IMPACT OF MINOR REDUCTIONS IN ADULT AND LARVAL SURVIVAL, FECUNDITY AND HATCH ON THE POPULATION DYNAMICS OF *PSOROPHORA COLUMBIAE*: A SIMULATION STUDY[1,2]

D. A. FOCKS

Medical and Veterinary Entomology Research Laboratory, ARS, USDA, Gainesville, FL 32604

ABSTRACT. Laboratory work has shown that mosquitoes obtaining blood meals from animals treated with ivermectin exhibit lowered adult survival, fecundity, egg hatch and larval survival. Computer simulation evaluated the consequences of this phenomenon in field populations of *Psorophora columbiae* feeding on cattle in the rice agroecosystem. Results suggest that rather minor reductions, on the order of 10% below normal, in these life history parameters would significantly affect the population dynamics of this species in this particular system. Significant reductions in the amount of insecticide used for mosquito abatement are also projected.

INTRODUCTION

The avermectins are a class of macrocyclic lactones produced by fermentation of the soil microorganism *Streptomyces avermitilis*. The low toxicity of ivermectin, a mixture of dihydroavermectins, in most vertebrates and its activity against a broad range of parasites at therapeutic doses of <1 mg AI/kg permits this agent to be used as a systemic to control insects, acarines and helminths in domestic animals (Cambell et al. 1983). Administered orally or parenterally, ivermectin is effective against arthropod endoparasites such as the common cattle grub, *Hypoderma lineatum* (Villers) and the common horse bots, *Gasterophilus nasalis* (Linn.) and *G. intestinalis* (DeGeer) (Drummond 1985). Ectoparasites affected by ivermectin include many species of ticks, mites and lice (Miller et al. 1986).

Ivermectin reduces adult survival and subsequent fecundity and egg hatch of intermittent ectoparasites such as tsetse flies (Langley and Roe 1984), stable and horn flies (Miller et al. 1986), mosquitoes (Focks et al. 1991a) and ceratopogonids (Standfast et al. 1984). Given a sufficiently high dose of ivermectin, a single blood meal taken on mice (Pampiglione et al. 1985) or rabbits (Koopman et al. 1989) will kill mosquitoes. Pampiglione et al. (1985) proposed that these compounds might be appropriate for the control of human and animal vector-borne diseases if administration of the drug at suitable dosage to vertebrate hosts could cause the death of hematophagous arthropod vectors after a single blood meal on the treated animals. Where domestic animals are the primary host for the arthropod, lower, non-lethal doses sufficient to reduce one or more reproductive parameters could contribute to population suppression (Langley and Roe 1984).

My interest in ivermectin stems from field (McLaughlin and Focks 1990) and computer simulation studies (Focks et al. 1988a, 1988b) on the population dynamics of *Psorophora columbiae* (Dyar and Knab). These studies indicated that the abundance of cattle, the primary blood source for this mosquito, is a key factor determining *Ps. columbiae* densities in some rice-cattle agroecosystems. The biological dependency of *Ps. columbiae* upon cattle led Kuntz et al. (1982) to propose a form of host management, the treatment of cattle with insecticide, as a potential control method. Computer simulations showed that host management techniques, by exerting continual pressure on female survival and fecundity, could result in significant, long-term population suppression (Focks and McLaughlin 1988). In addition to attacking the key regulatory factor in the life history of *Ps. columbiae* in this environment, host management has the additional advantage of being, unlike current practice,[3] spatially confined to the host animals which are visited by virtually

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[2] This paper reports the results of research only. Mention of a commercial or proprietary product does not constitute a recommendation or an endorsement of this product by the U.S. Department of Agriculture.

[3] Olson, J. K. 1983. Final report of the Riceland Mosquito Management Program for the development of strategies optimizing non-chemical approaches to managing mosquito populations in freshwater irrigated cropping systems using the riceland agroecosystem as a model. Texas A & M Research Foundation, College Station, TX.

Table 1. Estimates of various life history parameters as a function of dose of ivermectin and time since drug administration. These reductions were used in the simulation studies and are based on data from Focks et al. (1991a).

