Economic evaluation of mosquito control programs

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Studies with statistical models show source reduction to be more economically efficient than chemical controls.

Mosquito population management in California is centered in 75 mosquito abatement districts, which are all publicly organized and have the power of taxation. County boards of supervisors carry out a budgetary oversight responsibility. The goal is to reduce the mosquito population, at a minimum cost, to a level at which the incidence of diseases the mosquitoes transmit and the annoyance they cause to humans are tolerable.

California's Central Valley has become an ideal mosquito breeding place because of the complex agricultural enterprises and expanding acreage of irrigated land. In this area insecticides have been intensively used to control mosquito larvae. Because each generation of mosquitoes may require chemical treatment, 15 to 20 treatments a year may be necessary. Several important mosquito species, particularly *Culex tarsalis* and *Aedes nigromaculis,* have exhibited a high level of resistance to organochloride and organophosphate insecticides. Abatement district managers must therefore be aware of the long-run costs of using chemical control methods as well as the short-term benefits of quickly reducing a mosquito population.

We examined the responsiveness of *A. nigromaculis* and *C. tarsalis* population levels to various control methods and environmental factors. Control methods included spot spraying and wide-area spraying with larvicides, construction of ditches and levees, drainage of pond water, and encouragement of irrigation return flow systems. Environmental factors included monthly average temperature, rainfall, river flows, and the quantity of pesticides applied to agricultural lands. Primary data were collected in the Kern Mosquito Abatement District (MAD). The period of analysis covered the years from 1955 to 1974.

To estimate the bioeconomic relationships, two statistical models, a monthly-data and an annual-data model, were developed. The empirical estimation of these models describes the effects of environmental and control variables on mosquito populations and provides a description of the abatement district's past behavior and decision-making process.

Table 1. Cost of a 1 Percent Reduction in Mosquito Population, by Control Method, Kern MAD, 1975-76 Average Costs

	Aedes nigromaculis				*Culex tarsalis*					
			Ditches				Sumps	Ponds	Ditches	
Control method	Spot locations treated	Fills, levees, etc.	1-year effect	10-year effect	Spot locations treated	Fills, levees, etc.	1-year effect	10-year effect	1-year effect	10-year effect
1. Average value of control factors	338,220	27.93	22.26	22.26	338,220	27.93	16.38	16.38	22.26	22.26
2. New light-trap numbers from 10% increase in control variable	4.0573	3.8160	4.1068	3.7952	4.8717	4.8906	5.0258	4.3033	4.9530	3.9305
3. t values for control coefficients in regression equation*	(−0.23)	(−1.26)	(−0.23)	(−0.23)	(−2.71)	(−1.88)	(−2.33)	(−2.33)	(−1.38)	(−1.38)
4. Percent reduction in light-trap numbers	2.90	8.75	1.8	9.25	15.93	5.96	3.36	17.25	4.75	24.4
5. Cost/unit	$6/1,000 locations	$150/1,000 cu. yd.	$43/mile	$48/mile	$6/1,000 locations	$150/1,000 cu. yd.	$480/1,000 cu. yd.	$480/1,000 cu. yd.	$48/mile	$48/mile
6. Total cost for 10% increase in control variable	$202.93	$418.40	$106.84	$106.84	$202.93	$418.50	$787.20	$787.20	$106.84	$106.84
7. Cost per 1% reduction in light-trap index (6 ÷ 4)	$69.97	$47.83	$59.35	$11.55	$12.74	$70.22	$234.28	$45.63	$22.49	$ 4.38

* Light traps are not a good method of measuring levels of *A. nigromaculis* because of flight characteristics. However, it should be noted that coefficients for *C. tarsalis* are all significant.

TABLE 2. Results of the Programming Model at Original, One-Half Original, and Double Original Maximum Acceptable Mosquito Numbers Per Light-Trap Night*

Activities or items in the optimal solution	Annual level of activities or items under: Plan 1 (original)†	Plan 2 (50% below plan 1)‡	Plan 3 (100% above plan 1)§
Acres sprayed with pesticides	5,000	5,000	5,000
Locations treated with pesticides	500,000	500,000	418,067
Fills, levees, etc., constr. (1,000 cu. yd.)	49.45	48.31	48.76
Sumps, ponds, etc., constr. (1,000 cu. yd.)	0	0	0
Ditches constructed (miles)	5.50	18.72	0
Aedes nigromaculis mosquitoes per light-trap night	0.589	0.29	1.17
Culex tarsalis mosquitoes per light-trap night	2.67	1.33	5.34
Hours of labor	2,198	2,277	2,083
Total direct costs	$24,832	$25,295	$23,973

* All other parameters are held at their original levels.
† *Aedes nigromaculis* light-trap numbers no more than 0.589; *C. tarsalis* numbers no more than 2.67 per light-trap night.
‡ *Aedes nigromaculis* light-trap numbers no more than 0.29; *C. tarsalis numbers* no more than 1.33 per light-trap night.
§ *Aedes nigromaculis* light-trap numbers no more than 1.17; *C. tarsalis* numbers no more than 5.34 per light-trap night.

