Pacific regions where no males have been recorded.

Young larvae feed on the organic content of the mud and on diatoms, Protozoa, and various small organisms. As they mature, their food and foraging habits vary and a high population may become a serious problem to the rice grower. The rice seed is broadcast in fields flooded to an average depth of 6 inches, which is maintained throughout the season. Young, submerged rice seedlings are delicately rooted and often coated with small gas bubbles. The shrimp dislodge seedlings by chewing leaves and roots and by burrowing in the mud. The dislodged plants often float to the surface, and wind movement collects them in large masses on the rice levees. Such windrows of rice plants on the shoreline do not necessarily indicate shrimp activity, since wind and wave action alone can produce the same effect if the seedbed is prepared improperly and the water is shallow. If shrimp are responsible, however, the uprooted seedlings will generally show some evidence of chewed leaves.

Damage.—To demonstrate chewing damage, rice seeds were placed between two 16-mesh screen disks about 3 inches in diameter in a rice field heavily infested with shrimp. One set of disks and seeds was placed in the rice paddy and protected from shrimp with a 16-mesh screen enclosure. A second set was left open in the infested rice paddy. The unprotected rice plants were chewed until they were considerably retarded or died, as indicated by a 27% seedling reduction in the exposed group of plants. Figure 2 (page 37) shows a set of protected and unprotected plants.

Muddy water is generally a reliable indicator of a shrimp infestation, particularly if only a section of the field is muddy, because shrimp frequently localize in certain rice checks. This localization may be repeated annually in the same checks. Rosenberg (1947) reported that the silt suspension from shrimp movements resulted in poor plant growth.

Chemical tests for control of *T. longicaudatus* with copper sulfate and with DDT were reported by Rosenberg (1947), and with DDT by Portman & Williams (1952) in conjunction with mosquito control. Unsatis-

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Fig. 1.—*Triops longicaudatus* (Le Conte).