		Response in treated mosquitoes as a percentage of response in untreated				
Dose	Days after treatment	Adult survival	Fecundity	Egg hatch	Larval survival	Average[1]
2 mg AI/kg body weight	3	100.0	87.6	76.0	95.0	89.7
	10	100.0	80.8	66.3	85.0	83.0
	17	100.0	95.8	93.9	86.7	94.1
	24	100.0	97.2	100.0	86.7	96.0
10 mg AI/kg body weight	3	74.0	13.2	0.0	5.5	23.2
	10	76.0	15.9	0.6	21.8	28.6
	17	100.0	33.5	13.0	44.7	47.8
	24	100.0	73.9	68.0	65.9	77.0
	31	100.0	86.0	84.9	80.4	87.8
	38	96.0	86.4	86.5	88.4	89.3
	45	98.0	86.4	87.2	92.2	91.0
	52	89.1	86.4	87.8	93.5	89.2

[1] Arithmetic average of reductions in adult survival, fecundity, egg hatch and larval survival.

all adult females. A preliminary field test of this concept reduced *Ps. columbiae* populations by more than 80% (Focks et al. 1991b, Nasci et al. 1990), suggesting that host management may be a viable method for suppressing populations of *Ps. columbiae*.

Ivermectin-caused reductions in adult survival, fecundity, hatch and/or subsequent larval survival might impact *Ps. columbiae* populations in a fashion similar to that produced by killing cattle-visiting females. In this study, computer simulation was used to project the consequences of suppressing these life history parameters in field populations of *Ps. columbiae*. This study is conceptually similar to a previous simulation study of another noncatastrophic method. Throne (1989) suggested that resistant varieties, in causing minor changes to some life history parameters (increased development time leading to increased immature mortality and decreased fecundity) of the flat grain beetle, *Cryptolestes pusillus* (Schönherr), could have significant impact on population growth when applied over an entire growing season. He stated that the combination of noncatastrophic techniques with other methods of control may improve the cost effectiveness of pest management techniques even if the noncatastrophic control methods do not by themselves provide adequate suppression.

DATA SOURCES AND SIMULATION METHODS

Ivermectin: There are no reports in the literature on the consequences of *Ps. columbiae* obtaining blood meals from ivermectin-treated cattle. In lieu of using completely hypothetical values in the simulation studies, data from a laboratory model, *Aedes aegypti* (Linn.) and ivermectin-treated rabbits, were used (Focks , et al. 1991a). In that study, *Ae. aegypti* were blood fed on rabbits which had been injected 3–52 days earlier with either 10 or 50 times the labeled dose (2 or 10 mg AI/kg body weight) of ivermectin.[4] Depressions in adult survival, fecundity, egg hatch, and larval survival were monitored during the first gonotrophic cycle for females fed up to 52 days after injection. Table 1 presents the depressions in these parameters due to ivermectin treatment as a percentage of normal values.

Briefly, the results were as follows: As more time between drug administration and the blood meal transpired, drug titers in the rabbit's blood declined and the effect of ivermectin diminished. At the lower dose, adult female survival was not influenced even among females feeding on rabbits treated 3 days previously. The other parameters were only depressed slightly ranging between ca. 75 and 100% of normal. Females fed on rabbits within a few weeks of drug administration at the higher dose exhibited significant reductions in all parameters—adult survival was ca. 75% of normal, and fecundity and larval survival were <20% of normal; of the few eggs laid, virtually none hatched. As drug titers declined with time, the reductions were less severe but never did completely return to normal values—blood meals taken up to 52 days after drug

[4] The material used was Ivomec, MK-933, a commercially available (Merck and Company, Rahway, NJ 07065) 1% formulation of ivermectin for veterinary use in cattle and reindeer.

treatment when the experiment was terminated, were still reducing all parameters to about 90% of normal.

