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STRATEGY OF MOLLUSCICIDE APPLICATIONS IN RESERVOIRS

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PART - I

CHAPTER VI

STRATEGY OF MOLLUSCICIDE APPLICATIONS

After the optimum chemical has been selected on the basis of local suitability, the next step is to determine the best strategy for applying that chemical to the varied habitats. This strategy is primarily a function of the environmental conditions in the snail habitats and the population dynamics of the snails. In most cases the population dynamics of the parasite do not have to be known since application of a molluscicide usually has the simple objective of eliminating or minimizing the average number of snails. If the objective is more sophisticated and involves a continuing program to reduce transmission by minimizing the number of snails only during certain months, then methodologies including seasonal dynamics of schistosome transmission would have to be used. However, limiting the scope of the analysis to snail control allows detailed development of strategies for areas where adequate information is available on the snails and their habitats.

Irrigation Systems

As a framework for discussion it is instructive to estimate the molluscicide cost for a typical irrigation system, based on data from a sugar cane irrigation project in Central Africa. A government-owned reservoir with a storage capacity of 10 x 10^{10} cubic meters supplies water via a high canal to several private estates, with a total of each of which has 25,000 hectares under sugar cane cultivation. The approximate costs for a single application of Bayluscide to the irrigation system are given in Table VII.

Obviously there is no possibility of treating the entire reservoir economically. Even treating the shoreline alone would cost about $10 million. About the only alternative, if chemical control is used, is treat the downstream portion

TABLE VII. Estimated costs for a single application of Bayluscide to a typical sugar cane irrigation system of 30,000 hectares in central Africa

UNIT	SIZE	APPLICATION METHOD	CHEMICAL COST IN US DOLLARS 1972	TOTAL COST IN US DOLLARS 1972
Main Reservoir	$10x10^{10}$ cubic Meters	Spray from boats	$1 Billion	$1 Billion
Main Canal	20 M^3/sec	Water carriage	$2 800	$3,000
Offtake from main canal into and thru all night storage Ponds	Total of 20 m^3/sec	Water carriage	$3,000	$4,500
Drains	1 Kilometer	Surveillance hand spraying	$2.00	$9.00
All drains in system for 1 year	500 kilometers	Surveillance every 4 wks. and hand spraying.	$10,000	$45,000

of the irrigation system whenever necessary. Each treatment of the main canal would cost $3,000, and treating canals leading into the night storage ponds as well as the ponds costs $4,500. Since the main canal is not a very good snail habitat due to high velocity, it can be ignored.

A yearly surveillance program for treating the drainage ditches and main drains costs $9.00 per kilometer of drain, or $45,000 for the entire system. Snails are usually more abundant in the drains, escape the molluscicide more easily, and thus reinfest the drains more often than the irrigation canals.

During the first year of chemical control, it is estimated that the delivery system (off-take from main canal to fields) will need two treatments per year at a cost of $9,000 (Table VIII). The drainage system of 500 kilometers will require about 10 surveys with treatments as necessary at a cost of $45,000. Thus molluscciding cost for an average year will be $54,000 for the entire irrigation system, or $100 per hectare.

The conclusions to be drawn from this simple analysis of a modern sugar cane irrigation system have general importance for chemical control of snails.

1. Chemical control in large reservoirs is undoubtedly a waste of money. Environmental or biological methods for snail control would have to be used.

2. Chemical control in primary or high canals where velocities are rapid, thus limiting snail population and human contact, is very expensive due to large flows of water. These costs can be eliminated with proper design and maintenance of the canal.

3. The delivery canals and night storage ponds are relatively easy to control, the major cost being chemicals, with labor cost about 30% of the total cost.

4. The drainage system is much more expensive to control and labor costs are the major item, about 80% of the total.

TABLE VIII. Estimated Cost of Molluscicide program for average year in irrigation system of 30,000 hectares.

PORTION TREATED	COST IN US DOLLARS 1972	
	CHEMICAL	TOTAL
RESERVOIR	OMIT	OMIT
Main Canal	OMIT	OMIT
Offtakes and storage Ponds	$ 6,000	$ 9,000
Drainage system	$10,000	$45,000
TOTAL	$16,000	$54,000

In each case there are possibilities for decreasing chemical costs by improving design, construction and maintenance of each element in the irrigation and drainage systems.

Standing Water

Most of the detailed information collected on snail habitats and population dynamics comes from still water habitats such as lakes and reservoirs. The stategy for such habitats can thus be developed in some detail. It must be recognized however that there is a limit to the size of reservoir which should even be considered as a case for chemical control of snails. With current prices of molluscicides that limiting size is about one million cubic meters of water or less.

The analysis of molluscicide applications can now be carried to a cost/benefit comparison of alternate chemicals, alternate dosages and alternate strategies of control.

When organizing a program based on control of snails, a question to be answered early in the program is whether timing of the control measures is important. In the case of molluscicides, is there a month or season when the cost/effectivness ratio is unusually low? If not, timing is unimportant, but if the cost/effectiveness can be minimized by applying chemicals at a specific time of the year, this should be designed into the program.

Selection of the best timing cannot easily be done experimentally since it involves large numbers of field tests with expensive and time-consuming evaluation. A simpler method is to obtain information on population dynamics of the snail and on seasonal characteristics of habitats typical to the area, and then to rationally evaluate the effect of control measures at different times of the year. To assist in this mental exercise, a computer program for modeling a snail program has been developed.

Its reliability has been previously tested using data for a population of African snails. Comprehensive field studies were not available for other species at the time the model was developed

The manipulation of the model for the purpose of predicting population histories is accomplished by proposing increased death rates for simulation of application of a molluscicide, desiccation, and other catastrophic events. For a given species the number of survivors in a group, over a given time-interval is

$$s = s_o \times p_a \times p_c$$

where s_o is the original number of snails, p_a is the age-specific survival rate for the time interval, and p_c is the probability of surviving any catastrophic event which might have occurred in the time interval.

Description of the Mathematical Model

The computational model of a population of aquatic snails was written in Fortran IV. The model requires input information on the snail species (age-specific survival rates, age-specific birth rates, a fecundity factor, the relationship of fecundity to temperature, the volume of the crowding zone), and information on the habitat, (volume, temperature, and food) From these data a 3-year prediction of the snail population is calculated. The population is described by the model for 10-day intervals in the terms of total number of snails, and number of eggs.

