Mosquito and chironomid midge control by planaria

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Planaria offer practical substitutes to chemicals for controlling mosquitoes and chironomid midges in some aquatic pest management systems. Unlike chemical larvicides, planaria produce a sustained high level of control that endures through the entire season without pest upsets.

There is today a critical need for alternatives to chemical larvicides for mosquitoes and chironomid midges. Resistance, costs of chemicals, and environmental contamination make this necessary. One potentially useful but heretofore little explored group of natural control organisms of mosquito and midge larvae are the freshwater planaria (Platyhelminthes: Turbellaria). Planaria have been shown experimentally to devastate laboratory cultures of mosquitoes and midges, killing far more larvae than they consume, and they have been recently reported by workers in California, New York and Maine to be equally effective in natural habitats. Among those habitats are rice fields, roadside ditches, water sloughs, agricultural and constructional drain depressions, catch basins, canal seepages, treated sewage effluents, snowmelt pools, flood control channels and water-settling basins.

Planaria hold unique potential as biological control agents for freshwater mosquito and chironomid midge larvae. Unlike predaceous insects, planaria can be mass produced and confined at high densities without any danger of cannibalism. In addition, it is potentially possible to rear large numbers of planaria because laboratory cultures can double in number from 4 to 8 days when conditions are suitable (and depending upon the species). Planaria also produce semi-dormant "winter" eggs which can be stored and disseminated with the convenience currently possible with insecticides. Also, and unlike most predaceous aquatic insects, planaria have no autonomous means of dispersal beyond their immediate habitat. Thus, if conditions are favorable to their survival they will remain and reproduce in the environment into which they are introduced.

In the search for alternatives to chemical larvicides it is unlikely that many organisms, except perhaps larvivorous fishes and freshwater hydra, will be useful over such a broad spectrum of habitats as planaria will. Furthermore, planaria are unique among invertebrate predators in that they have characteristics that satisfy three basic requirements of biological control: amenability to mass production;

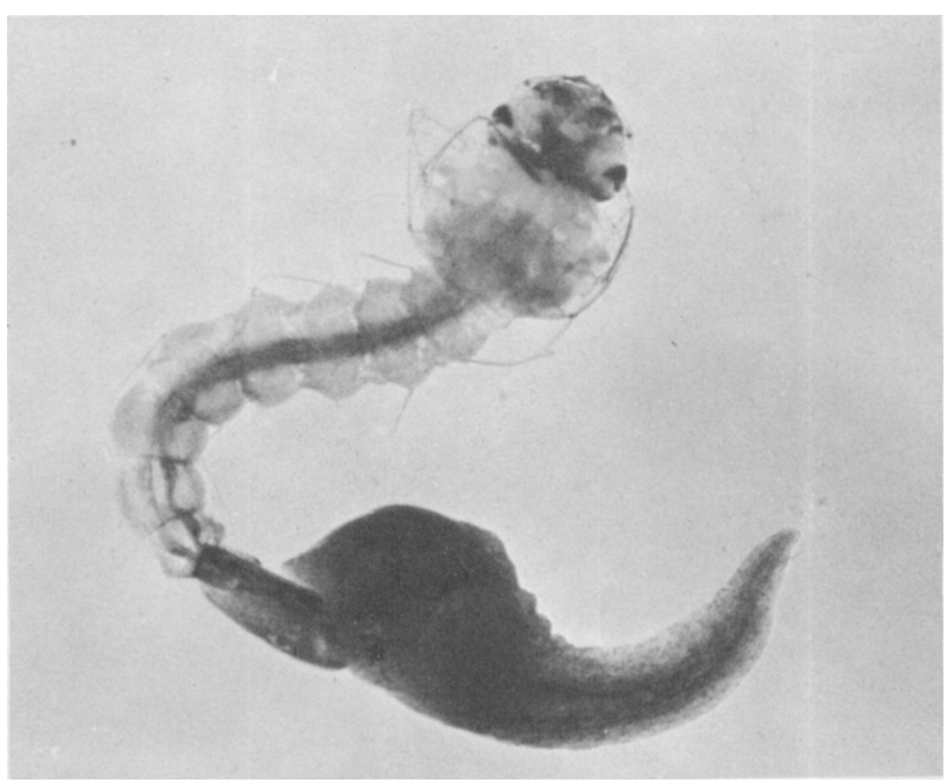


Fig. 1. Planarian contacting and paralyzing a mosquito larva.

ease of storage; and practicality of applying to infested areas. With respect to mosquito and midge control, planaria are presently somewhere in between larvivorous fishes and disease-causing microorganisms. They are effective predators and they have storage, reproductive, and dispersal capacities similar to pathogens. Moreover, like pathogens they can be used in water that is too shallow or temporary for fish — but unlike many pathogens they are not host specific.