Simulation methods: Computer simulation estimated the consequences in field populations of reductions in adult and larval survival, fecundity and hatch due to ivermectin. The value of the simulation studies is that realistic projections can be made of the dynamics of field populations, reflecting both the influence of ivermectin on reproductive parameters and the various density dependent feed back mechanisms which counter control measures. The model used, PcSim, is a dynamic life table model of the population dynamics of *Ps. columbiae* in the rice/cattle agroecosystem (Focks et al. 1988a). PcSim predicts populations (light trap captures and absolute estimates of adult, larval and egg densities) by integrating information on weather (date and amount of rainfall, maximum and minimum temperature and pan evaporation rates), agricultural practices (host density, rice acreage, planting and harvesting dates), mosquito control activities (dates and areas of space spray and larvicidal operations), the influence of the residual animal treatments, and a host of abiotic and biotic factors. The model has been validated with field data (Focks et al. 1988b) and used to evaluate and optimize management strategies for this mosquito (Focks and McLaughlin 1988). PcSim also has been used to evaluate a field trial in Louisiana involving insecticide-treated cattle for the suppression of *Ps. columbiae*; here, PcSim- based predictions of adult abundance were within 9% of observed populations (Focks et al. 1991b).

The projected effect of ivermectin presented below assumes an on-going, wide area, and asynchronous treatment of cattle at rates and frequencies such that the *average* titer among host animals is sufficient to produce in *Ps. columbiae* the depressions in reproductive function seen in Table 1. For details on model equilibration, specific values used for land use, agricultural practices, etc., see Focks and McLaughlin (1988); large host animal densities were assumed to be 0.33/ha.

RESULTS AND DISCUSSION

The projections in Fig. 1A indicate that even minor suppressions in the life history parameters associated with the lower treatment rate would have a significant impact on *Ps. columbiae* populations. For this dose, season-long, average treated population densities averaged 55% of normal and ranged between 34 and 70% of normal depending on which set of values, associated with various lapses of time between drug administration and blood meal, were used. At the higher dose, one or more parameter values seen for days 3, 10, 17 and 24 were so low that zero populations were projected. For parameter values observed with lapses of 31 or more days, population densities were projected to average 55% of normal (range: 31–73%). For all simulations at the high dose (days 3–52), adult densities averaged 28% of normal. These reductions reflect the combined effect of pressure on adult and larval survival, fecundity and egg hatch.

Figures 1A and 1B also present the projected number of adulticide applications required as a function of dose and elapsed time after drug administration. Adulticide applications were triggered when projected populations of *Ps. columbiae* adults exceeded 2.8/m^2 (an operational threshold for mosquito control operations); spray mortality was assumed to be 90% and the proportion of land treated assumed to be 15% (see Focks and McLaughlin 1988 for additional details). Because it is peak populations which require insecticide treatments (Focks and McLaughlin 1988), the relationship between the number of spray applications and average population densities is not linear but rather logistic. Therefore, although population densities averaged ca. 55% of normal at the low dose, the number of spray applications during the season averaged <20% of normal, ranging between 8 and 25% (Fig. 1A). At the higher dose (Fig. 1B), no insecticide was required through day 24; thereafter spray frequencies averaged <20% of normal. Over the entire 52-day period, spray frequency was reduced to a single spray during the season, an average ca. 9% of the normal 12 applications.

CONCLUSIONS

These simulations are not offered as a precise prediction of the effect of ivermectin on *Ps. columbiae* populations in the rice agroecosystem since the estimates of the effect of ivermectin-treated host animals were based on data obtained from rabbits by using *Ae. aegypti*. Rather, the simulations were conducted to call attention to the fact that even relatively minor reductions, on the order of 10% below normal, in certain life history parameters, however caused, could significantly suppress field populations of *Ps. columbiae*. The simulations suggest that even more dramatic reductions in insecticide use could be expected in this system. In light of the role of cattle as the primary blood meal source for *Ps. columbiae*, the current labeled use of ivermectin in cattle, and the discovery of novel avermectins with unprecedented activity (ca. 1,500-fold more active than ivermectin [Mrozik