TABLE 3. Results of the Programming Model at Five Levels of Pesticide Effectiveness and the Original Standards of Mosquito Numbers

Activities or items in the optimal solution	Annual level of activities or items under: Pesticide effectiveness on acres and locations				
	100%	75%	50%	25%	5%
Acres sprayed with pesticides	5,000	5,000	5,000	5,000	5,000
Locations treated with pesticides	500,000	500,000	381,501	500,000	500,000
Fills, levees, etc., constr. (1,000 cu. yd.)	49.45	41.83	47.40	48.73	50.24
Sumps, ponds, etc., constr. (1,000 cu. yd.)	0	0	2.32	29.65	55.99
Ditches constructed (miles)	5.50	60	60	60	60
Aedes nigromaculis mosquitoes per light-trap night	0.589	0.589	0	0	0
Culex tarsalis mosquitoes per light-trap night	2.67	2.67	2.67	2.67	2.67
Hours of labor	2,198	2,406	2,663	4,303	5,384
Total direct costs	$24,832	$25,594	$28,251	$41,570	$51,441

Notes: Different effectiveness levels were generated from sensitivity tests on the coefficients of acres sprayed and the locations treated in the mosquito population relations. The changes in the coefficients were assumed to be linear; e.g., the coefficients of acres sprayed and locations treated at 75% pesticide effectiveness were in each case equal to 0.75 × the original coefficient.
All parameters were held at their levels of the original model except those for acres sprayed and locations treated with pesticides.
Aedes nigromaculis no more than 0.589 per light-trap night and *C. tarsalis* no more than 2.67 per light-trap night.

A linear programming model (a sophisticated budgeting technique) was also developed for the Kern district using data from the statistical model plus additional data from the district's records. The linear programming model provided a normative solution to the abatement problems—that is, it suggested what the district should do to provide the most economically efficient mosquito abatement.

Summary findings from the statistical model were as follows:

■ Pesticide treatments of small mosquito-breeding sites were generally more significant than extensive spraying of large areas in reducing the mosquito population.

■ Source reduction activities were generally correlated in the model with a reduction in mosquito population levels.

■ The pesticide effectiveness index (or resistance of mosquitoes to pesticides) was an important factor in the long-run indirect effect of pesticide control measures.

■ Past use of pesticides was directly correlated with mosquito resistance to pesticides (lower pesticide effectiveness).

■ Source reduction activities tended to influence pesticide effectiveness positively: the more a district invested in source reduction, the less resistance mosquitoes had to pesticides.

■ In Kern MAD, the model ranked methods to control *A. nigromaculis* according to economic efficiency as follows: (1) ditch construction, (2) construction of fills, levees, and the like, and (3) treating spot locations with pesticides. Spraying small trouble spots for a 1 percent reduction in average numbers of *A. nigromaculis* cost 6.05 times more than ditching and 1.46 times more than land fills and levees (table 1). For *C. tarsalis* the rank was: (1) ditch construction, (2) spot locations treated with pesticides, (3) construction of sumps and ponds, and (4) construction of land fills, levees, and the like. Constructing fills and levees for a 1 percent reduction in the average number of *C. tarsalis* mosquitoes cost 16.03 times more than ditching, 3.37 times more than spot locations treated with pesticides, and 5.15 times more than construction of sumps and ponds.

The linear programming model was used to assess the optimum combination of control methods when the maximum permissible mosquito densities were varied around their 20-year minimum populations as estimated by light-trap night indices. Results of the model indicate that, to reduce mosquito population indices by 50 percent, major budgetary allocations should be made for construction of ditches within the district to minimize long-term costs (table 2). However, if the acceptable mosquito population index were relaxed to a level double that of the base standard, district costs would be minimized by continuing the spraying program and significantly curtailing the source reduction program.

The linear programming model was also used to evaluate the impact on mosquito population indices, district costs, and the least-cost combination of control methods when pesticide effectiveness (resistance) was varied. In the model, district costs increased rapidly when pesticide effectiveness dropped below 50 percent (resistance increased) (table 3). As effectiveness declined, greater and greater reliance would have to be placed on constructing sumps, ponds, and ditches to minimize costs while maintaining population indices within acceptable limits. Interestingly, the model indicates that *A. nigromaculis* light-trap night counts would drop to zero with this heavy emphasis on source reduction.