An iterative process is used for the computations. The computational program begins with a specified population, grouped into 10-day intervals. The first step is to calculate the number of snails surviving to the next time-period in each age-group The time-period and the age-interval were set at 10 days to approximate the hatching time for eggs of *Biomphalaria glabrata* and *Bulinus globosus*. The number of snails is then calculated for the first period, both for output and various parameters for the first time period, such as average age of the population and food density in the habitat After testing for population crowding, the egg production is calculated for each age-group, according to the age-specific fecundity factor and water temperature If the poulation is not crowded , fecundity is proportional to food density, whereas if the population is crowded, fecundity is calculated as being proportional to the ratio of food density and the number of snails per crowding zone (Jobin and Michelson, 1968) The number of eggs produced is then summed for the first time period, reduced according to hatching and catastrophic death rates, and transferred to the first age-group of the next time period. The entire process is then repeated, advancing one period at a time.

Since the original development of the model several field studies have been completed on Biomphalaria glabrata (Jobin, 1970). To determine if the model was also reliable for B. glabrata the field rates of survival and the environmental conditions from Pond B in the Puerto Rican study were used in the model to predict the history of the snail population. The prediction agreed quite well with the observed number of snails (Figure 11A). In a similar manner the environmental data from Pond C of the same study was put into the model. Again the predicted number of snails was quite similar to that observed in the actual pond (Figure 12). It was therefore assumed that the model is also reliable for predicting population histories of these snails.

The major requirement for simulating snail populations with an acceptable degree of accuracy is a determination of the age-specific survival rates for the species under consideration. Many field studies in the past few years have provided this data for a number of snail species of interest in the control of schistosomiasis, as well as other related problems (Figure 13). The comparison of laboratory survival with survival in the field for the same

NUMBER OF BIOMPHALARIA GLABRATA, POND B

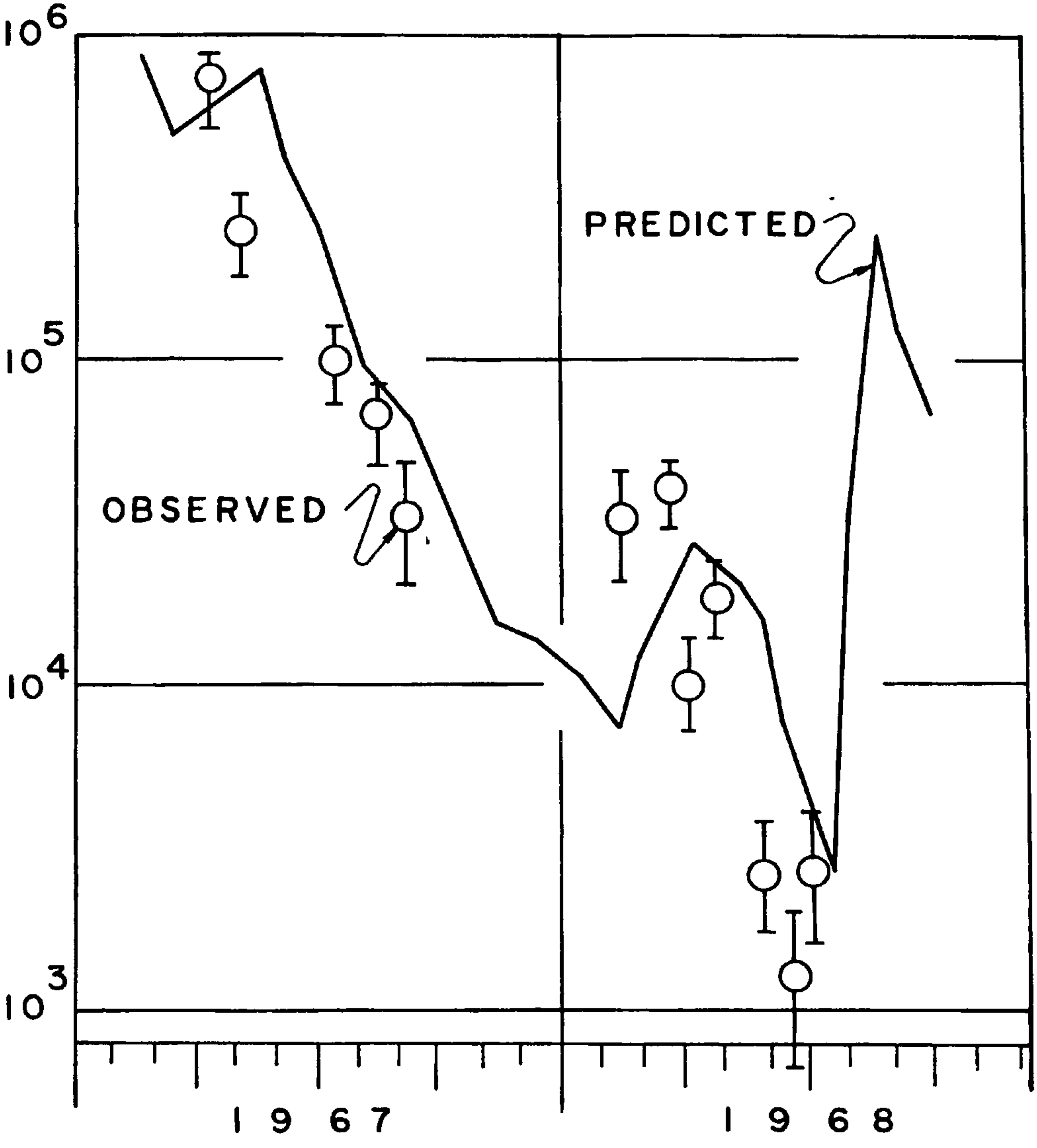
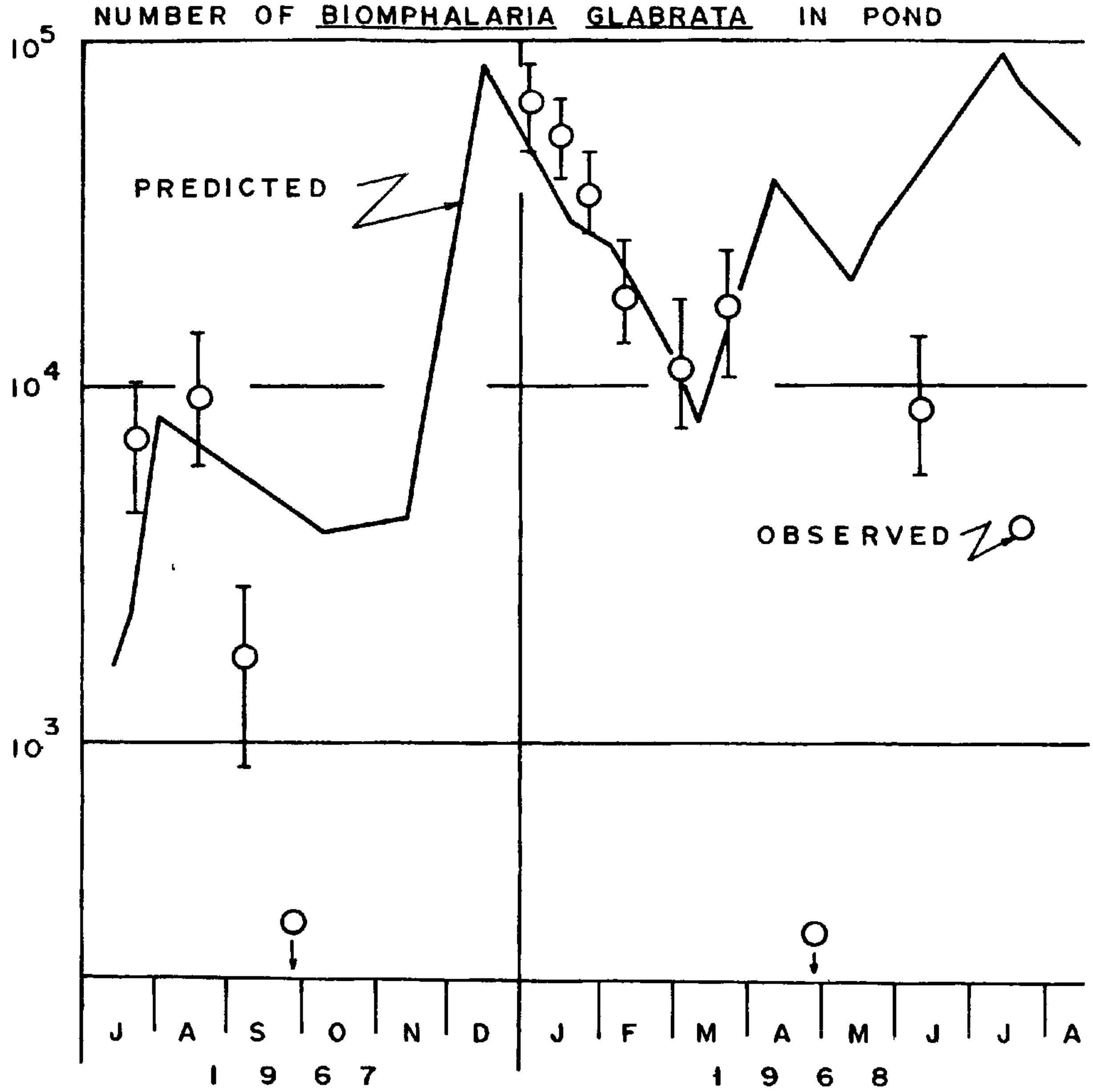


