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SEASONAL STUDIES ON *AUSTRALORBIS GLABRATUS* SAY FROM TWO LOCALITIES IN EASTERN PERNAMBUCO, BRAZIL (1)

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Extensive field observations were made, on *Australorbis glabratus* living in a variety of natural habitats in Eastern Pernambuco, Brazil, a well-known endemic center for schistosomiasis mansoni which is transmitted by that species. It was expected that information from these studies might be used to improve our understanding of the epidemiology of schistosomiasis and to devise better methods for the control of the snail vectors of the disease.

In Eastern Pernambuco most of the annual rainfall occurs during a rainy season extending from March or April to July or August. The average annual rainfall (14 years) is about 1700 mm. The average monthly rainfall for the months of March through August are as follows: 156 mm. 253 mm. 374 mm. 293 mm. 215 mm. and 161 mm. Throughout the remainder of the year the average monthly rainfall ranges from 26 to 66 mm. As a result of this

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(2) U. S. Department of Health, Education, and Welfare, Public Health Service, National Institutes of Health, National Microbiological Institute, Laboratory of Tropical Diseases, Bethesda, Maryland.

(3) Serviço Nacional de Malária do Departamento Nacional de Saúde, Brasil.

marked seasonal rainfall cycle, there is an annual wet season in which the water table is very high, the streams are full, and there is much standing water in low areas. This alternates with a dry season in which the water table falls, the streams become shallow or dry up, and there is little standing water. As a consequence, many of the natural habitats of *A. glabratus* are dry during a substantial part of the year.

The snails were studied in both temporary and permanent habitats, but the former produced more clear-cut and useful information. Detailed information from two such habitats will be presented below. The data did not differ significantly from observations made in the other temporary habitats and may be taken as typical.

METHODS OF STUDY

The procedure for field study of these areas consisted essentially of making repeated observations and collections over a long period of time. During the wet seasons snail collections were made by the use of round, sheet-metal, dipper-shaped sieves about 20 cm. across the top, about 15 cm. across the bottom ,about 20 cm. deep, and with holes in the bottom about 3 mm. in diameter. The sieves were mounted on wooden handles about one meter long. Such a sieve is strong and is large enough to permit sampling a large area in a short time. The size of the holes permits the rapid release of water. On the other hand, small snails under 3 millimeters in diameter can not be collected with accuracy. This fact did not seriously affect the results of the study but must be taken into account in evaluating the collection records for small snails. For some of the wet season collections made in Paulista, a method was used which permitted calculation of the number of snails collected per man per minute (Olivier and Schneiderman, 1956). This permitted direct comparison of serial collections made in the same place. Snails collected from the water were always returned to the water after measurement, except that occasionally a small sample was brought into the laboratory for preservation or further study. During the dry season collections were made from the soil, vegetation, and debris in dried habitats.

The snails of all collections were measured. The maximum diameter of each shell was determined to the nearest millimeter by the use of a wooden block on which was mounted a millimeter scale with a barrier at one end against which the shell could be held. This method is rapid, easy, reasonably accurate ,and suitable for use in the field. Suture whorl counts were made on many of the shells that were brought into the laboratory for study. The length of the suture was measured to the nearest tenth of a whorl starting at the apex. Some error was inherent due to the fact that the origin of the suture cannot be determined with a high degree of accuracy. Nevertheless, it was felt that indication of the whorl count to the nearest tenth was justified. Two persons recorded the whorl counts for a large series of *A. glabratus,* and they seldom differed by more than one tenth of a whorl.

OBSERVATIONS ON *A. GLABRATUS* FROM ARRUDA, RECIFE

The first of the two habitats to be considered lies within the limits of Recife in a sector called Arruda. A large drainage ditch running from Agua Fria to the sea flows under the principal street between Encruzilhada and Agua Fria. The collections were taken from a low field, about 50 by 75 meters in size, which lies adjacent to the ditch just upstream from this point.

During the wet season, the ditch, which harbors no *A. glabratus*, is filled with water, and the field is flooded to a maximum depth of about 0.7 meter. The field is almost entirely unshaded by trees, but coarse grass covers part of the area. One end of the area is heavily polluted with effluent from a stable. The field is not directly connected with any other body of water.