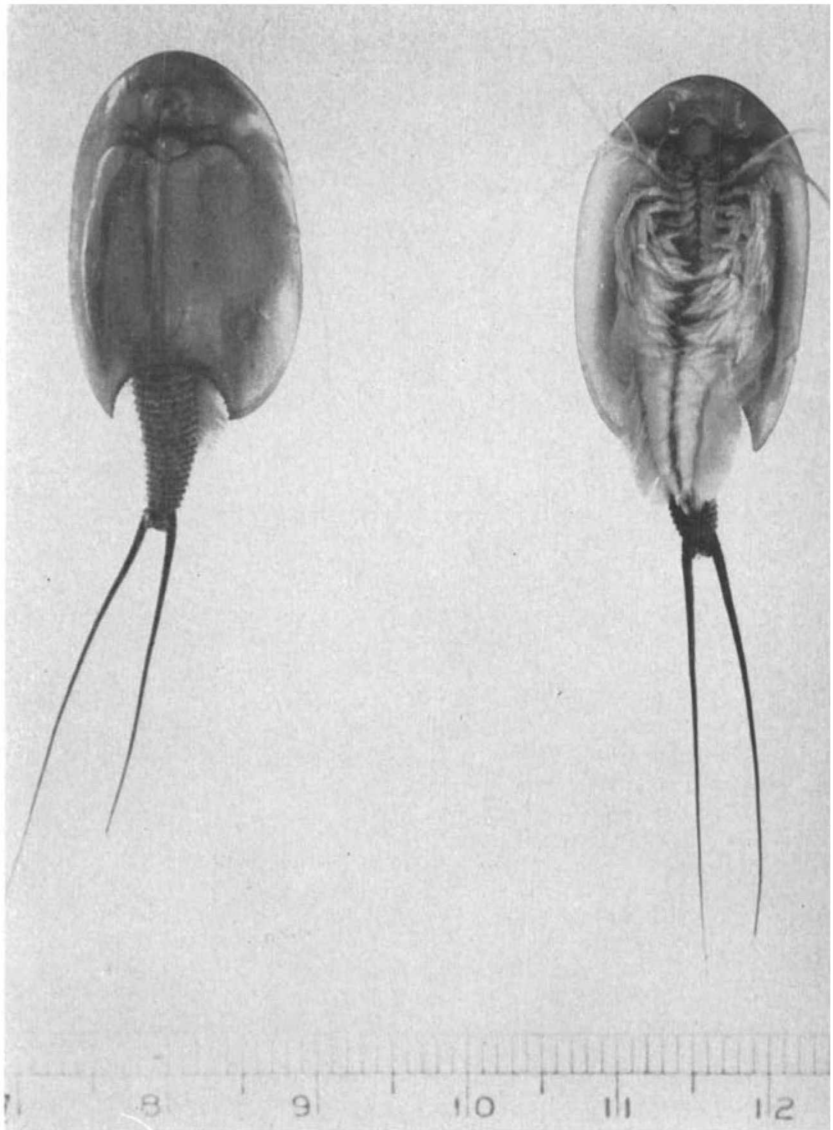

Fig. 2.—Three-week-old rice seedlings from a field heavily infested with shrimps. Left—plants exposed to shrimps. Right—plants protected by a screen.

Table 1.—Results of field test for control of *Triops*, June 17, 1954.

Formulation and Concentration	Active Ingredient/ Acre (lb.)	Per Cent of Shrimp Affected at Hours Shown Following Treatment					
		24		48		72	
		Moribund	Dead	Moribund	Dead	Moribund	Dead
DDT, EC[a] 2.0 lb./gal.	2.0	45	55	0	100	—	—
Dieldrin, EC 1.5 lb./gal.	0.5	98	2	22	78	0	100
Dieldrin, 2%, granules	0.5	57	0	51	49	16	84
Heptachlor, EC 2.0 lb./gal.	0.5	0	0	15	3	28	46
Malathion, 15%, granules	4.0	54	46	0	100	—	—
Copper sulfate, 99%, crystal	10.0	28	13	0	24	0	28
Check	—	0	0	0	0	0	0

[a] EC, Emulsifiable concentrate.

factory control with copper sulfate reported by growers in 1954–55 indicated a possibility of resistance to that chemical. This development, plus outbreaks of the rice leaf miner, *Hydrellia griseola* Fall., and rice seed maggots (chironomid larvae), prompted the present tests. Chemicals were selected for their possible value not only for shrimp control but for control of other rice pests as well. All tests were conducted at the Rice Experiment Station, Biggs, California.

1954 FIELD TESTS.—*Methods*.—The materials and application rates given in table 1 were used in 1/10-acre rice paddys containing water to an average depth of 6 inches. Applications were made with hand sprayers (10 gallons of water per acre) and manual granule dispensers. Two cylindrical cages, made of $\frac{1}{4}$-inch hardware cloth 17 inches high by 18 inches in diameter, were placed one on each end of the plot. About 20 shrimp were placed in each cage, and counts were made 24, 48 and 72 hours after treatment. Percentages of moribund and dead shrimp are reported in table 1. Moribund shrimp were generally at the bottom of the cage, on their backs and exhibiting weak gill movement, though they occasionally swam and sometimes recovered completely. Shrimp were considered dead after gill movements ceased.

Results.—The differences between the test materials (table 1) in speed of action and resultant mortality made it possible to rate them in decreasing order of effectiveness as follows: (1) DDT, (2) malathion, (3) dieldrin, (4) heptachlor, and (5) copper sulfate. The mortality resulting from dieldrin occurred sooner from the emulsion than from the granular form. Mortality from copper sulfate crystals was only 28% at 72 hours, which appeared to substantiate grower reports of poor performance.