FIGURE 11A. FIRST VERIFICATION OF SNAIL MODEL FOR PLANORBID SNAILS IN PUERTO RICO

FIGURE 12. SECOND VERIFICATION OF SNAIL MODEL FOR PLANORBIDS IN A PUERTO RICAN HABITAT, POND C



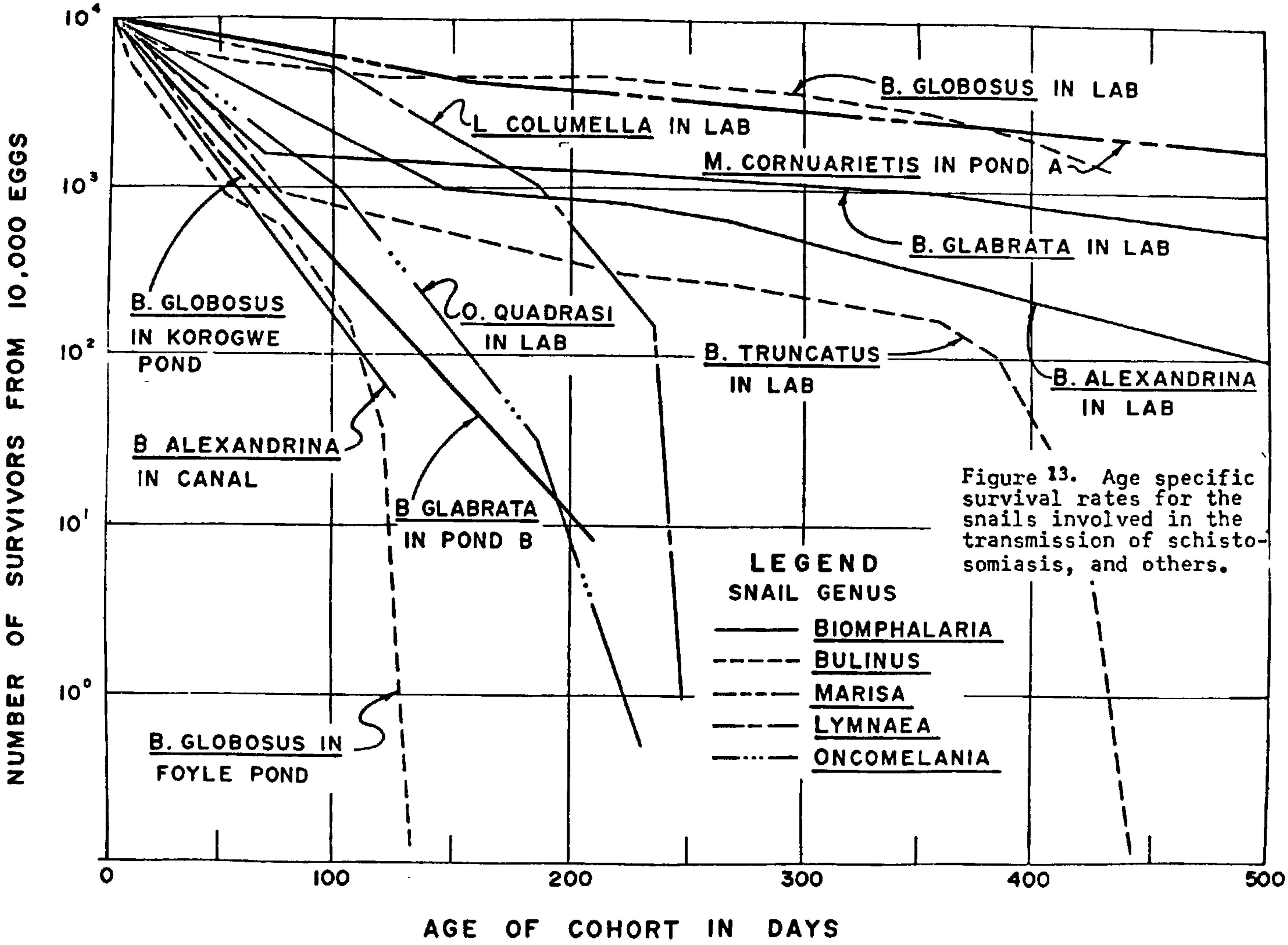


Figure 13. Age specific survival rates for the snails involved in the transmission of schistosomiasis, and others.