At the start of the dry season, the water level of the field falls, and usually by September there is no standing water though the soil may be moist. Later the soil over most of the field dries, cracks, and becomes hard.

The first collections were made during the dry season of 1952-1953. A group of adjacent meter-square quadrats were laid out in each of three parts of the field. Series 1 and 2 were in unshaded areas, and the soil was baked hard and deeply cracked. Series 3 lay in a shaded, moist location with a dense grassy cover. The collection procedure was to examine, systematically, all vegetation and debris in each quadrat and then examine all the soil of the quadrat to a depth of three centimeters. All the shells found were brought to the laboratory where the living snails were sorted out and measured.

On November 28, 1952, two men searched one quadrat in each series, and in a collection of 197 shells, they found 117 living snails, most of which were very small. All were found at the soil surface in the shade of living or dead vegetation. None was found in the soil.

On December 29, two quadrats in each series were searched for snails in the same way, and among 220 shells collected, there were 39 living snails. Two additional quadrats in each series were examined on January 29, February 28, and March 27, 1953. The numbers of living snails found were as follows: January, 16 of 208 shells; February, 14 of 128 shells; and March, 1 of 110 shells. The diameters of the living snails ranged from 1 to 23 mm. but 57 per-cent of the snails were 1 to 4 mm. in diameter while the remainder were scattered among the other diameters. The collections from the three series did not differ significantly with respect to the numbers of living snails found, sizes of snails, etc.

The first heavy rains of the 1953 wet season fell in the week of April 16 (76 mm.) and were followed the next week by 158 mm. These rains flooded all low areas in the vicinity of Recife. On April 30, the water was 30 cm. deep in the quadrat areas sampled during the dry season.

The first collections from the water were made from May 4 to 7 at which time the snails were found to be relatively scarce. The diameters of these snails and those of all subsequent collections from this place are presented in Table 1. Seventy-six snails of the May 4 collection were examined in the laboratory. It was found that each shell consisted of a central portion which was hard, thickened, and usually deeply colored and a terminal portion that was fragile, thin, and usually light colored and set off from the central portion by a ridge so that the two portions of the shell were readily distinguishable. The snails averaged 13.5 mm. in diameter (range 7 to 18 mm.) and averaged 4.7 suture whorls (range 3.6 to 5.7). The central portions of the shells averaged 2.3 suture whorls (range 1.2 to 5.2). The diameters of the central portions could not be measured with accuracy, but they were estimated to range from 2 to 5 mm. The thin outer portion of the shells averaged 2.4 whorls (range 0.2 to 3.4).

It was concluded that the thickened, rough shell material at the center of the shell disc was old and represented the size of the snail at the time the pool became flooded. The thin, terminal portion of the shell was considered to be new shell material that had been added after the pool had become flooded. Based on these assumptions, it could be concluded that all the snails of the May 4 collection had survived the dry season as very small specimens and had made very rapid growth in the short period since the pool had become flooded.

The May 16 collection substantiated the conclusions based on the May 4 to 7 collections. Fifty-one shells averaging 17.3 mm. in diameter (range 10 to 21) were examined in the laboratory. Again, all the shells consisted of an old, thickened, rough ,central portion, usually very small, and a large outer portion consisting of thin, fragile, transparent material. The former had an average of 2.4 whorls (range 1.3 to 4.3) while the latter averaged 2.8 whorls (range 1.4 to 3.8). It was apparent that all the snails of this collection had survived the dry season, usually as very small snails, and that they had grown rapidly since the pool had flooded. Between May 4 to 7 and May 16 the average snail diameter had increased 3.8 mm, and the average whorl count had increased from 4.7 to 5.2. Some of the snails had added 3.8 whorls of new growth in this short period. The amount of new growth added between May 4 to 7 and May 16 was also measured in another way. Ten snails of the May 4 to 7 collections with 1.8 to 1.9 whorls of old shell averaged 3.1 whorls of new shell. On May 16, ten snails with the same amount of old shell averaged 3.7 whorls of new shell, a difference of 0.6 whorls. When 11 snails of the May 4 to 7 collections and 9 of the May 16 collection, all with 2.0 to 2.1 whorls of old shell, were compared, the new shell averages, for the two groups were 3.1 and 3.7 whorls respectively.