1957 LABORATORY TESTS.—*Methods*.—The following four chemicals were used at dilutions of 1, 2, 4, 20, and 200 parts per million: DDT (2.0 lb. per gal. emulsible concentrate), dieldrin (1.5 lb. per gal.), malathion (4.0 lb. per gal. emulsible concentrate), and copper sulfate (99% crystals placed in saturated aqueous solution). Stock solutions were pipetted into glass jars with 2 liters of rice field water to the desired dilutions. Fifteen field-collected shrimp were divided into 3 replications of 5 per jar for each dilution. A check container of five shrimp accompanied each dilution. The shrimp were kept within the jars by plastic insert screens that allowed the test animals to be brought to the surface for examination. Observations were made periodically, and mortality recorded over a 20-hour period. The criterion for death was lack of gill movement.

Results.—Table 2 shows the time necessary to kill 50% and 100% of the shrimp and the per cent mortality at the end of the test. At the two highest dosages shrimp mortality was complete for all chemicals except DDT and malathion. The chemicals in decreasing order of toxicity at the highest dosage were: (1) DDT and dieldrin, (2) malathion, and (3) copper sulfate. At the lowest dilutions the most effective chemical was copper sulfate.

The surviving treated shrimp were all affected and probably would have died, but the check shrimp were beginning to die from confinement. Mortality in the check was 4% to 10% at 10 hours and 28% to 36% at 20 hours. Mortality at the three lowest dilutions did not always directly correlate with the strength of the dilution. It was felt that more accurate comparisons of toxicants with these laboratory methods would require a greater spread between the chemical dilutions.

1958 FIELD TRIALS.—*Methods*.—The methods and plot

Table 2.—Results of laboratory test with chemicals for control of *Triops*, June 6, 1957.

Treatment Concentration		Time (minutes for 50% and 100% mortality) and Per Cent Final Mortality at 20 Hours											
		Copper Sulfate			Dieldrin			DDT			Malathion		
P.p.m.	Lb./Acre	50%	100%	Final	50%	100%	Final	50%	100%	Final	50%	100%	Final
200	278.0	30	64	100	4	6	100	6	8	100	29	37	100
20	27.8	105	156	100	30	40	100	75	—	67	190	—	80
4	5.5	117	192	100	990	—	60	990	—	53	230	—	93
2	2.7	153	197	100	—	—	27	1,020	—	53	232	310	100
1	1.4	147	216	100	—	—	40	—	—	47	285	365	100
Check	—	—	—	28	—	—	36	—	—	36	—	—	36

sizes used in this test were the same as those described in the 1954 trials except that the test shrimp were arranged in three replications of 10, 10, and 20 shrimp per treatment. The 10-shrimp replications were contained in 16-mesh screen cylinders 8 inches in diameter and 18 inches high, with screened bottoms. A total of 33 shrimp were used in the dieldrin treatment. Mortality of the check animals was omitted in table 3 since one replication was killed by chemical drift and another was eaten by predators. Field confinements of this type in other trials have not normally resulted in high mortality.

Table 3.—Results of field test with insecticides for control of *Triops*, June 5, 1958.

Formulation and Concentration	Active Ingredient/Acre (pounds)	Shrimp Affected at Hours Shown Following Treatment (%)			
		24		48	
		Moribund	Dead	Moribund	Dead
DDT, EC, 2.0 lb./gal.	2.0	97	3	0	100
DDT, 50%, granules	4.0	50	30	5	88
Dieldrin, EC, 0.5 lb./gal.	0.5	18	9	52	42
Malathion, EC, 5.0 lb./gal.	2.0	17	78	0	100
Copper sulfate, solution, 99% crystal	10.0	0	100	—	—
Copper sulfate, crystals, 99%	10.0	30	70	0	92
Diazinon, EC, 2.0 lb./gal.	2.0	30	70	0	100
Kepone, EC, 2.0 lb./gal.	2.0	22	68	0	93

Results.—The mortality percentages in table 3 show that the rates of copper sulfate (solution), DDT (emulsible concentrate), malathion (emulsible concentrate), and Diazinon® (emulsible concentrate) (*O*, *O*-diethyl *O*-(2-isopropyl-4-methyl-6-pyrimidinyl) phosphorothioate) at the dosages selected all gave 100% shrimp control within 48 hours. The other chemicals gave 86% control or better, except dieldrin, which was applied at a considerably lower rate. The high percentage of moribund shrimp in the dieldrin test at the 48-hour interval indicated that more shrimp would have succumbed after an additional 24 hours. The fastest-acting chemical was copper sulfate applied as a solution.

