Control of Aquatic Weeds by the Snail Marisa cornuarietis
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triazines, this procedure appears to be a simple method for retaining all the radioactivity on planchets for counting solid samples. If this procedure is to be employed, appropriate conditions for hydrolysis of *s*-triazines should be determined.

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Control of Aquatic Weeds by the Snail *Marisa cornuarietis*[1]

D. E. SEAMAN[2] and W. A. PORTERFIELD[3]

Abstract. Experiments were conducted in 200-gal concrete tanks to evaluate a large fresh-water snail, *Marisa cornuarietis,* as a biological aquatic weed control agent. Adult *Marisa* snails were collected from a canal near Miami, Florida, where a colony had recently become established. These snails are of South American origin and appear identical to those being used in Puerto Rico for biological control of schistosomiasis. The snails controlled *Ceratophyllum demersum, Najas guadalupensis,* and *Potamogeton illinoensis* completely and *Pistia stratiotes* and *Alternanthera philoxeroides* partially. *Eichhornia crassipes* was not completely eaten, but its growth and flowering were greatly retarded by the root-pruning action of the snails. *Marisa* preferred submersed weeds to floating or emersed weeds, but the floating weed *Salvinia rotundifolia* was eaten nearly as readily as submersed weeds. Little damage was done by *Marisa* to 4- and 5-week-old rice plants, but younger rice was killed when the snails had no other source of food. A common snail-eating bird, *Cassidix mexicanus,* was found to be a predator of *Marisa* in Florida. Except for its possible deletarious effects in rice-growing areas, *Marisa* was regarded as very promising for control of aquatic weeds at least in confined bodies of water.

RECENT investigations of the use of *Marisa cornuarietis* L. for control of schistosomiasis in Puerto Rico have called attention to the voracious feeding habits of this large fresh-water snail on aquatic vegetation (2–4, 7, 8, 10). *Marisa* was observed to reduce populations of *Australorbis glabratus* Say, the snail intermediate host of *Schistosoma mansoni,* through successful competition for food (3, 7, 8, 10) and probable incidental predation on the eggs and young of *A. glabratus* (1, 10). In a laboratory study (1), *Marisa* was routinely fed watercress *(Nasturtium officinale* R. Br.) and was observed to feed actively on cabomba (*Cabomba* sp.), elodea (*Elodea* sp.), and several cultivated vegetables. Ferguson and Palmer (2) reported that malanga (*Xanthosoma atrovirens* Koch and Bouché) was most commonly eaten by *Marisa* in Puerto Rico, and that the snail thrived on waterhyacinth [*Eichhornia crassipes* (Mart.) Solms] in culture tanks. Dense growths of an ornamental waterlily (*Nymphaea ampla* DC.) were essentially eradicated from five Puerto Rican ponds in about 1.5 years after 200 mature *Marisa* were introduced into each pond (10). These observations suggest that *Marisa* might be an effective biological agent for control of aquatic weeds as well as snail and insect vectors of diseases commonly associated with aquatic weeds and their habitats.

A flourishing colony of *Marisa cornuarietis* was recently discovered in a canal near Miami, Florida (5). Since this supply of mature snails was readily available within 30 miles of the Plantation Field Laboratory, a study was undertaken in 1961 to evaluate the ability of *Marisa* to control some common aquatic weeds of southeastern United States. The results of this evaluation as well as some observations made during this study are given in the present paper.