The May 25 collection contained large snails 12 to 24 mm. in diameter which resembled those of the two previous collections in that they had small old shells with much superimposed new growth. Sixteen of these snails, averaging 19.2 mm. in diameter (range 15 to 24), had an average of 2.2 whorls (range 1.1 to 3.1) of old shell and 3.3 whorls of new shell (range 2.5 to 4.6). This collection also contained many snails, ranging up to 15 mm. in diameter and 5.0 suture whorls, whose shells were entirely thin and fragile and showed no evidence of a thickened old shell at the center. These snails were considered members of a new generation derived from eggs laid, after the pool flooded, Table

Numbers of snails in successive collections

Date	Diam														
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
May 4, 7, 1953					1	4	10	3	11	18	27	20	27	18	1
May 16								2	7	3	17	10	12	34	4
May 25			8	17	12	15	7	10	8	11	12	5	2	7	4
June 5	8	28	34	44	69	89	80	88	43	55	22	34	11	15	6
June 16		2	12	20	28	31	22	17	12	22	25	31	11	15	5
June 30	4	5	3	13	16	34	32	39	58	68	75	74	44	33	11
July 21	2	1	1	1	0	0	0	4	2	6	13	28	39	49	5
Aug. 13							1	1	1	2	3	3	4	6	11
Sept. 3										1	2	4		8	3
Sept. 23									2	2	2	2	4	2	1
April 27, 1954			9	13	13	6	2		2	1	1	2			
May 4								2	1	3	1	4	9	16	3
May 14					3	3	1	1	6	3	15	15	9	10	7
May 24			2	1	6	16	16	10	17	4	8	4	5	3	4
June 7					1	3	3	4	21	10	31	34	22	30	14
June 16									3	3	4	8	6	7	10

by the snails which survived the dry season. The largest of these snails must have grown very rapidly to have achieved such a large size in a little over one month.

Starting with the June 5 collection very large numbers of small snails were collected, and it was noted that the total population of the pool had increased greatly. These small snails grew rapidly, and by June 30, there were relatively few small snails in the collections but many snails from 7 to 15 mm. in diameter. The rapid growth of the snails is also attested to by the fact that in the June 16 collection there were snails up to 29 mm. in diameter which had small, old shells at the center of the disc estimated to be 1.5 to 3.0 mm. in diameter. Thus, these snails grew from less than 3.0 mm. to 29 mm. in about one month. Except for a few in the July 21 collection, very small snails were not found after June 30. Evidently, introduction of new snails into the population did not occur to any great extent during the latter part of the wet season.

The water level in the field fell gradually during September, 1953, and the field was dry in October. The first heavy rains of the 1954 rainy season fell on April 9 to 11 and as a result, the pool was reflooded. On April 15, no snail was found by two men searching for 25 minutes. However, the same men, on April 27, found 49 snails in 35 minutes, an indication of a very low population density. These snails were similar to those found at the beginning of the previous wet season in that they had what was interpreted to be a small old shell to which new shell material had been added. The snails of the May 4, 1954, collection were much larger, and all had much new shell superimposed on very small old shells. Seventeen of these snails, ranging from 14 to 17 mm. in diameter, had old shells with an average of 2.3 whorls (range 1.9 to 3.7) and new shell material averaging 3.5 whorls (range 2.1 to 4.1).

A few of the smallest snails in the May 14 collection were apparently those of a new generation produced by the older, larger snails since the pool flooded. On May 24, all of the small snails were of the new generation, and all of the large snails were obviously of the old generation. The ranges overlapped at the level of 12 to 13 mm. In the June 7 collection only a few of the largest snails, 23 to 26 mm. in diameter, were of the old generation, and the snails of the new generation ranged up to 19 mm. in diameter (5.7 whorls).