species, underscores the need to make careful adjustments when extrapolating laboratory data to planning of control programs.

Strategy for Brazilian Lakes and Reservoirs

Brazil has the most extensive problem with schistosomiasis of any country in the western hemisphere Data was obtained on typical reservoirs in the northeast of Brazil near Recife, and in Minas Gerais near Belo Horizonte The climates are quite different in the two areas, and so are the abilities of the local strains of snails to resist desiccation. Thus the normal population histories in similar reservoirs would be quite different, and the optimum timing of control measures would not be the same for the two areas

Reservoir in North-East

The natural environmental conditions in a reservoir in the north-east were taken from a description of snail habitats near the City of Recife (Barbosa, 1962) There is a 4 month period from December through March when the habitat is dry and the snails survive by estivation These snails have a very high resistance to desiccation. The rains begin in April and the reservoir is full of water by May, gradually diminishing in volume from July to November as the rains decrease The amount of vegetation increases from April to August and then stays at a constant relative density (kilograms of vegetation per cubic meter of habitat), until the dry season. Water temperatures are always above 25°C and go as high as 35 to 40°as the habitat dries. This typical climate produces a maximum number of snails in August through October, with the minimum occurring in April or May at the end of the drought (Figure 14).

Chemical Applications

In order to determine the optimum time of year for application of molluscicides in a reservoir in the north-east, 99% mortalities from chemical treatment were simulated for one month at a time for April, May, June, July, August, September, and October, assuming double applications of molluscicides during a month, spaced 20 days apart. Only 99% mortalities were simulated in order to show the population recovery to be expected following the chemical treatment.

The effect of the molluscicides was least pronounced if the chemical was applied during the breeding season, primarily because of the high reproductive rate of the snails (Table IX) and Figure 14). If the applications were made in May, the lowest number of snails during the year was 111, immediately following the first application. The next week there was a burst of egg-laying due to the environmental conditions and the uncrowded habitat, thus the number of snails rose to 2251, and 23,000 eggs were deposited, leaving 182 snails alive after the second application. At this time the reservoir was full, containing 9000 cubic meters of water. For the remainder of the breeding season the number of snails increased steadily.

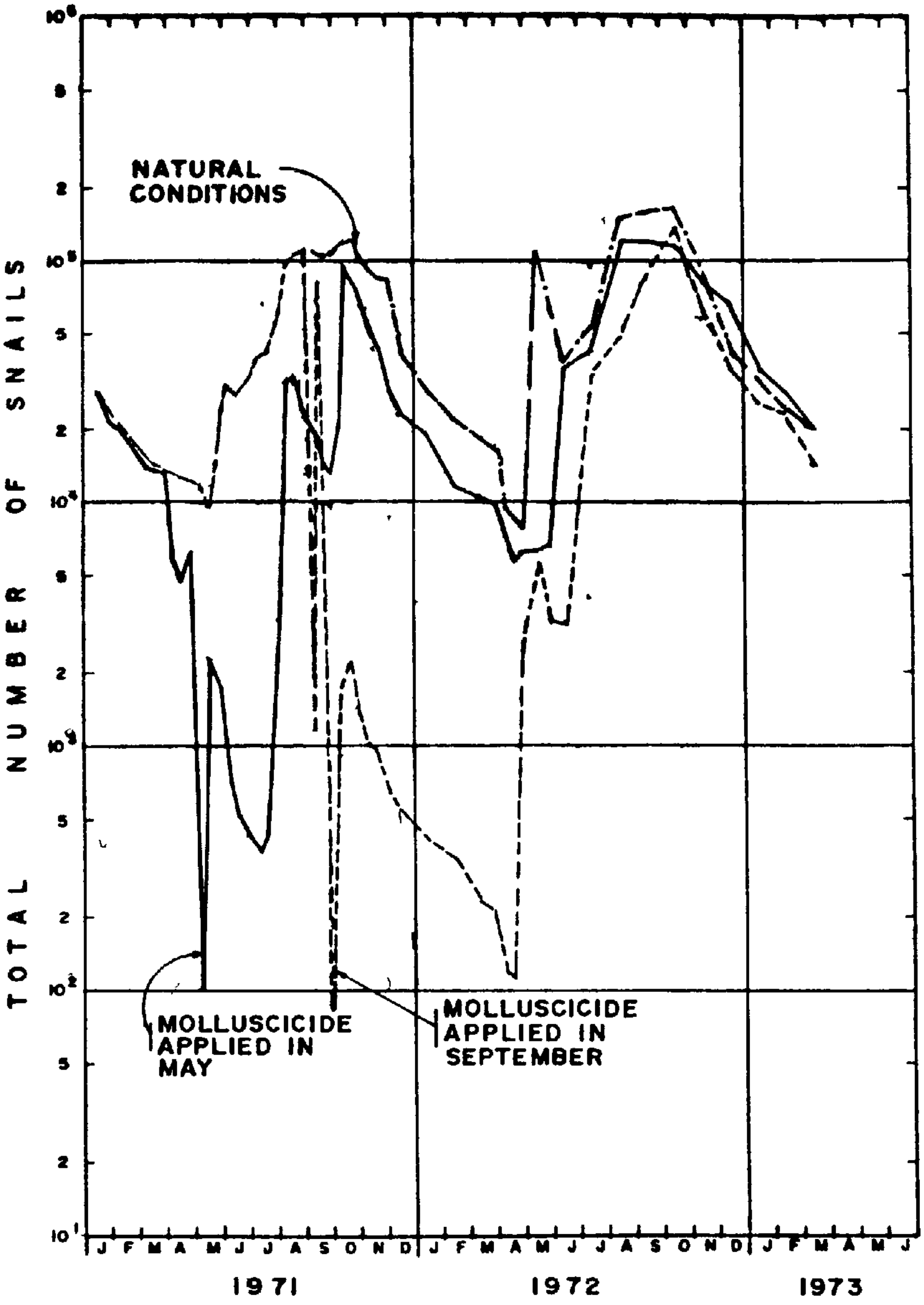
In contrast, the chemicals applied in November caused the snail population to drop to 10 by April. There was no recovery of the population following the application of molluscicides since water temperatures were too high for oviposition and the habitat dried-out completely by December, forcing the 48 survivors to estivate (Table X and Figure 15). At the time of the November treatment the reservoir was low containing only 50 cubic meters of water.