General characteristics

Planaria are nearly all free-living non-parasitic worms. Their extraordinary regenerative capabilities have been known since the early 1800's (some investigators considering them almost immortal under the blade of a knife).

We first observed *Dugesia dorotocephala* (Woodworth) as a contaminating organism in mosquito rearing ponds at the University of California, Riverside in 1971. Repeated observations of this species in a series of ponds, and subsequent eradication therein of immature *Culex* mosquitoes, gave startling testimony of the planarians' destructive capabilities. Subsequent studies revealed that reproduction by fission was accelerated by higher feeding rates and by crowding. Experimental field populations of *Culex* larvae were reduced by over 90% in 26 days during July and August, 1973. Mucus secreted by the planaria effectively immobilized larvae and their body fluids were consumed. The optimum field activity ranged between 68 to 80°F.

Planaria are found in nature in a manner that increases their chances of contacting mosquito and midge larvae. Both organisms frequent shallow water habitats. Planaria are found adhering to such substrata as blades of grass, twigs, stones, and even mud. Although midge larvae are easily contacted in the mud, mosquito larvae at the surface of the water are equally easy prey for swimming planaria.

Behavior studies at Riverside showed that *Dugesia dorotocephala,* one of our largest planarians, was capable of killing and consuming the fluid contents of all developmental stages of mosquitoes and midges, although a preference was shown for the older stages.

Other advantages of planaria

Planaria can reproduce asexually. Once a grown planarian consumes a larva it has sufficient food to initiate the process of fission. Planaria fed one full meal a day in the laboratory double in number asexually about once a week, depending on the species. Thus, the more successful planaria are in preying on larvae, the greater the chances of those planaria increasing in sufficient number to eradicate larvae in the habitat.

Planaria are almost immortal and can go for long periods without food. During starvation they become smaller and eventually disappear after about 4 months at room temperature. Hence, given food, oxygen and water, the planaria can survive indefinitely.

Planaria can go through a dormant stage. When a body of water

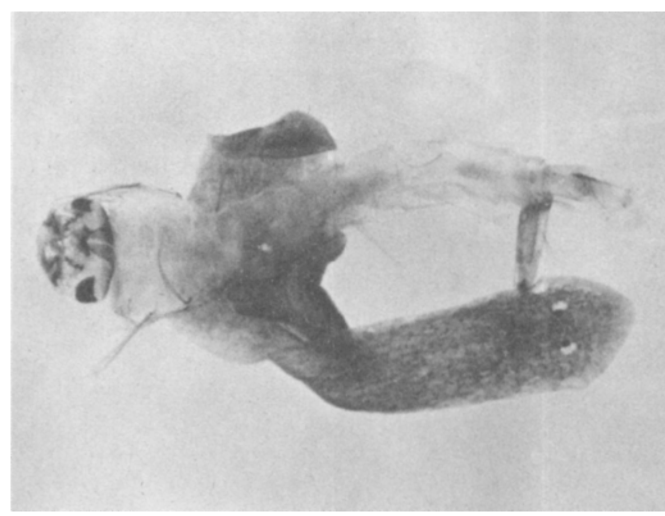


Fig. 3. Planarian with feeding tube inserted into mosquito larva and in the process of sucking out its body fluids.