MATERIALS AND METHODS

Altogether about 3,500 mature *Marisa* snails (Figure 1), 30 to 60 mm in diameter, were collected from the Coral Gables and Tamiami Trail canals near Miami, Florida. The snails were brought to the laboratory in plastic containers of canal water and placed temporarily in holding tanks where they were fed masses of cabomba (*Cabomba caroliniana* Gray) on which most of them were feeding when they were collected. The experiments were conducted in 20 identical concrete tanks (Figure 1) purchased from a burial-vault manufacturer. Sixteen

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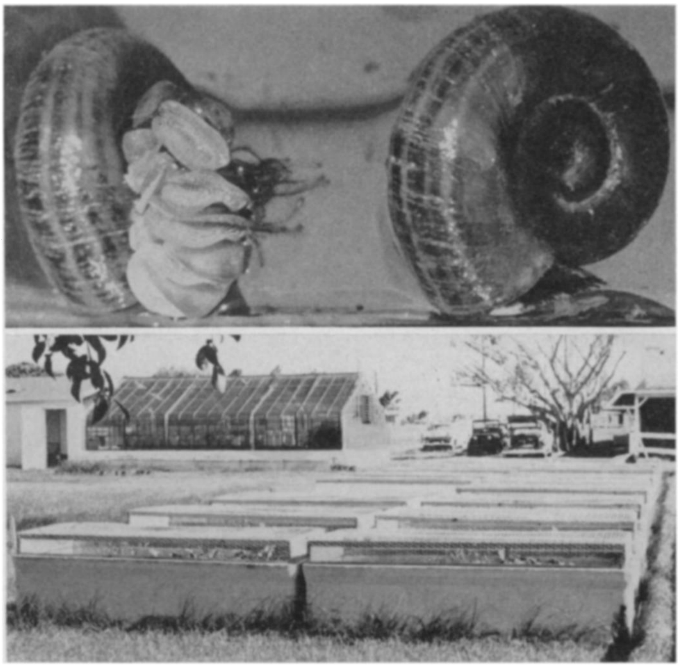

Figure 1. Upper, *Marisa cornuarietis* snails (about 50 mm in diameter) shown feeding on *Salvinia rotundifolia*. Lower, concrete tanks used for the experiments with aquatic weeds and snails.

tanks were each divided into two equal compartments (42 by 30 by 19 inches) by windowscreen partitions. Poultry-wire cages were placed over all the tanks to prevent predation and accidental spread of the snail by birds. The tanks were filled with unchlorinated well water (pH 7.5) as needed to maintain depths between 12 and 15 inches.

The aquatic weeds were collected from nearby canals and placed in appropriate tanks under simulated natural growth conditions. The submersed species, illinois pondweed (*Potamogeton illinoensis* Morong) and southern naiad [*Najas guadalupensis* (Spreng.) Magnus], were rooted in submerged flats of soil, while the non-rooted coontail (*Ceratophyllum demersum* L.) was placed in the water unattached. The floating species, salvinia (*Salvinia rotundifolia* Willd.), waterhyacinth, and waterlettuce (*Pistia stratiotes* L.), required no special treatment. Floating stems of alligatorweed [*Alternanthera philoxeroides* (Mart.) Griseb.] were used in one experiment, but otherwise apical stem cuttings of this emersed species were prerooted for two weeks in metal cans of soil and then partially submerged when used in the tanks.

The ability of the snails to control the various aquatic weeds was evaluated in three main experiments.

In the first experiment, equivalent (randomly selected) groups of 150 snails were placed in one side of each of seven double-compartment tanks each containing equal amounts of a different weed in both compartments. Experimental runs during this single-species experiment were continued until definite effects of the snails were observed on the weeds. Runs were usually terminated when the snails completely consumed the vegetation in their compartments. At the end of a run in each tank the change in initial wet weight of weeds in the compartment without snails minus the wet weight change in the compartment with snails was regarded as "net control," because the weeds should have grown equally in each side. Control rates were calculated by dividing the net control by the elapsed time of each run.

In another experiment, approximately equal amounts of seven different weeds were placed together in each of four full-size tanks. At the start of this mixed-species experimental run, groups of 200 snails were placed in three of the tanks while the fourth received none. Daily observations were made of the relative snail activity on each weed species, and elapsed times were noted as several of the weeds were completely eaten in succession. This run was terminated after 25 days, and the effects of the snails on the weeds that remained were evaluated by comparing their final wet weights with those of similar species in the control tank. A second run was conducted in like manner with similar quantities of only three different weeds placed together in the four full-size tanks.