In summary, it may be said that at the start of the wet season the snails that survived the dry period were usually very small specimens, few in number. These grew very rapidly and soon produced a new generation of snails, some of which reached a diameter of 19 mm. within 7 weeks after the pool flooded. The old snails reached maximum size in about two months after the flooding of the pool and tended to disappear late in the rainy season. The snail population seemed to reach its maximum density during the first half of the wet season, since new snails did not appear in the collections made late in the wet season.

Table 2

llections of *Australorbis glabratus* from

n Paulista, Pernambuco

)iameters of snails in millimeters																		
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Total	Mean (mm)
																	49	
8	4	2				1											151	
6	8	9	5	7	4	7											328	
22	24	11	17	6	3	2	3	4									441	12.0
10	32	30	12	20	8	5	3	5	6	2							612	13.0
18	38	24	9	19	1	1	1										351	14.5
44	41	29	28	20	15	14	7	4	1								322	16.6
18	22	21	28	37	33	42	28	22	13	3	8						314	19.8
2	3	8	13	21	34	38	42	33	28	29	14	9	2	2	1		283	22.9
3	8	7	7	25	30	34	22	16	27	6	5	1	1	1	2		195	22.2
				12	20	34	39	58	41	17	27	21	6	5			280	24.3
	1	3	2	2	6	2	8	5	13	9	6	8	5	2	1		74	24.6
		2	2	2	1	3	7	5	5	3	3	8	4	4	1		64	
2	2	3	2	2	3	3	4	3	3	1	2	1	2	1		1	49	
2		3	4	4	1	5	6	10	6	2	2	2			1		49	
		1	4	6	2	5	2	1	6			1					31	
	1	1	2	4	1	11	7	8	18	19	8	5	2	3	2		246	
13	12	7	12	14	5	5	4	2	7	4	2	1		1	1		699	9.6
11	8	3	2	3		1		2	1	4							291	12.1
29	39	25	19	18	3	5	1	2	1	4	1		2				269	16.9
12	28	23	18	22	7	10	4	3	1								234	15.9
36	34	34	31	27	2	4	2	2									257	16.6
																	5589	

by the snails which survived the dry season. The largest of these snails must have grown very rapidly to have achieved such a large size in a little over one month.

Starting with the June 5 collection very large numbers of small snails were collected, and it was noted that the total population of the pool had increased greatly. These small snails grew rapidly, and by June 30, there were relatively few small snails in the collections but many snails from 7 to 15 mm. in diameter. The rapid growth of the snails is also attested to by the fact that in the June 16 collection there were snails up to 29 mm. in diameter which had small, old shells at the center of the disc estimated to be 1.5 to 3.0 mm. in diameter. Thus, these snails grew from less than 3.0 mm. to 29 mm. in about one month. Except for a few in the July 21 collection, very small snails were not found after June 30. Evidently, introduction of new snails into the population did not occur to any great extent during the latter part of the wet season.

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In summary, it may be said that at the start of the wet season the snails that survived the dry period were usually very small specimens, few in number. These grew very rapidly and soon produced a new generation of snails, some of which reached a diameter of 19 mm. within 7 weeks after the pool flooded. The old snails reached maximum size in about two months after the flooding of the pool and tended to disappear late in the rainy season. The snail population seemed to reach its maximum density during the first half of the wet season, since new snails did not appear in the collections made late in the wet season.

SEASONAL STUDIES ON *A. GLABRATUS* IN PAULISTA, PERNAMBUCO

The second habitat in which *A. glabratus* was studied is near Paulista, Pernambuco. Paulista, lying on the highway between Recife and João Pessoa, has been known to be an important endemic focus of schistosomiasis for many years, and a large proportion of the human population is infected.

One of the most important habitats for the snail vectors in the Paulista area is immediately adjacent to the town and within 100 meters of the main street near the school. The habitat is a small, low valley about 50 meters wide and 200 meters long lying between low hills. A large drainage ditch running through the valley is flanked by high banks apparently formed from the soil dug out to make the ditch. Behind these banks lie small, grassy fields cut off from the main ditch by the high banks and separated from each other by low earthen dikes.