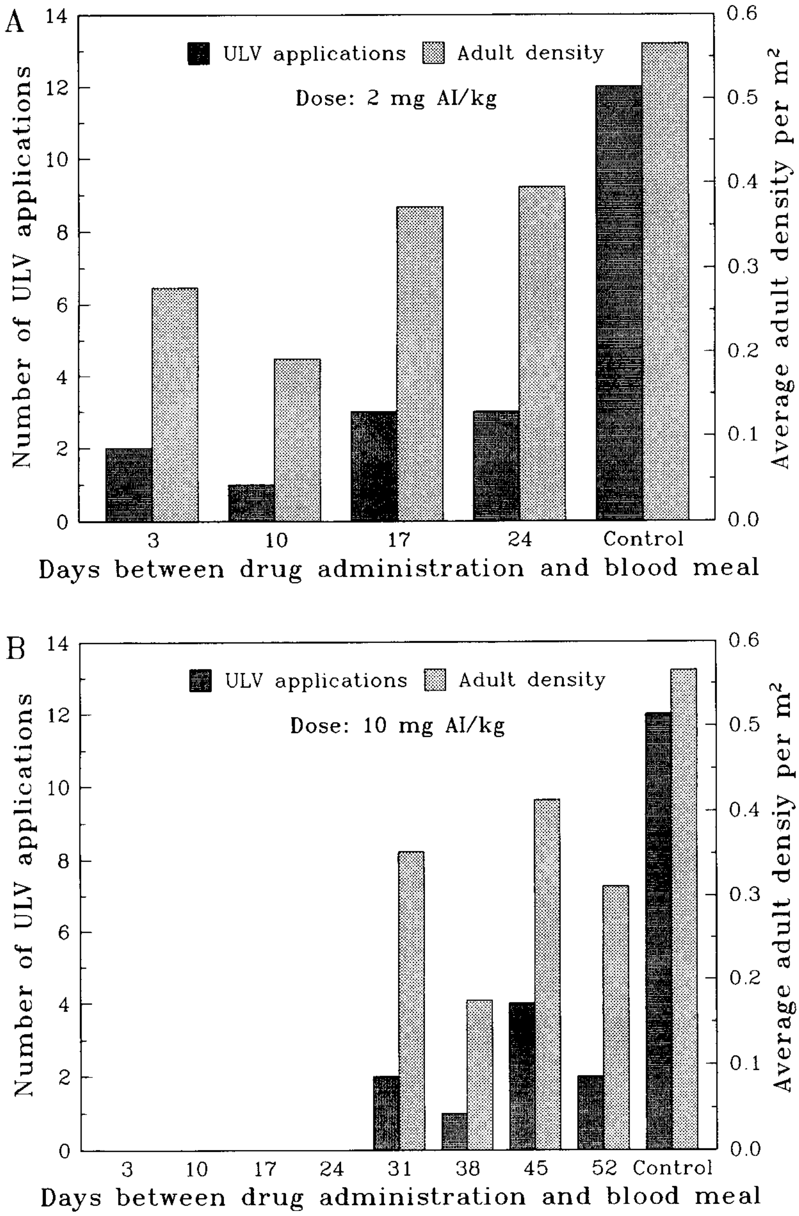

Fig. 1A and 1B. Required adulticide applications and average season-long adult *Psorophora columbiae* densities based on PcSim projections when adult and larval survival, fecundity and hatch in *Ps. columbiae* are reduced to the degree seen in Table 1. Adulticide applications triggered when populations of *Ps. columbiae* adults exceeded $2.8/m^2$; spray mortality was assumed to be 90%, proportion of land treated was assumed to be 15% (See Focks and McLaughlin (1988) for additional details).

et al. 1989]), more effort should be devoted to developing management for *Ps. columbiae* via the use of ivermectin-based systemics. The recent report of significant correlations between most mosquito species in this environment and cattle density (McLaughlin and Focks 1990) suggests that the method could have application for other riceland mosquito species as well.

Further research questions include the following: Could existing methods for administration of insect growth regulators to cattle, e.g., ground feed (Bay and Boyde 1987), sustained-release boluses (Miller et al. 1979), drinking water (Miller et al. 1977) or mineral blocks (Harris et al. 1974), be adapted for delivery of ivermectin? What are the dose/response relationships in the *Ps. columbiae* cattle system? What about other species of mosquitoes? Ivermectin is expensive—are there situations where costs would not be prohibitive?

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