The final weed control experiment involved a study of the effects of different snail populations during separate runs with two weed species in double-compartment tanks. Groups of 50, 100, and 200 snails per compartment were compared with respect to control of salvinia during two runs and with respect to control of waterhyacinth in one run. A second run with waterhyacinth compared the effects of 100, 200, and 400 snails per compartment. The results of this snail-population experiment were determined in the same manner as those of the single-species experiment.

Marisa was also evaluated with respect to its possible damage to rice. A preliminary experimental run was conducted in a double-compartment tank in which two greenhouse flats of 4-week-old rice (Gulfrose variety) were placed in each side of the tank together with 150 snails in only one side. The water was maintained at a depth of 6 to 8 inches above the soil surface in the flats. The amount of damage to the rice was observed from time to time during this run, but no measurements were made. In a second run, separate flats containing rice plants of different ages (0, 1, 2, 3, 4, and 5 weeks) were placed in each of four full-size tanks, and groups of 150 snails were placed in three of these tanks. During this 3-week run, the water depth was also kept at 6 to 8 inches above the soil surface, and snail damage was assessed by making weekly stem counts of undamaged plants of each age group and comparing these with similar counts of surviving plants in the tank without snails.

RESULTS AND DISCUSSION

The performances of equivalent groups of snails in control of separate single-species cultures of aquatic weeds are summarized in Table 1. The snails controlled most species except waterhyacinth by completely eating initial amounts of weeds in varying lengths of time. Coontail and southern naiad were eaten most rapidly of all, and initial amounts of each were consumed (Figure 2) within 4 to 8 days during five successive runs. Consumption of the apparently less edible stems of illinois pondweed was delayed an additional week after the snails ate the membranous leaves of this weed within the first weeks of two successive runs. The initial amount of floating alligator-

Table 1. Relative edibility and control of aquatic weeds by *Marisa cornuarietis*.

Weed	Initial wet wt lb	Elapsed time days	Change in wet wt		Net control lb	Control rate lb/day
			With snails lb	Without snails lb		
Coontail[a]	3.0	6	− 3.0	+ 0.2	3.2	0.53
Southern naiad[a]	3.0	7	− 3.0	+ 0.1	3.1	0.44
Illinois pondweed[b]	3.0	12	− 3.0	+ 0.3	3.3	0.28
Waterhyacinth	4.5	92	+19.6	+47.2	27.6	0.30
Waterlettuce	2.5	26	+ 1.1	+ 4.8	3.7	0.14
Waterlettuce (alga-free)	2.5	11	− 2.5	0.0	2.5	0.23
Alligatorweed (floating)	2.0	33	− 2.1	+ 1.3	3.3	0.10
Alligatorweed (emersed)	1.0	90	− 0.8	+ 0.1	0.9	0.01

[a] Mean of five successive runs.
[b] Mean of two successive runs.

weed was eaten in 33 days, but the snails ate only 0.8 lb of emersed (rooted) alligatorweed in a 90-day period. Waterhyacinth actually grew in the presence of the snails, but since less than half as much growth occurred in their presence as in their absence, the snails achieved some control of this weed by growth inhibition rather than by direct consumption. Similar growth in the presence of snails occurred during one run with waterlettuce, but in this run the snails delayed feeding on the waterlettuce until they had eaten some filamentous algae (mainly *Spirogyra* sp. and *Pithophora* sp.) that happened to be present. The same amount of alga-free waterlettuce was completely eaten in only 11 days during another run.