The rainfall and seasonal water level cycles in Paulista are the same as those described for Arruda. During the wet season the water table is very high and water stands in the drainage ditch and in all the adjacent fields. Because of the ditch banks and the dikes, a separate pool forms in each field cut off from the ditch. Coarse grass and water plants grow profusely in the flooded fields, and all the fields harbor *A. glabratus* though the ditch does not.

In the dry season all the pools become dry and remain so for 5 to 7 months, but the soil remains humid in some parts of the fields. All the fields lie in the full sun, and all receive effluent from homes and stables nearby.

Four of the fields were chosen for special study. The pools of fields 1 and 2 are separated from one another and from all other pools. The pools of fields 3 and 4 become joined together when the water level is very high. The observations made on one of the four fields will be presented in some detail. The observations made in the other three were in essential agreement with those made in the first field, and so they will be presented in briefer form.

Field 1.

This field is about 50 meters square and during the wet season it contains a pool about 30 by 20 meters and about 0.5 meters deep.

The first collection from this locality was made on October 24, 1952, near the end of the wet season. Only large snails 27 to 31 mm. in diameter were collected. During November, the pool lost its water, and on November 24, there was no standing water, though the soil was quite moist. At this time no living snails were found in the plant debris or on the soil surface. On March 19, 1953, 5 meter-square areas in the lowest part of the field were searched for living snails by removing all the vegetation and debris and the top centimeter of soil and sifting these through a fine screen. No living snail was found. This is taken to indicate that the number of living

Data from successive

Field

Date	2	3	4	5	6	7	8	9	10	11	12	13	14	1[illegible]
May 8, 1953				4	4	11	9	6	5	6	2		2	
May 27			7	18	14	13	6	10	7	13	13	16	10	[illegible]
June 6	8	12	22	15	19	27	26	36	27	25	24	21	10	[illegible]
June 18		6	10	14	19	27	28	23	17	35	31	60	38	[illegible]
July 1			5	10	23	33	26	30	39	53	66	75	46	[illegible]
July 13			1	1			6	3	15	17	37	47	55	[illegible]
July 30		1						1	7	11	8	21	33	[illegible]
Aug. 19								3	3		4	9	12	[illegible]
Sept. 14												2	1	
Oct. 8														
Nov. 4														
April 20, 1954														
April 29						1	2	3	2	2	2		1	[illegible]
May 3											3	5	5	[illegible]
May 13														
May 19					1	1	1							
May 28		1	5	13	27	35	12	4	27	1	17	4		[illegible]
June 4	22	57	29	55	55	83	69	30	56	23	43	37	18	[illegible]
June 14				4	5	12	11	22	45	17	60	48	16	[illegible]
June 28					4	4	3	4	8	4	15	22	18	[illegible]
July 7					3	3	2		7		25	18	19	[illegible]
July 15									6	2	16	18	8	[illegible]

snails in the field was very small, and that the collecting method was not adequate to find them.

The field became flooded between April 20 and 25, 1953, and living snails were found in the first collection of the season made on May 8. The diameters of these snails and all others collected from this locality are presented in Table 2.

The snails collected on May 8 were relatively small, and it was noted that all the shells consisted almost entirely of new growth which was thin, smooth, and fragile. However, at the center of the shell one could readily see a very small, old shell which was thick, opaque, rough, and usually of a darker color than the remainder of the shell. The juncture of this old shell with the new shell deposit was always distinct and was usually marked by a ridge. The average size of the old shell was 1.7 whorls (range 1.2 to 2.5, and the estimated diameters of these old shells ranged from 1.5 to 3.0 mm. and averaged 2.1 mm. The new shell material averaged 2.3 whorls (range 1.6 to 3.2).

It was concluded that these snails had passed the dry season as very small specimens, and that on the return of water the snails had grown very rapidly adding much new growth before they were collected on May 8, about 15 to 25 days after the first heavy rains.