By tabulating the minimum number of snails predicted following the molluscicide application for each month, it became clear that November ranked first as the month for treatment which would cause the small population to drop to its lowest level, with April, October, May and September following in that order of effectiveness.

TABLE IX

Model prediction of the population history of *Biomphalaria glabrata* in north-east Brazil with double application of 99% effective molluscicide in May 1971

Date		Number of snails predicted	Habitat volume in cubic meters
1971	April	4,796	500
		(first molluscicide application)	
	May 1	111	9,000
	May 11	2,251	9,000
		(second molluscicide application)	
	May 21	182	9,000
	June	511	8,000
	July	398	6,000
	August	31,708	3,000
	September	16,672	1,000



PREDICTED SNAIL POPULATIONS IN RESERVOIR OF NORTHEAST BRAZIL, UNDER NATURAL CONDITIONS AND AFTER MOLLUSCICIDING.

FIGURE 14

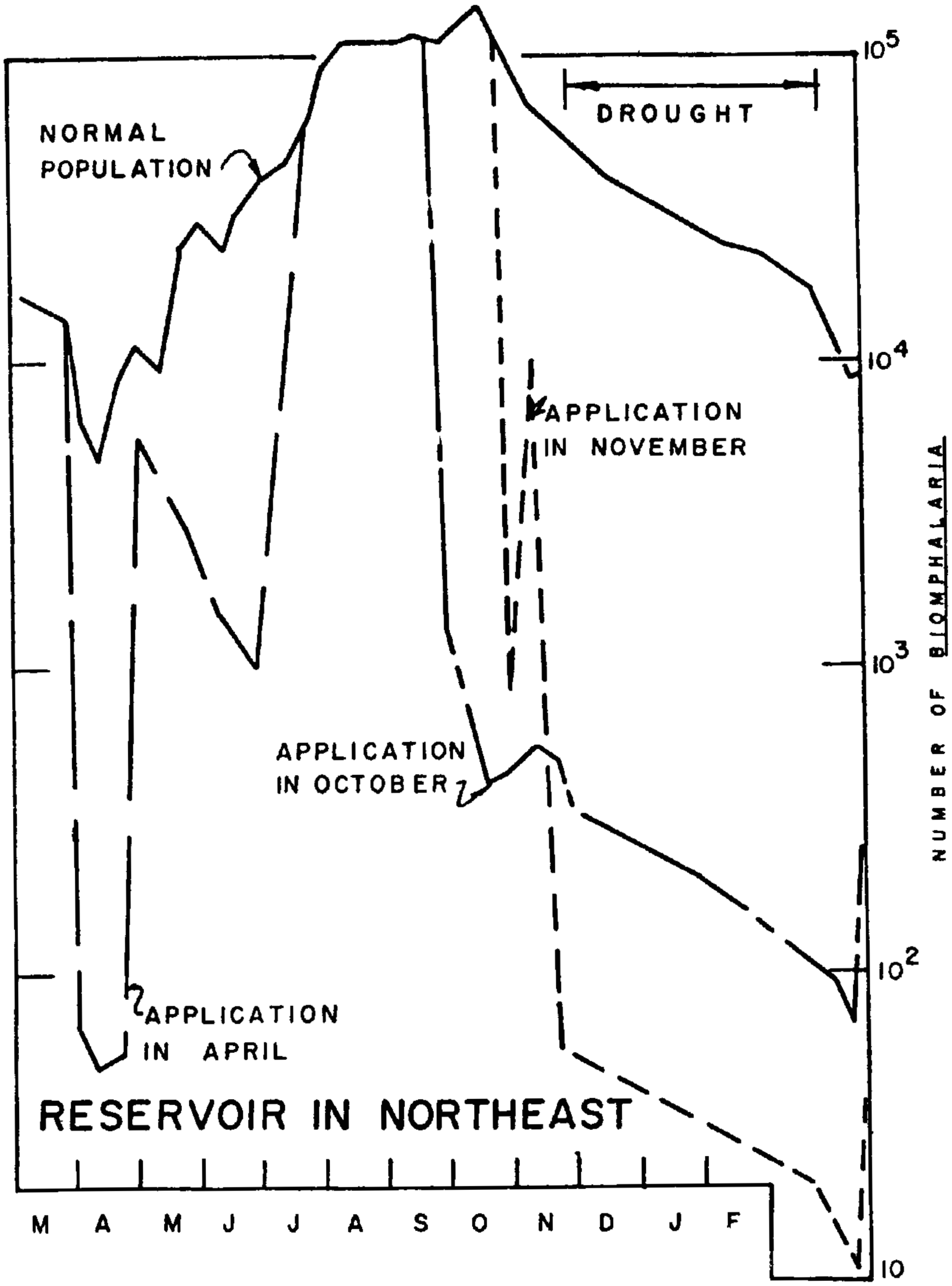


Figure 15. Predicted Snail Population after Mollusciciding.

TABLE X

Model prediction of the population history of *Biomphalaria glabrata* for reservoir in north-east Brazil with double application of 99% effective molluscicide in November 1971.

Date			Number of snails predicted	Habitat volume in cubic meters
1971	October		152,373	100
			(first application of molluscicide)	
	November	1	855	50
	November	11	9,018	50
			(second application of molluscicide)	
	November	21	57	50
	December		48	0
1972	January		37	0
	February		28	0
	March		22	0
	April		10	500
	May		556	9,000
	June		955	8,000
	July		16,012	6,000

Although the precise numbers developed in the analysis have little significance, it is clear that the best time to apply molluscicides in the north-east is immediately before the drought, in October and November.