1959 FIELD TESTS. *Methods.*—The chemicals and rates indicated in table 4 and 5 were applied with hand sprayers and granule dispensers to 1/200-acre sections of a rice field. The treated areas were separated by plastic levees 2 to 3 inches higher than the average water depth of 6 inches. Separate inlets and outlets allowed independent water flow through each treated area. Shrimp were

Table 5.—Results of field test with copper sulfate in solution for control of *Triops*, June 1, 1959.

Active Ingredient/Acre (lb.)	Shrimp Affected at Hours Shown Following Treatment (%)			
	4		24	
	Moribund	Dead	Moribund	Dead
5.0	27	27	0	97
10.0	0	100	—	—
None	0	0	0	0

field-collected and placed in screened cages like those used in the previous tests. About 50 shrimp were divided into three replications (10-30-10) for each treatment. A new complement of shrimp was used for each of the three series listed in table 4. A second test was made with copper sulfate alone (table 5) in which three replications of shrimp were used (10-10-10). Mortality counts were made in the same manner as for previous tests.

Results.—The various differences noted in table 4 suggest the following ranking of the test chemicals in decreasing order of toxicity: (1) copper sulfate (solution), (2) Sevin® (1-naphthyl methylcarbamate) (3) Diazinon, (4) DDT formulations, (5) malathion, (6) Kepone® (decachlorooctahydro-1, 3, 4-metheno-2*H*-cyclobuta[cd]pentalen-2-one) and (7) copper sulfate (crystals). Sevin was the most effective chemical with short residual properties, and DDT granular formulation A had the longest residual activity. As indicated in table 5, copper sulfate in solution was nearly as effective as one-half the 10-pound rate previously recommended for field use.

DISCUSSION.—These tests indicate not that *Triops longicaudatus* is resistant to copper sulfate but that past failures may be caused by the application practices or the type of crystal formulation used. Control was maximum when the copper sulfate was applied in solution and it appeared that the rate at which it went into solution determined its effectiveness. Since copper sulfate solution is quite corrosive to most application equipment, it should be applied dry, as a dust or at the smallest crystal size available. This chemical caused little shrimp mortality a week after treatment and probably would not be effective when applied before planting or with the seed. The selectivity of copper sulfate and its low toxicity to wild life call for its continued consideration for shrimp control.

Table 4.—Field test of residual activity of chemicals (May 25, 1959) for control of *Triops* introduced into plots along with chemicals and after two intervals.

Formulation and Concentration	Active Ingredient/Acre (lb.)	Shrimp Affected at Hours Shown Following Treatment (%)													
		Series A—introduced 5/25						Series B—introduced 5/28				Series C—introduced 5/31			
		24		48		72		48		72		24		48	
		Moribund	Dead	Moribund	Dead	Moribund	Dead	Moribund	Dead	Moribund	Dead	Moribund	Dead	Moribund	Dead
DDT, EC, 2.0 lb./gal.	2.0	96	4	28	72	0	100	0	100	—	—	0	0	0	65
DDT, 50%, granule A	2.0	60	7	24	76	0	100	5	95	0	100	10	10	5	85
DDT, 50%, granule B	2.0	62	2	10	79	0	86	20	25	0	65				
Malathion, EC, 5.0 lb./gal	2.0	46	54	40	60	2	98	20	80	0	100	0	0	0	0
Copper sulfate, 99% crystals, solution	10.0	0	100	—	—	—	—	0	35	0	45				
Copper sulfate, 99%, crystals	10.0	2	0	0	24	3	52	0	0	5	5				
Diazinon, EC, 2.0 lb./gal.	2.0	54	46	9	91	0	100	0	100	—	—	5	25	0	45
Kepone, EC, 2.0 lb./gal.	2.0	18	0	33	24	6	89	0	60	0	70				
Sevin, WP, 50%	2.0	70	30	0	100	—	—	0	15	0	30				
Check	—	0	0	0	0	0	3	0	0	0	0	0	0	0	0

DDT at 2 pounds actual per acre is the chemical most widely used for shrimp control. It is being applied as a granular material with the seed, or as a spray soon after the fields are flooded. Where mosquitoes are not resistant to it, it is often used for dual mosquito-shrimp control. Dieldrin and heptachlor at 0.5 pounds per acre (double the concentration used for rice leaf miner control) did not provide adequate control.