On May 27, the snails were still very scarce, and all the largest snails collected had shells consisting of much new growth superimposed on a small old shell. On the other hand, all the smallest snails had shells consisting entirely of new growth, and it was concluded that these small snails were derived from eggs laid after the return of water by the few snails which survived the dry season.

The sizes of the snails in the other 1953 collections can best be followed in the table. On June 6 and 18, there were many small snails of the new generation, and the impression was gained that the total snail population in the pool had increased greatly. In July, August, and September, the average snail size shifted steadily upward. Apparently few new snails entered the colony during July and August since few very small snails were encountered in the collections after July 1. This is especially noteworthy since, on July 30, enormous numbers of *Australorbis glabratus* eggs were seen on the lily pads in the pool and yet no new generation of snails appeared in the following weeks. Either the snails failed to emerge from these egg masses or the snails, once they emerged, failed to survive and take their place in the colony.

In November, almost all the snails were very large and the pool dried rapidly. During the dry season, the lower parts of the field were covered with a dense mat of grass, roots, and organic debris. The soil remained moist and numerous living snails were found on the soil throughout the dry season. No small snails were found, and no snails were found in the soil.

The pool became flooded between April 10 and 15, 1954, and the first collection from the pool was made on April 20. On this date the snails were scarce as indicated by the very small number collected, and they were all large, old specimens. On April 29 a few small specimens were found and these had small, old shells with much new growth superimposed while the larger specimens found along with them were old and had almost no new shell material. The same situation obtained on May 3. All the smaller snails, from 12 to 17 mm. in diameter, had from 2.4 to 3.3. whorls of new shell growth superimposed on 1.7 to 2.8 whorls of old growth while all the large snails had old shells with almost no new growth.

Apparently both large and small snails survived the 1953-1954 dry season in this field.

On May 19, three small shells, consisting entirely of new shell material, were found. These were the first collected specimens of the new generation produced by the snails that survived the dry season.

On May 28, there were very many small, new snails in the collection. This trend was followed in the June 4 collection and the average size of the snails increased steadily. Again, there were few small snails in the collections made after the entrance of the large new generation into the colony.

The July 15 collection contained only two snails, 23 and 24 mm. in diameter, that had survived the previous dry season. All the other snails were of the new generation.

Field 2.

This field is about 8 by 16 meters in size and during the wet season, it contains a pool about 6 by 8 meters in size and up to 30 cm. in depth. Twenty-four collections, totaling 6,345 snails, were made between May 9, 1953 and July 15, 1954. Ten of these collections are plotted in Figure 1 to show the size trends of the snail population. The numbers of snails are expressed as percentages of the total collected that day.

The first collection included snails 16 to 21 mm in diameter, which were obviously old and had little new shell material, and a few snails which had 1 or more whorls of new shell superimposed on small, old shells estimated to be 1 to 3 millimeters in diameter.

On May 20, the snails were still in two distinct size groups. The larger snails averaged 20.9 mm. in diameter and had an average of 0.5 whorls of new shell superimposed on old shells averaging 5.4 whorls in size. The smaller snails, belonging to the new generation, averaged 5.5 mm. in diameter and 3.2 whorls.

On May 27, the size distribution curve of the snails collected was still bimodal, but the snails of both groups were larger. All the snails from 2 to 13 mm. in diameter were young and all above 15 mm. were old.

The collections from May 20 to September 14 inclusive showed the appearance of a large new generation of young snails and the steady growth of these snails. It should be noted again that few recently hatched snails were collected after July 1.