Reservoir in Minas Gerais

The only area in Brazil besides the north-east where a great deal of data is available on population dynamics of *B. glabrata* is near Belo Horizonte in Minas Gerais. A typical small reservoir with environmental conditions of water temperature, volume and amount of food was simulated for Minas Gerais, using data from Lake Santo and from Lake Pampulha (Table XI and Figure 16).

The predicted history of the snail population was similar in general terms to that observed for Lake Santo (Paraense and Santos, 1953), and for Lake Pampulha (Andrade, 1963). Water temperatures fall below 20°C from May through July, restricting the breeding season to the other 9 months of the year. Even during the warmer season, mean monthly temperatures of the water do not exceed 25°, being much cooler than the north-east. Although there isn't a severe dry season in Minas Gerais, the water levels do recede during the cold season, reaching a minimum before the rains start in October. During the hot rainy season (October through April), the heavy rains cause the lakes to fill and also produce high levels of turbidity due to the fine silt carried in by the flood waters. This high turbidity restricts growth of algae and thus retards the amount of food available for snails until about April when the rainfall decreases. During the dry season the water becomes clearer and aquatic growths increase, providing more food for the snails. Under these conditions the model predicted a maximum snail population in September with a minimum in July and August, agreeing in general terms with the observation for lakes in Minas Gerais. The reservoir simulated for Minas

Gerais has a maximum volume value of 900 cubic meters, the same as the reservoir simulated for the north-east, making treatment costs comparable.

A double application of molluscicides was simulated for each month, assuming the applications occurred on the 1st and 21st days of the month and that each application caused 99% mortality, identical to the treatment regime simulated for the reservoir in the north-east. Under these conditions the snails were completely eliminated if the molluscicide was applied during May, June or July. Since this made it impossible to rank the months comparatively, the mollusciciding was resimulated assuming only 90% mortality (Tables XII and XIII).

The fact that the mollusciciding in Minas Gerais had a greater effect on the snail population than did the mollusciciding in the north-east indicates that snail control programs are more likely to succeed in Minas Gerais, due to the nature of the environment. The lower temperatures in Minas Gerais cause a lower average oviposition rate, requiring more time for the snail population to recover from a catastrophe.

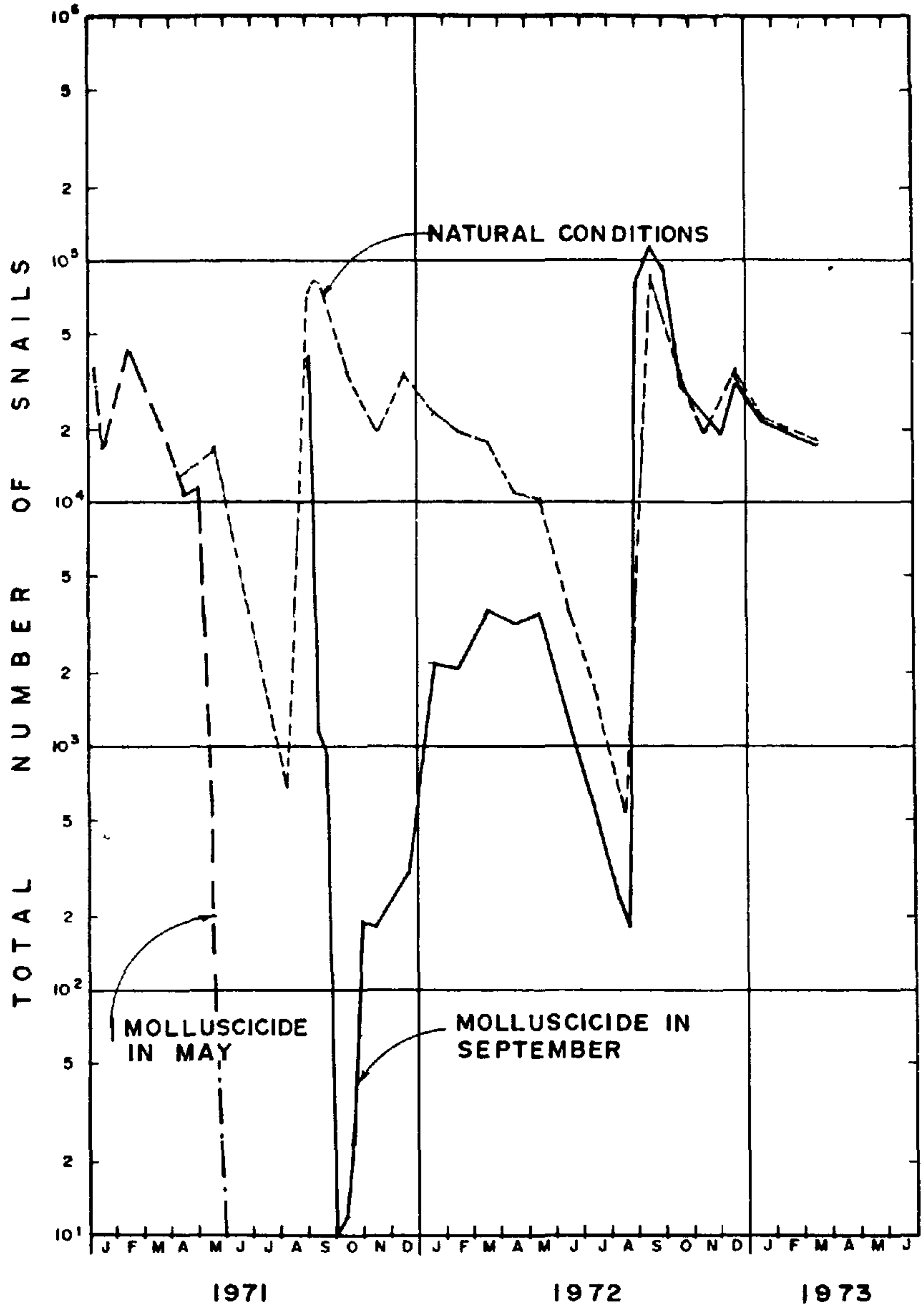
For a reservoir in Minas Gerais, the best month for mollusciciding was found to be July, while May and June (the other months when it is too cold for oviposition) are almost as good. Chemicals applied during the breeding season have markedly less effect on the number of snails. In addition to having a greater effect if molluscicides are applied during the cold months, the cost will be slightly lower since the reservoirs, although far from dry, will have somewhat less water than normally.