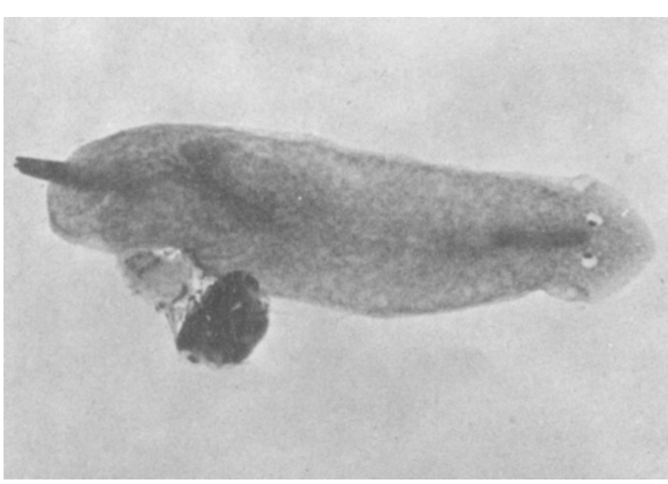
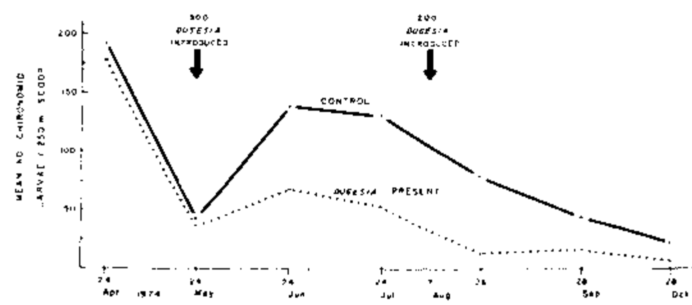
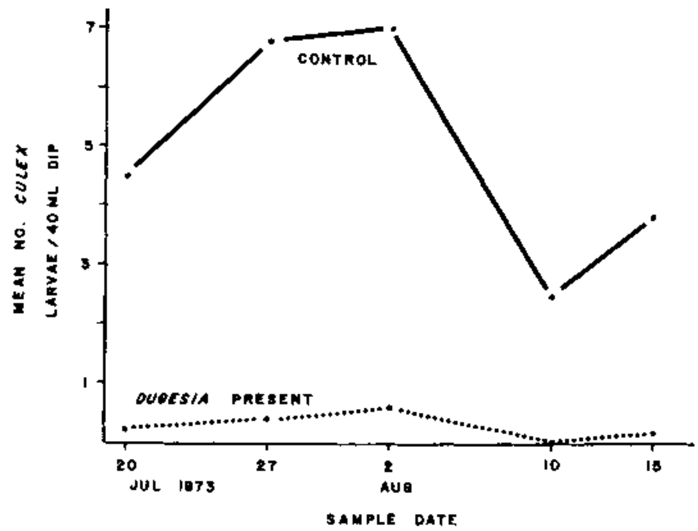


Fig. 2. Planarian enveloping paralyzed mosquito larva in preparation for insertion of the feeding tube.

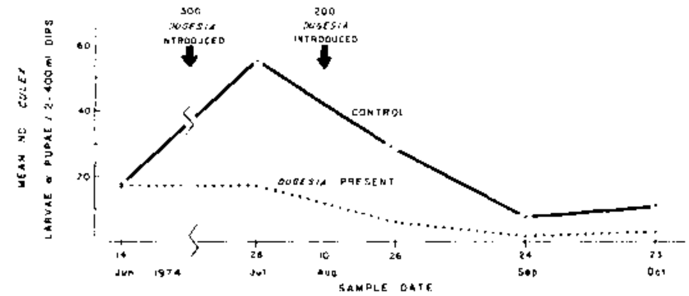
GRAPH 1. REDUCED CHIRONOMID MIDGE LARVAL DENSITY IN 30-36-FOOT WATER—SETTLING BASINS TREATED WITH FIVE *DUGESIA DOROTOCEPHALA* PER SQUARE YARD, WHITTIER NARROWS, 1974.



GRAPH 2. *CULEX* LARVAL DESTRUCTION IN SHALLOW METER-SQUARE PONDS TREATED WITH *DUGESIA DOROTOCEPHALA* AT THE RATE OF 100 PER SQUARE YARD, RIVERSIDE, 1973.



GRAPH 3. REDUCED *CULEX* LARVAL AND PUPAL DENSITY IN 10- X 22-FOOT RICE PADDIES TREATED WITH 25 *DUGESIA DOROTOCEPHALA* PER SQUARE YARD, RIVERSIDE, 1974.



containing planaria dries up, becomes foul, or depopulated of prey, the planaria can lay semi-dormant eggs. When favorable conditions arise again, the eggs may hatch.