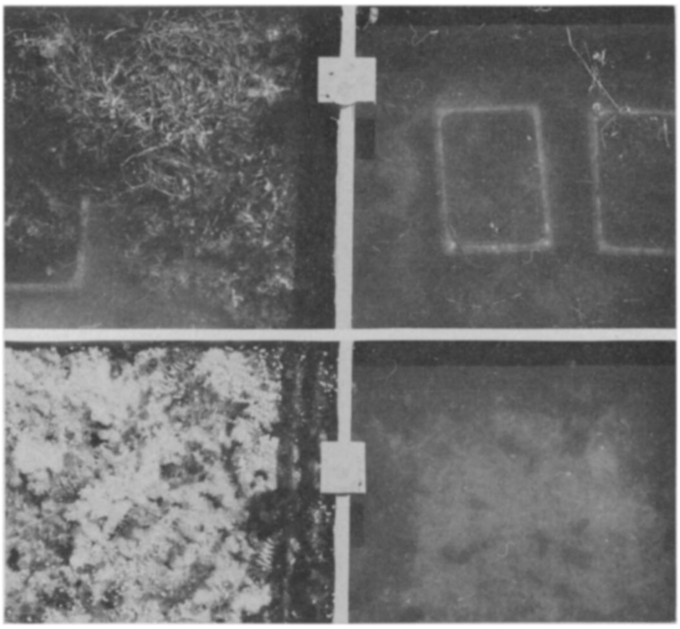

Figure 2. Compartmented tanks in which southern naiad (upper, no. 8) and coontail (lower, no. 9) were each eaten within seven days by 150 snails in the right side while the weeds grew normally in the left side in the absence of snails.

Similar differences in ability to control the different weeds were demonstrated by *Marisa* during the first run of the mixed-species experiment in which the snails were given a choice of seven species growing together in the same tanks. The initial 1- or 1.5-lb amounts of southern naiad, illinois pondweed, salvinia, and coontail were completely eaten in the three experimental tanks in mean elapsed times of 3, 14, 20, and 22 days, respectively. When this run was terminated after 25 days, an average of 7 percent of the initial amount of emersed alligatorweed had been eaten, but both waterlettuce and waterhyacinth had increased in weight in the presence as well as in the absence of snails. The growth of waterlettuce was retarded slightly by the snails, while waterhyacinth more than tripled its initial weight in each tank and was damaged hardly at all. The snails exhibited selective food preferences in this run, because greater numbers of them fed on the submersed weeds and salvinia than on alligatorweed, waterlettuce, and waterhyacinth. The choice of weeds was reduced by one as each of the more edible species was consumed; consequently, increasingly greater numbers of snails were observed to feed on the less edible weeds during the remainder of the run.

At the start of the second mixed-species run, each of the four tanks contained 2 lb of coontail, 3 lb of salvinia, and 16 rooted alligatorweed plants with stems about 15 inches long. Figure 3 shows the appearance of the control tank and one experimental tank five days after 200 snails were placed in each of the three experimental tanks. All that remained of the weeds in the tanks with snails at that time were defoliated stems of alligatorweed and the small amount of salvinia shown floating in the tank in the lower photograph of Figure 3. The remaining salvinia was eaten during the next two days, and after two more weeks the snails had eaten the alligatorweed stems as well. The snails showed nearly the same preferences for coontail and salvinia in this run, but they did not eat much of the alligatorweed until the other weeds were no longer available.