Thus the comparative analysis of the reservoirs showed that mollusciciding will be more effective in Minas Gerais than in the north-east, primarily due to more favorable temperatures for reproduction of the snails in the north-east. In addition the analysis shows that molluscicides should be applied just before the dry season in the north-east, but during the dry season in Minas Gerais.

TABLE XI

Model prediction of the population history of *Biomphalaria glabrata* for reservoir in Minas Gerais under natural conditions

Date	Number of snails predicted	Water temperature in °C	Habitat volume in cu meters	Amount of food in kilograms
1971 May	14,742	19.0	8,000	200
June	5,418	18.0	7,000	400
July	2,060	18.0	6,000	500
August	745	20.5	5,000	500
September	79,320	21.0	4,000	500
October	31,945	21.5	4,000	500
November	19,590	22.0	9,000	50
December	29,403	22.5	9,000	50
1972 January	22,663	23.0	9,000	50
February	19,928	22.0	9,000	50
March	17,239	21.0	9,000	50
April	11,467	20.5	9,000	100



PREDICTED SNAIL POPULATIONS IN RESERVOIR OF MINAS GERAIS UNDER NATURAL CONDITIONS AND AFTER MOLLUSCICIDING.

FIGURE 16

TABLE XII

Model prediction of the population history of *Biomphalaria glabrata* for reservoir in Minas Gerais with double application of 90% effective molluscicide in December 1971.

Date			Number of snails predicted	Habitat volume in cubic meters
1971	June	11	5,418	7,000
	June	21	3,978	7,000
			(first application of molluscicide)	
	July	1	289	6,000
	July	11	206	6,000
			(second application of molluscicide)	
	July	21	15	6,000
	August	1	11	5,000
	August	11	7	5,000
	August	21	69,496	5,000
	September		78,532	4,000

TABLE XIII

Model prediction of the population history of *Biomphalaria glabrata* for reservoir in Minas Gerais with double application of 90% effective molluscicide in December 1971.

Date			Number of snails predicted	Habitat volume in cubic meters
1971	November		19,590	9,000
			(first application of molluscicide)	
	December	1	3,015	9,000
	December	11	2,940	9,000
			(second application of molluscicide)	
	December	21	991	9,000
1972	January		1,229	9,000
	February		2,072	9,000

	June		1,290	7,000
	July		499	6,000
	August		187	5,000
	September		78,880	4,000

The process employed in arriving at these conclusions on the timing of molluscicide operations is a general procedure which can also be applied for other control methods, for other regions, and for other species of snails It can also be applied without the use of the computer model, although it then becomes much more time consuming

B Flowing Water

In applying molluscicides to streams and canals there are many other factors which must be considered in addition to the timing of applications and those factors affecting the normal birth and death rates of the snails The most important fact is the transport of the chemical causing the toxic dose of chemical to traverse a great deal of snail habitat, in proportion to the velocity of the flow.

The second important factor is whether the flowing water is part of a drainage system - usually meaning a converging system of streams eventually joining into a large river-or whether it is part of an irrigation system which diverges from a single source, branching out to numerous small canals and finally the furrows of the cane field or the rice paddy. The labor involved in applying molluscicide via an irrigation system is much less than that for a drainage system, thus labor saving techniques become more important in drainage systems. In general the strategies, and perhaps the preferred molluscicide may be different for a drainage system and for an irrigation syste in the same valley.

Drainage Systems

Intensity of Treatment

Natural rivers and stream systems, replete with numerous lakes and swamps are the basic natural habitat of the snails involved in disease transmission. The fluctuating and varied habitat characteristics which protect the snail population from natural catastrophies also protect them from the toxic effects of molluscicides Muddy, weed-choked banks of small streams provide a perfect haven for adult and juvenile snails The same mud and weeds block and detoxify the pesticide as it flows by in the main current. The snail species have adapted to the continual rise and fall of the river level, not by following the fluctuations, but by resisting the temporary drying until the waters return. Thus a molluscicide application at low river stage will miss numerous snails which are temporarily stranded or which are surviving in pockets of water temporarily disconnected from the mainstream.

Thus a program to kill the snails by applying chemicals to the stream must include ways of getting the chemical to penetrate the marginal habitats at the required concentration and must also deal with the large numbers of snails which will be out of the water at the time of the molluscicide application. There is no point in contemplating a molluscicide application program for natural streams which envision a simple toxic wave transported down the riverbed by the flow. Such a program will kill many snails but will make only one or two month reduction in the average number of snails since they can quickly repopulate.

There are three ways to deal with the problem of dispersing the chemical to the streams edge. One is to over-dose the stream so that the large transverse gradient in chemical concentration will drive the toxicant out to the margin

The second is to spray an additional amount of chemical directly into the margins, along both edges of the stream throughout the treated length The overdose technique requires very little labor and not too much chemical if the stream discharge is small The marginal spraying requires a lot of labor but it can save a tremendous amount of chemical if the stream has a large discharge The third method is to deepen the margin and eliminate the shallow portion by digging or clearing the margin of the stream

There are also three ways of dealing with the problem of snails temporarily out of the water connected to the main flow One method is to repeat the molluscicide application once or twice, allowing time for the stranded snails to return to the main flow. In small streams in Puerto Rico, the molluscicide was applied 3 times at 15 day intervals at each application point Since this involves a 30 day interval between the first and last application it allows considerable changes in water level to occur, thus bringing in the snails stranded at the time of the first application. The second method for reaching these snails is to spray the margins above the water level with a concentrated high-pressure spray of molluscicide which will penetrate thin overlays of mud and debris and will soak into the estivating snail. In some cases flame-throwers have been used instead of the chemical spray The reason for this king of marginal spraying is not the same as the reason for spraying in the shallow perimeter of the stream, but the two procedures should obviously be combined into one process, spraying the dry banks and the shallow edge of the stream at the same time. The third method is also ditching but in this case it involves provision of rapid drainage for stranded areas to increase the desiccation and thus the death rate of the of the stranded snails.