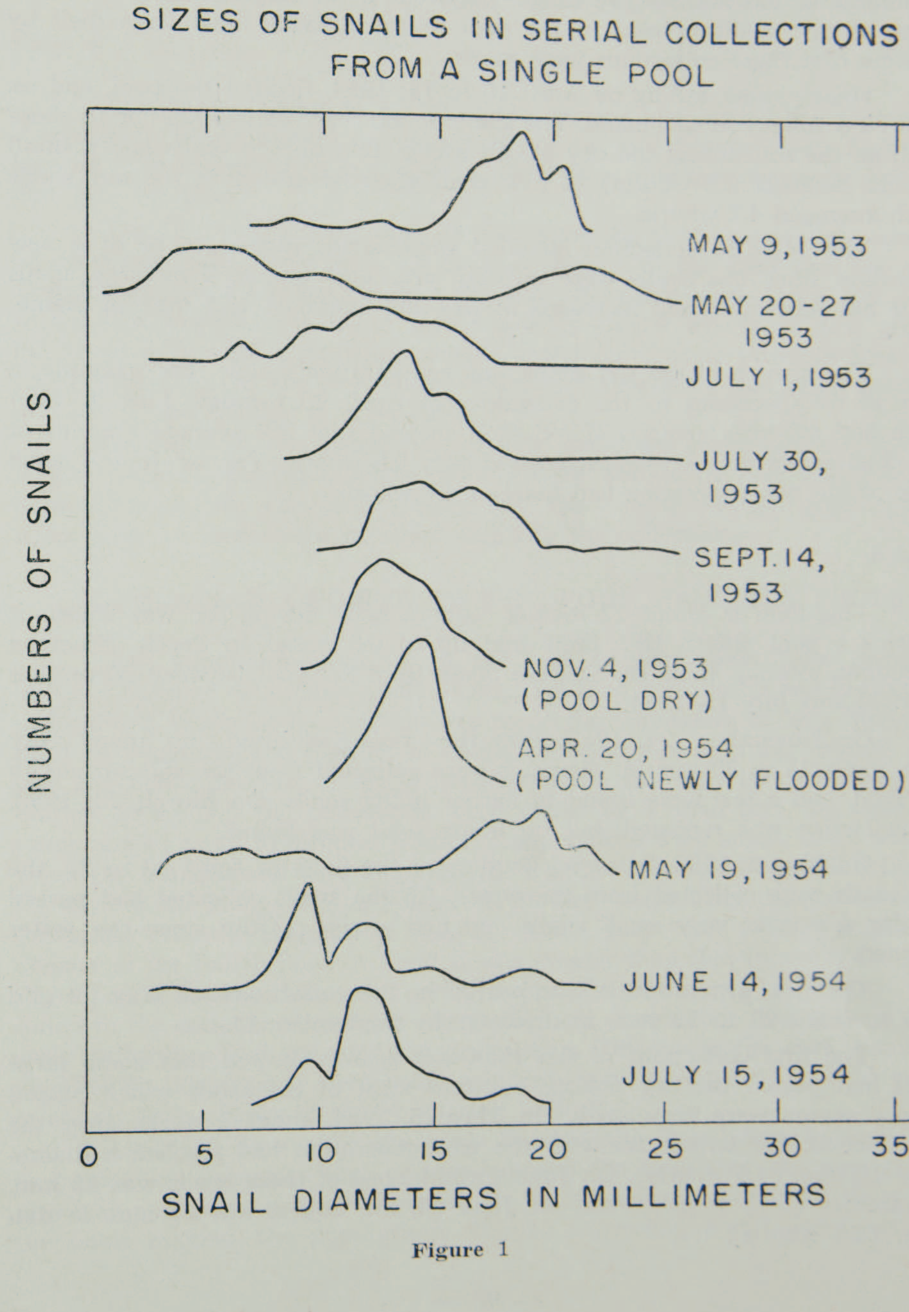
SIZES OF SNAILS IN SERIAL COLLECTIONS
FROM A SINGLE POOL
NUMBERS OF SNAILS
MAY 9, 1953
MAY 20-27
1953
JULY 1, 1953
JULY 30,
1953
SEPT. 14,
1953
NOV. 4, 1953
(POOL DRY)
APR. 20, 1954
(POOL NEWLY FLOODED)
MAY 19, 1954
JUNE 14, 1954
JULY 15, 1954
0
5
10
15
20
25
30
35
SNAIL DIAMETERS IN MILLIMETERS

Figure 1

The snails collected on October 14, November 4, 1953 and January 7, 1954 were taken during the dry season from the surface of the moist soil in the lowest portions of the field. All the snails in these collections were near the middle of the normal size range. Apparently, the largest snails, which includes all the snails present in the pool in April, 1953, must have died by the time that these collections were made.