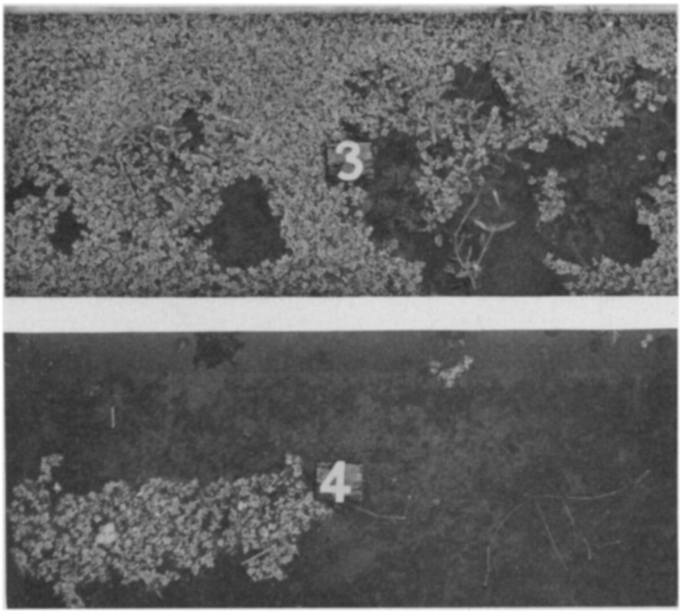

Figure 3. Upper, control tank (no. 3 without snails) showing alligatorweed (emersed), coontail (submersed), and salvinia (floating). Lower, one of three tanks (no. 4) in which 200 *Marisa* were placed five days before the photograph was taken.

Figure 4 illustrates the control of salvinia by different populations of *Marisa* on the eighth day of a preliminary run. In this run, groups of 50, 100, and 200 snails per compartment ate 3 lb of salvinia in 17, 10, and 8 days, respectively. Similar groups of snails all limited the growth of waterhyacinth to 20 percent of the amount that occurred in their absence, but even the highest population (200) of snails failed to eradicate the initial 4.5 lb of this weed during a 26-day preliminary run.

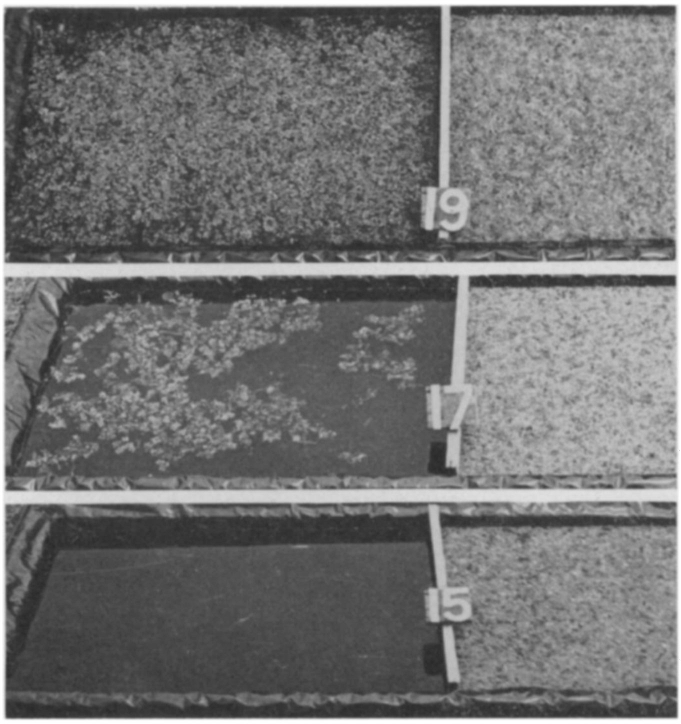

Figure 4. Tanks of salvinia as they appeared eight days after placing 50 (upper, no. 19), 100 (middle, no. 17), and 200 (lower, no. 15) snails in the compartments to the left of the center partitions. These tanks were lined with polyethylene plastic for easier cleaning between runs.

The results of succeeding runs of the snail-population experiment are shown in Table 2. Although the second run with salvinia was terminated before the weed was completely eaten in any of the tanks, the results showed the same relation between population and control as in the preliminary run. The group of 100 snails gave better control than the 50-snail group, but there was little difference in control by the 100- and the 200-snail groups during this run. This indicates that 100 snails per compartment was probably near the maximum effective population density for control of salvinia. The larger population used in the second run with waterhyacinth were more effective, but again the highest population (400) of snails failed to eradicate the initial amount of this weed. Both growth and flowering of waterhyacinth were greatly retarded by the 400-snail group (Figure 5), and similar but proportionally less inhibition of growth and flowering was caused by the smaller groups of snails. Some leaves and petioles at and beneath the water surface were eaten, but the principal action of *Marisa* on waterhyacinth was root-pruning (Figure 5). The resulting poor root development probably limited adequate uptake of water and nutrients so that the plants remained in a juvenile stage of slow growth.