Planaria can grow in and withstand a wide range of environmental conditions. They are generally considered ubiquitous because they are found in most bodies of freshwater throughout the world. Various extremes in temperature, oxygen tensions, pollution levels, etc. have been reported for a large number of species. However, for practical use their numbers will probably have to be artificially increased, as natural populations working alone do not seem to produce the high degree of control usually required.

1974 field control studies

Field studies to evaluate the control potential of *Dugesia dorotocephala,* a common large species in southern California, (Figs. 1-3) against naturally breeding mosquito and chironomid midge populations were conducted in the southern California area during 1973 and 1974. Chironomid investigations were performed in ten 30- x 36-foot-wide and 1- to 1.6-foot-deep earthern settling basins at Whittier Narrows in Southeast Los Angeles. Mosquito studies were performed in 10- x 22-foot earthern ponds planted to rice early in May at Riverside. The ponds were filled to a depth of 1 to 1.5 ft. with irrigation water, and water flow was maintained at a controlled rate of ca. 2000 gal./day. Inoculation rates were about 5 and 25 planaria per square yard for the chironomid and mosquito studies, respectively. Periodic samples of mosquito larvae and pupae were taken with the standard 1-pint dipper and midges were measured with a half-pint dredge.

Chironomid destruction

A significant chironomid larval reduction appeared on June 24th with 50% destruction in treated ponds compared to the controls (graph 1). Midge destruction was 52% on July 24th and reached a maximum of 84% on August 26th. Differences in density between inoculated plots and the controls were significant at the 95 to 99% confidence levels. Midge destruction declined to 61% on September 28th, but increased again to 64% on October 28th. The total average larval reduction from June through October was about 60% (99% significance).

The principal midge genera considered in these data and their total destruction were *Tanypus* spp. (76%), *Chironomus* spp. (72%), *Cricotopus* spp. (62%), and *Procladius* sp. (34%).

Mosquito destruction

A significant mosquito larval destruction of 68% was reached on July 26th, 4 weeks after planaria inoculation. This increased to a maximum of 80% on August 10th. Differences in larval density between inoculated plots and the controls were significant at the 90% confidence level or greater; however, there were no significant differences between pretreatment samples taken on June 14th. Mosquito destruction declined slightly to 75% on September 24th, but increased again to 77% on October 23rd. Average larval reduction from July through October was 73% (graph 2). An even higher level of control can be achieved by increasing the planaria inoculation rate to 100/sq. yd. (graph 3).

Among five different immature larval stages of mosquitoes, the highest reduction (80%) was recorded from the pupal stage, followed by 4th instar larvae (77%). The earlier 1st and 2nd instars, although numerically predominant and easier to subdue, sustained a somewhat lower reduction of 70% and 75%, respectively. The pupal stage of mosquitoes was not collected in the planaria-treated replicates after July 26th, although it persisted in the controls until August 26th. This means that no mosquitoes emerged from the treated ponds after August. Higher planaria inoculation rates in the spring could have resulted in an even earlier mosquito eradication.

Observations in an outdoor benthobservatory showed that planaria in rice were most active from dawn to sunrise, and again at dusk when they could be seen gliding over the water surface or on stalks of rice plants seeking and destroying mosquito larvae. During daylight hours planaria were observed resting underneath fallen eucalyptus leaves or other benthic debris. Presumably, much of the destruction of benthic chironomid larvae took place during daylight hours.

Planaria reproduction

Although a rapid reproduction rate of 5 to 7 days was obtained with *Dugesia* in the laboratory, our field samples showed a population doubling only about every 30 days in both the chironomid midge and the mosquito experiments.

Conclusions

The results show that *Dugesia dorotocephala* is capable of regulating both *Culex* mosquitoes and several genera of economically important chironomid midges at densities below that attainable with other natural controls in the area. The degree of control attained in these studies falls well within the range usually considered acceptable, although higher planaria inoculation rates would have undoubtedly produced greater control. Unlike pesticide-treated midge and mosquito populations, modest planaria treatments produced a sustained supression with no notable population rebounds and no resistance. This stability might be partially caused by the planarians' ability to utilize several kinds of food, to withstand long periods of starvation, to respond with increased numbers produced by fission to increasing mosquito densities, and their harmlessness to other beneficial insects in the ecosystem (such as notonectids and hydrophylid beetles). Planaria are worthy biological control substitutes for chemical pesticides in some aquatic pest management systems.