If the local eradication of the snail is being attempted then all of these techniques must be used simultaneously If the objective is only to interrupt transmission then the attack could be reduced simply to stream dosing at two or three times the toxic requirement. The general experience with such control program has been that it is more profitable to begin with a concerted full-scale effort as if snail eradication were the objective Even when all of these techniques are used simultaneously the snails have eventually returned. Continuous surveillance and control attemps against Biomphalaria glabrata in Puerto Rico reduced the extent of snail population in the municipalities of Vieques, Patillas, Guayama, and Arroyo to a few small foci but the snails continued to reappear sporadically, even after 20 years of molluscicide operation. Obviously transmission had come to a halt during this period but the snails remained, ready to repopulate and invade all the old habitats if left undisurbed for three or four months. The snails always come back

Sequence of Treatment

Because the snails can be washed downstream by the flow, a molluscicicding program must also proceed downstream begining with the snail at the top of the stream basin Many times the sources of the stream may be a lake or marshy area. The initial habitat must be treated or otherwise cleared of the snails before any chemical application is attempted below.

In a highly branched network of stream courses it is sometimes advantageous to make a synchronized application of chemical to the several stream sources, thus preserving the toxic concentration as the sychronized waves of chemical join at the several confluences If only one source is treated each day, the toxic effect of the dose would be lost at the first confluence because of dilution by the tributary. Thus the benefits from the single treatment are limited to the snail habitats above the confluence If the several branches were treated in a pattern that caused the doses to meet at the confluence then the toxic concentration is maintained and the benefits extend downstream, limited only by the detoxication of the molluscicide

The half-life of Bayluscide is roughly two days. If the applied concentration is four times the toxic dose the value of sychronized treatments is limited to stream branches where the travel time to the next tributary is less than four days since the wave would lose its toxic impact by the time it reached the confluence. If the travel time on each branch was only 1/2 day or a few hours then synchronized treatment would be very beneficial. Synchronization can be planned from travel time studies using salt waves If the flow in the stream and then the travel time fluctuate rapidly, synchronized treatment is not recommended due to the considerable expense and difficulty of determining the correct timing for application.

Equipment

The most important element in treating natural streams and rivers is the careful, intensive nature of the process. Natural stream systems are often in almost inaccessible areas requiring hours of walking and cutting through heavy growth simply to reach the application points. When accesibility is so difficult, the best equipment is usually no equipment. Otherwise very large amounts of time can be lost because of simple malfunctions of dispensers, weirs, sprayers, timers, etc. Bayluscide is remarkably adapted to this philosophy since it is most toxic when applied in a short high dose. It is thus sufficient to mix the chemical in a drum and allow the drum to drain completely in one hour, making minor adjustments to the flow rate of a hose attached to the bottom of the drum.

Several kinds of automatic dispensers have been developed recently but one of the advatages of Bayluscide is that it avoids the necessity for these dispensers. A drum with an attached hose is usually sufficient.

Measurement of discharge in such situations does not have to be very precise. Usually the timed-float method is adequate especially when the overdose technique is being used. The application of an initial concentration 3 to 5 times the toxic dose gives a factor of safety for errors in stream flow measurement.

Irrigation Systems

Mollusciciding in large irrigation schemes is very costly because of the large flows and the large amounts of chemical required. Labor costs become less important than in natural streams, especially if the velocity in the irrigation canal is above 10 or 20 cms/sec, thus transporting the applied chemical for 9 to 18 kilometers in one day.

If the irrigation canals flow at very slow velocities, such as the dead end situations in some ancient canal systems there is little transport of the chemical and the process should be handled as a standing water application.

Because of the expensive chemicals involved, both the measurement of the canal flow and the control of the chemical discharge must be accurate. For this reason it is necessary to use fairly sophisticated dispensing devices, and to make repeated measurements of canal and dispenser flows. Various kinds of constant-flow dispensers can be used, or manual adjustments can be made at 30 minute intervals to insure a steady rate of discharge: Usually in an irrigation system the owners can supply flow figures for the canals and dosages can be calculated on the basis of these flow measurements. If the authority cannot provide accurate measurements then current meters should be used to gage the flow, or a hydraulic engineer can determine the flow as it passes over certain structures such as spillways or weirs. The timed-float method is not sufficient for measurements in large irrigation canals.

If a primary canal is unlined and has velocities suitable for snail colonization below 30 cms/sec it will undoubtedly be an important snail habitat and probably also be a transmission site. Thus the need for regular mollusciciding is evident. This will have to be continually repeated unless the reservoir is freed of snails. Fast-flowing canals with concrete-lining not only are poor habitats but are also difficult for human access thus reducing their importance as transmission foci.

In some schemes no molluscicides have been applied to the high canal, instead they begin the molluscicide application at the off-take gates which also mark the begining of suitable habitat conditions for the snails. The application to these secondary canals can be timed to also treat equalizing reservoirs downstream by begining the application when the reservoirs are nearly empty, thus filling them with the molluscicide solution which has passed down the secondary canal.

In the case of well-maintained, lined canals the difficulties of dispersion, so pronounced in natural streams, do not present a problem. A single application is sufficient to control the snails and spraying of the shoreline is not necessary. If deposits of mud and debris are common in the canal a second application should be made two weeks after the first to kill the snails which might have been temporarily protected.

Wetlands

Some species of snails colonize wetland areas which have low depths of water in the presence of heavy vegetation. Although molluscicides can be used effectively in these wetlands it is invariably more sensible to improve the drainage network by ditching or by other methods requiring a minimum of maintenance. It is possible to determine the desirability of drainage works simply by calculating the annual cost for construction and maintenance of the drainage system and comparing it with the annual cost of mollusciciding In such areas the mollusciciding will have to be repeated every year at about the same level The seasonal requirements and timing should be worked out carefully to get maximum impact of the molluscicide A simpler rule of thumb would be to expect to molluscicide every two months during the breeding season

Thus the cost for Bayluscide control for <u>Biomphalaria glabrata</u> in Puerto Rico for swamps with year-round water and temperature favorable for breeding would be

six applications at $0.5 \ \frac{mg}{L} \times 10{,}000\ m^2 \times 0.1 m$ depth $\times$ \$13/kg ai

$6 \times 0.5 \times 1000 \times \frac{\$13.00}{1000} = \$39$/hectare annual cost

of chemicals The labor cost depends on the method of application In most cases it must be done on foot If a sprayman in Puerto Rico covered one hectare per two hours with a wage of $1.00/hr the labor cost would be $2.50 per hectare. Thus the annual cost for mollusciciding the swamp would be $41.00 per hectare, providing a comparison for any proposed ditching or drainage system The beneficial aspects of land reclamation should also be deducted from the cost of the drainage works before making the comparison but it may be offset by the annual cost of mollusciciding in the drainage ditches since they usually become good snail habitats. As a general rule, the reclamation of the land by drainage is always a better approach than using chemicals for wetlands.