Table 2. Effects of different snail populations on growths of salvinia and waterhyacinth.

Plant and snails per compartment	Initial wet wt lb	Elapsed time days	Change in wet wt: With snails lb	Change in wet wt: Without snails lb[a]	Net Control lb	Control rate lb/day
Salvinia						
50	3	15	− 1.8	+ 1.7	3.5	0.23
100	3	15	− 2.5	+ 1.7	4.2	0.28
200	3	15	− 2.4	+ 1.7	4.1	0.27
Waterhyacinth						
100	5	48	+10.5	+26.2	15.7	0.33
200	5	48	+ 8.5	+26.2	17.7	0.37
400	5	48	+ 2.5	+26.2	23.7	0.49

[a] Mean wet weight change in three compartments without snails.

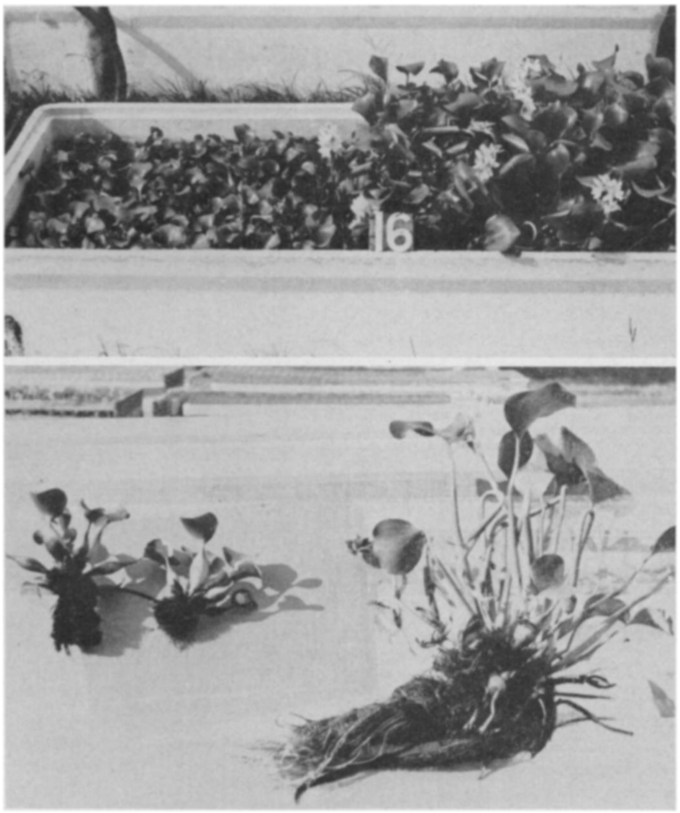

Figure 5. Upper, compartmented tank of waterhyacinth as it appeared 48 days after placing 400 snails in the left side and none in the right side. Lower, waterhyacinth plants taken from each side of the tank shown in the upper photograph. The plants on the left show retarded growth and root damage caused by the snails compared with the normal undamaged plant on the right.

These evaluations showed that *Marisa* is very promising for control of several important aquatic weeds. Very few aquatic herbicides have given such rapid and complete control of coontail, southern naiad, illinois pondweed, and salvinia as that achieved repeatedly by the snails during this study. Since *Marisa* is strictly aquatic and feeds only on vegetation under the water surface, its control of alga-free waterlettuce and partial control of waterhyacinth and alligatorweed were indeed remarkable.