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Separation of Blank Mechanical

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TABLE 1. DISTRIBUTION OF 'KERMAN' PISTACHIO NUTS HARVESTED FROM INDIVIDUAL TREES BY BOOM-SHAKING, AND STRIPPING BY HAND THOSE REMAINING.

Tree no.	Method of harvest	Yield (lb.) Good nuts	Blank nuts	Total	Percent blanks	Percent of total crop removed
1	Shake	11 0	7	11.7	6.0	85.4
	Strip	.9	1.1	2.0	55.0	14.6
	Total	11 9	1.8	13.7	13.1	100.0
2	Shake	18.4	.8	19 2	4.2	76.2
	Strip	1.9	4.1	6.0	68.3	23.8
	Total	20 3	4.9	25.2	19.4	100 0
3	Shake	18.9	2 0	20.9	9 6	72.3
	Strip	3.7	4.3	8.0	53.7	27.7
	Total	22.6	6 3	28.9	21 8	100.0
4	Shake	41.8	2.2	44.0	5.0	83 2
	Strip	3.7	5.2	8.9	58 4	16.8
	Total	45.5	7.4	52.9	14.0	100.0
5	Shake	21 1	7	21.8	3.2	70.6
	Strip	3.3	5.8	9.1	63.7	29.4
	Total	24 4	6 5	30.9	21.0	100 0
6	Shake	22.4	1.3	23.7	5.5	85 9
	Strip	1.5	2.4	3.9	61.5	14 1
	Total	23.9	3.7	27.6	13.4	100.0
Avg.	Shake	22.2	1.3	23.5	5.5	78 9
	Strip	2.5	3.8	6.3	60 3	21.1
	Total	24 7	5.1	29.8	17.1	100.0

The pistachio nut tree (*Pistacia vera* L.), which is native to the Mid-East and Central Asia, was introduced into California in the early part of this century. Commercial plantings were few and small until the last several years, but there are now over 1,000 acres in production and about 23,000 acres will come into bearing in the next 2 to 4 years. The majority of the plantings are in Kern and Kings Counties, with some over 2,000 acres in size.

As with many tree crops, the cost of harvest is a major portion of the total production expenses. Most growers harvest pistachios by vigorously shaking the tree with a mechanical device such as is used to harvest walnuts and almonds. However, to avoid contaminating the nuts with soil organisms, especially those which produce aflotoxins, a catching frame is combined with the shaker. The vigorous shaking usually removes almost 100% of the nuts.

In a recent study, a boom-shaker was used in conjunction with canvas sheets spread on the ground under the trees to harvest nuts from experimental pistachio trees at the University's Wolfskill Experimental Orchards, Winters, California. After the trees had been moderately shaken various amounts of nuts remained, most of which contained no kernel (embryo). Blank nuts primarily result from embryo abortion early in the growth and development of the nut. Unlike most fruits and nuts, which drop from the tree shortly after embryo abortion occurs, aborted pistachio nuts remain on the tree and grow to about the same size and shape as nuts containing fully developed embryos. The blanks mature and drop naturally from the trees somewhat later than the nuts that develop normally. The percentage of blanks produced by the 'Kerman' cultivar, the only one being planted commercially in California, varies from tree to tree and from year to year. Blank production in the Wolfskill Experimental Orchards has averaged about 25% over a 6-year period. If a grower could harvest only the good nuts, leaving the blanks on the trees, he would eliminate needless handling, and bypass the flotation procedure or other technique used to separate out empty nuts after harvesting. This would save time and money. Mechanical harvesting appears to offer a potential solution to a harvesting problem that will become more apparent when the large acreages of young pistachio trees in the San Joaquin Valley come into bearing.

Ten-year-old 'Kerman' trees in the Wolfskill Experimental Orchards were used in the present study. Although the optimum time for harvesting pistachios has not been determined, harvesting was done at what was considered the