Implications

The findings of the abatement models imply that, even though pesticides used for mosquito control usually reduced mosquito population levels, they were too extensively used, given the alternatives. Although source reduction activities were generally more economically efficient in controlling mosquitoes, the models suggest that the effect of these activities was underestimated and that they were not efficiently substituted for chemical control in the district. Based on the models, we recommend that mosquito control districts deemphasize pesticides and substitute various source reduction activities for unnecessary pesticide applications. This recommendation does not mean complete substitution of source reduction for use of pesticides in the control agencies' abatement programs, because in emergency cases, such as epidemics, pesticides must be employed to reduce mosquito populations immediately.

In the past, pesticides to replace those that have become ineffective against mosquitoes were more readily available than they are at present or will be in the future. It can be expected that the substitution of more source reduction for unnecessary pesticide applications would help in preserving pesticide effectiveness by reducing the amount of selection pressure on mosquitoes.

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Tomatoes make efficient use of applied nitrogen

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Processing tomatoes in California typically do not require heavy applications of nitrogen to attain maximum yields, presumably because they are able to use available soil nitrogen efficiently. A field trial was conducted in 1979 on Panoche clay loam at the University of California West Side Field Station using ^{15}N-depleted ammonium sulfate to measure fertilizer uptake efficiency and to distinguish between soil and fertilizer nitrogen utilized by the crop.

The variety UC 82 B was planted on 60-inch beds on March 7 and sprinkler-irrigated the following day to germinate the seed. Furrow irrigation was used after seedling emergence and stand establishment. All plots received 100 pounds of starter fertilizer 11-48-0 per acre at planting and 100 pounds phosphorus (P) as treble superphosphate at thinning time. The plants were thinned to clumps 10 to 12 inches apart and fertilized on April 25 with labeled nitrogen (N) at 0, 50, 100, 150 and 200 pounds per acre. Additional plots received 50 or 100 pounds N per acre plus 1 pound per acre of nitrapyrin nitrification inhibitor. Petioles were sampled at approximately three-week intervals during the season and analyzed for total and nitrate-N. Measurement of the isotopic composition of these forms of N permitted calculation of the amount of fertilizer-derived N present.

The tomatoes were harvested on August 1. In 25-square-foot sub-plots, whole plant samples were taken by pulling plants and shaking off the fruit for analysis of tissue and fruit. Fruit yields were obtained by harvesting the remaining 300 square feet of each plot with a mechanical harvester. Yield and quality determinations included total yield; average fruit weight; percentages of red, green, and cull fruit; soluble solids; pH; and color.

Petiole analyses

Except on the 35-day sampling date (May 30), total N in the petioles did not provide a basis of differentiating between fertilizer treatments. However, there were significant differences in fertilizer N in petioles on all dates except 15 days. The most responsive index of nitrogen status of the plants was fertilizer-derived nitrate-N in the petioles. The pattern of decrease in labeled nitrate-N in petioles during the course of the season was influenced to a pronounced degree by the level of N supplied (fig. 1.).

At the 50- and 100-pound application rates, the quantity of labeled nitrate-N in the petioles could be described quite well by an equation of the form

$$N = at^b$$

where N = nitrate-N derived from the added fertilizer, t = days since the fertilizer was applied, and a and b are constants. The rate of decrease of labeled N in petiole nitrate calculated from these equations for the 50-pound N application fell from 2,025 ppm N per day at 15 days to 52 ppm N per day at 30 days. The corresponding rates of decrease for the 100-pound N level were 2,480 ppm N per day at 15 days and 83 ppm N per day at 30 days. At the 150- and 200-pound N levels, the kinetics of petiole nitrate were more complex, but the rates of decrease were much smaller and the decline delayed in comparison with the lower fertilizer levels. It is clear from the very rapid changes in petiole nitrate that, if this value is used as an index of nitrogen sufficiency, the time of sampling is critical. Moreover, it is not surprising that the variability among replicate samples is high. The overall coefficients of variation for estimates of petiole nitrate varied from 14.4 to 38.1 percent, and the corresponding values for labeled petiole nitrate from 20.9 to 74.6 percent.

In this experiment, the persistence of fertilizer N in petiole nitrate beyond 55 days after fertilization was an indication that the crop had more N than it needed.

Yield

Fruit yields increased up to the 150-pound N level (fig. 2), but yield increases beyond the 43.8 tons obtained with 50 pounds N were not statistically significant. Yields obtained through use of nitrapyrin in conjunction with the 50- and 100-pound N appli-