Diazinon and malathion gave satisfactory shrimp control in all tests at 2 pounds of active ingredient per acre. Their residual activity was less than that of DDT, but may have been long enough to permit treatment at the time of planting. These chemicals may also be of value in controlling other rice-field pests and should be investigated further, particularly at lower rates. The shrimp mortality obtained from Kepone at 2 pounds of active ingredient per acre varied somewhat in the 2 years it was tested which indicates a necessity for additional study. Sevin was used only in the 1959 field test. Its application at 2 pounds of active ingredient per acre resulted in rapid shrimp control and low residual activity. These attributes plus low vertebrate toxicity make it a logical candidate for future tests.

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Preliminary Study of the Genetics of House Fly (*Musca domestica*) Resistance to Malathion[1]

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ABSTRACT

The genetics of malathion resistance in a strain of house flies (*Musca domestica* L.) was studied by selecting two strains, one susceptible and one resistant to malathion, from a slightly resistant field strain. The method of selection was by collecting eggs from individual females and increasing the population to sufficient numbers to determine their response. After three generations of selection a uniform malathion-resistant strain was obtained. A susceptible strain was obtained in one generation although selection was continued another generation. The parent strain was 1.7 times as resistant as the susceptible strain, while the resistant strain was 62 times as resistant.

All insects used to determine response to malathion were laboratory-reared females which were tested 4 days after peak emergence with solutions made by diluting 95% technical malathion in glass-distilled acetone. Flies were held in recovery jars containing food, at a constant temperature until 24-hour mortality counts were taken.

Strain differences other than malathion resistance were present. The resistant strain required a longer period from egg to adult than the susceptible strain. The males in the susceptible strain emerged significantly earlier than the females. The resistant strain was observed to have a lower fecundity than the parent and susceptible strains. The sex ratio in the selected strains did not differ from a 1:1 ratio.

The F_1 hybrids of reciprocal crosses between the susceptible and resistant strain segregated into 50% susceptible and 50% resistant individuals. The least tenuous explanation for this segregation is that malathion resistance is inherited by two allelic groups exhibiting incomplete duplicate dominance epistasis. The segregation of the F_1 hybrids cannot be explained on the basis of a single gene or independent assortment of multiple genes, as the resistant strain is homogeneous malathion-resistant. The F_2 hybrids did not differ significantly from the F_1 hybrids.

Maternal effects were present in the F_1 hybrids but had disappeared in the F_2 generation. That the F_2 progeny of reciprocal crosses did not differ indicates that no sex-linkage is involved in the inheritance of malathion resistance.

Over the past 14 years, evidence on the development of insecticide resistance has accumulated in more than 40 species of insects of public health importance. The species most frequently studied is the house fly, *Musca domestica* L. The first observation of DDT-tolerance in house flies was reported in 1946 in Sweden and more recently house flies have become resistant to organophosphorus insecticides. The first report was by Keiding (1956) in Denmark. March (1959) has presented the most recent summary of insects resistant to organophosphorus insecticides. Malathion-resistant house flies were reported by March (1959) and Wilson *et al.* (1959). Malathion is widely used for house fly control; therefore, resistance to this chemical is of primary concern.

It appears likely that a high percentage of the species of insects will develop strains showing resistance to insecticides, thus it becomes important to ascertain, in each case, the extent of that resistance. The deciding factor, of course, is the genetic potential for resistance. Although much work has been done on house fly resistance, much more is needed to determine the mode of

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