A dense population of *Marisa* might give much better control of waterhyacinth in the winter, when this weed grows more slowly than it did during these summer tests. Provided more-edible vegetation is not present to distract them, the snails might at least weaken the larger floating and emersed aquatic weeds and make them more susceptible to chemical control methods.

Little damage was done to the 4-week-old rice plants during the 30-day preliminary run with 150 *Marisa* in one side of a double-compartment tank. A few plants were destroyed when the snails nipped shoots off at their bases, but *Marisa* did not actually feed on the rice even though no other food was available. Many snails died during this run, presumably of starvation. The results of the second run with rice are shown in Table 3. Overnight-soaked seeds and 1-, 2-, and 3-week-old plants were fed upon and seriously damaged by the snails during the first week, but the older plants appeared to be spared by the preferential feeding of the snails on the younger plants. The slight decreases in survival of the 4- and 5-week-old plants between the second and third week showed that fewer of these plants were damaged as they grew older. About 12 percent of the snails in the three tanks died during this run, and these mortalities were also probably caused by starvation as the supply of acceptable food became depleted. Except for the snail mortalities, these results agree with those of a recent field experiment in Puerto Rico (9) in which 4-week-old transplanted rice plants suffered no apparent damage from a "heavy" *Marisa* population in a flooded field, but no rice seedlings survived in broadcast plantings of dry and presoaked seeds in another part of the same *Marisa*-infested field. This apparent proclivity of *Marisa* to destroy young rice might be a serious disadvantage if the snails were introduced into areas where this crop is grown by direct seeding of fields as in the United States, but *Marisa* probably would not be hazardous in areas where rice is grown from 4- or 5-week-old transplants as in the Orient.

Table 3. Survival of rice in the presence of *Marisa cornuarietis.* Values are average numbers of undamaged rice seedlings in three replicate tanks with snails expressed as percentages of surviving seedlings of the same age in a fourth tank without snails.

Age of seedlings at start of run weeks	Per cent survival		
	First week	Second week	Third week
0[a]	0	0	0
1	0	0	0
2	25	14	0
3	41	28	15
4	74	52	43
5	94	77	75

[a]Overnight-soaked seeds planted in flats of soil.

The boat-tailed grackle [*Cassidix mexicanus* (Gmelin)] was discovered to be a predator of *Marisa,* when some of these birds raided the tanks one weekend and destroyed nearly three dozen snails. This prompted the use of the anti-bird cages. We now believe that this common bird of south Florida, and possibly also the limpkin (*Aramus guarauna* L.), were responsible for the numerous *Marisa* shells found several feet above the high-water line along the banks of the Coral Gables and Tamiami Trail canals. These birds commonly feed on a large native fresh-water snail, *Pomacea paludosa* Say, as do other possible predators of *Marisa* in Florida including the nearly extinct everglade kite [*Rostrahamus sociabilis* (Vieillot)], alligator (*Alligator mississipiensis* Daudin), raccoon [*Procyon lotor* (L.)], and snapping turtle (*Chelydra serpentine* L.).[4] Apparently such predation has not seriously affected the survival and spread of the Miami *Marisa* colony, which was obviously increasing in size.

One characteristic in favor of the survival of *Marisa* in Florida is its rapid reproduction rate. *Marisa* egg masses were plentiful in the canals from May to September and also during December and January as reported by Hunt (5). Similar egg masses laid in the tanks were removed to aquaria where they hatched within 12 to 14 days. The newly hatched snails fed avidly on filamentous algae and several grew from 2 mm to 2 cm in diameter in only five months. Michelson and Augustine (6) reported that adult *Marisa* do not destroy their own eggs or young. We confirmed this by placing six large *Marisa* in an aquarium with a small waterlettuce plant on which a *Marisa* egg mass was deposited. Although no other food was available, the adult snails did not eat any of the plant until the eggs hatched about 12 days later. The plant was then quickly devoured, but the young snails were not harmed by the adult snails.

Our tests were conducted in concrete tanks to prevent further introductions of *Marisa* in the Florida Everglades until more could be learned about the snail's possible disadvantages. Information regarding the performance of *Marisa* under field conditions was therefore limited to observations of the Miami *Marisa* colony. Although the snails fed on cabomba in the holding tanks with the same alacrity as on coontail or southern naiad, the cabomba infestations in the Coral Gables and Tamiami Trail canals were hardly affected by the *Marisa* colony during the 5-month observation period. The colony had spread more than five miles from its site of probable introduction during the five years since its discovery (5); so the snails probably were spread out too thinly to exert much weed control pressure. Since it took *Marisa* over a year to build up effective populations to control waterlilies in the ponds in Puerto Rico (10), it appears that the snails are not likely to be effective for weed control unless confined to small bodies of water under conditions favorable to their increasing population. Additional data on *Marisa's* performance under field conditions are needed, but its probable susceptibility to temperatures below 56 F (5) and its effects on seeded rice might limit field experiments in areas outside Florida.

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ture, Fort Lauderdale, Florida, gave many helpful suggestions and some technical assistance with the experiments. Dr. R. J. Smith of the U. S. Department of Agriculture, Rice Branch Experiment Station, Stuttgart, Arkansas, supplied the rice seed.

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Influence of Air Movement on Persistence of EPTC on Soil[1]

L. L. DANIELSON and W. A. GENTNER[2]

Abstract. The persistence of soil-surface applied ethyl *N,N*-di-*n*-propylthiolcarbamate [EPTC] was studied at air velocities of ¾ to 4 mph in special air-flow equipment. Persistence was inversely related to velocity though the effect was quantitatively changed by soil composition and the materials used in formulating the EPTC spray.

THOUGH the effects of air movement on the persistence of volatile herbicides have been recognized, they have not been adequately studied. It has been observed, for example, that even the slight movement due to air drainage associated with soil topography and descending night-temperature gradients can produce readily discernible 2,4-dichlorophenoxyacetic acid [2,4-D] injury patterns due to vapor transfer.

The effects of air movement and the closely associated effects of temperature are not merely experimental curiosities, but are important in the practical use of herbicides and have been recognized independently by commercial growers. For example, isopropyl *N*-(3-chlorophenyl) carbamate [CIPC] and 2-chloroallyl diethyldithiocarbamate [CDEC] used independently or in combination as preemergence treatments in commercial fields perform more effectively in hot dry weather if applications are made during the night when wind velocity and soil temperature are at minimum levels for the diurnal period. The persistence of volatile herbicides including 2,4-D, 4,6-dinitro-*o*-*sec*-butylphenol [DNBP], and CIPC decreases as temperature increases (1, 4, 5, 7, 8, 9).

The present study was initiated to obtain experimental evidence on the effect of differential air movement velocities on the persistence of soil-applied EPTC as a representative volatile herbicide and to develop suitable experimental methods and equipment for the convenient general study of air-movement problems in herbicide performance and persistence.

MATERIALS AND METHODS

Equipment.

Various systems for establishing and maintaining constant airflow for herbicide-persistence studies were evaluated. These preliminary studies led to the design and construction of the equipment shown in Figure 1. The cost of parts and the time required for construction are modest. Standard dampers and galvanized sheet metal furnace pipe having a diameter of 9¾ inches were used. Overall length and width of the equipment is 78 and 40 inches, respectively.

A selection of fan/motor pulley ratios and a flow regulator in each exposure chamber and in the bypass combine to provide a broad selection of air-movement levels. Treated substrates in the airstream can be exposed to sunlight, infrared radiation, and artificial light. They can also be completely shielded from light. Aluminum shields were used to avoid exposure of samples to direct sunlight in the experiments reported.

The airflow rate-range of 0 to 4 mph used in all experiments was selected in preliminary time and airflow studies with EPTC. The greenhouse temperature was thermostatically regulated and ranged from approximately 75 to 80 F.

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