Heavy rains, falling on April 10 to 15, 1954, flooded the pool, and on April 20 a collection was made. The snails found were closely similar to those found on the soil during the dry season except that all the snails had a small amount (average 0.6 whorls) of new shell material added to the old shells which averaged 4.2 whorls.

The May 13 collection included small snails judged to be of a new generation since the shells were entirely new and fragile. The large snails of the old generation had increased in size and averaged 17.1 mm. in diameter.

The growth of the old snails was comparatively slow. For example, a study of 67 specimens in the collections of April 20 through June 4, 1954 which had 4.5 to 4.7 whorls of old shell showed that the average amount of new shell added during that period was only 0.5 whorls. Yet, on June 4 some snails of the new generation had reached 4.7 whorls.

Field 3.

This field is about 12 meters square and during the wet season it contains a pool almost that large and up to 0.5 meter in depth. Nineteen collections, totaling 4,795 snails, were taken from the pool between November 24, 1952 and July 15, 1954.

On November 24, 1952, after the pool had dried up, many very large shells 25 to 30 mm. in diameter were collected from the soil surface in this field, and a few were found to harbor living snails. On March 23, 1953, the collection was repeated, but no living snail was found.

On May 8, 1953, following flooding of the field on April 20 to 25, the first snails were collected from the water. All the snails collected had passed the dry season as very small snails and had grown rapidly since the water returned.

The new generation first appeared in the collections on May 20 and grew to reach 22 to 28 mm. in diameter by September 14.

The first collections of the 1954 wet season showed that some large snails had passed the dry season, but that most of the snails which passed the dry season were very small. On May 28, 1954, about 7 weeks after the pool flooded, the largest snails of the new generation had reached a diameter of 15 mm. (4.6 whorls). On June 4, the largest of these snails was 18 mm. in diameter (5.4) whorls), and on June 14, the largest was 21 mm. in diameter (6.4 whorls).

The population of the pool did not become large until about the first of June when very large numbers of new snails were collected. After that date the population density remained high. In the last collections, only a very small proportion of the snails collected were of the old generation.

Field 4.

This field is about 15 by 20 meters in size, and during the wet season it contains a pool about 10 meters across and up to 0.5 meter deep. Eight collections, comprising 1,883 snails, were taken from this field between April 29 and July 14, 1954.

The first collection, made 19 days after the first heavy rains, contained only large, old snails with 4.9 or more whorls of old shell and not more than 0.6 whorls of new shell growth. On May 19, there were large, old snails with 5.0 or more whorls of old growth and up to 0.9 whorls of new growth, but there were also many small, fragile snails showing no evidence that they could have survived the dry season. These had reached a maximum diameter of 13 mm. and had up to 4.7 whorls.

On May 28, the proportion of new snails was much greater and the largest were 15 mm. in diameter and had 4.8 whorls. In June and July, the population density increased greatly and the new generation grew rapidly. After June 14 there were no small snails in the collections.

POPULATION GROWTH IN THE FOUR PAULISTA POOLS

The population densities of the four Paulista pools were measured in the successive collections made during the 1954 wet season and are plotted in Figure 2. When each collection was made the population density was measured by recording the number of snails collected per man per minute (Olivier and Schneiderman, 1956). For convenience, this may be called the Population Index. All the collections were made by 1 man and the collection times ranged from 30 minutes when the populations were small, to 10 minutes when the populations were large. It will be seen that the Population Indices for three of the pools were very small in the first weeks after the pools flooded, indicating that the population densities were very low. The population density of the fourth pool, in Field 2, was greater than that found in the other three pools. During this early period, no snails of the new generation were found in the collections, and the conclusion was drawn that the snails in these early collections had survived the dry season. This being the case, relatively unchanging populations were being sampled, and therefore one would expect relatively little change in the Population Indices.

About 35 days after the pools flooded, the Population Indices in all four pools rose sharply. This occurred during the time that the new generation was appearing in the collections in large numbers. About 50 days after the pools flooded, the populations stopped increasing and leveled off. The

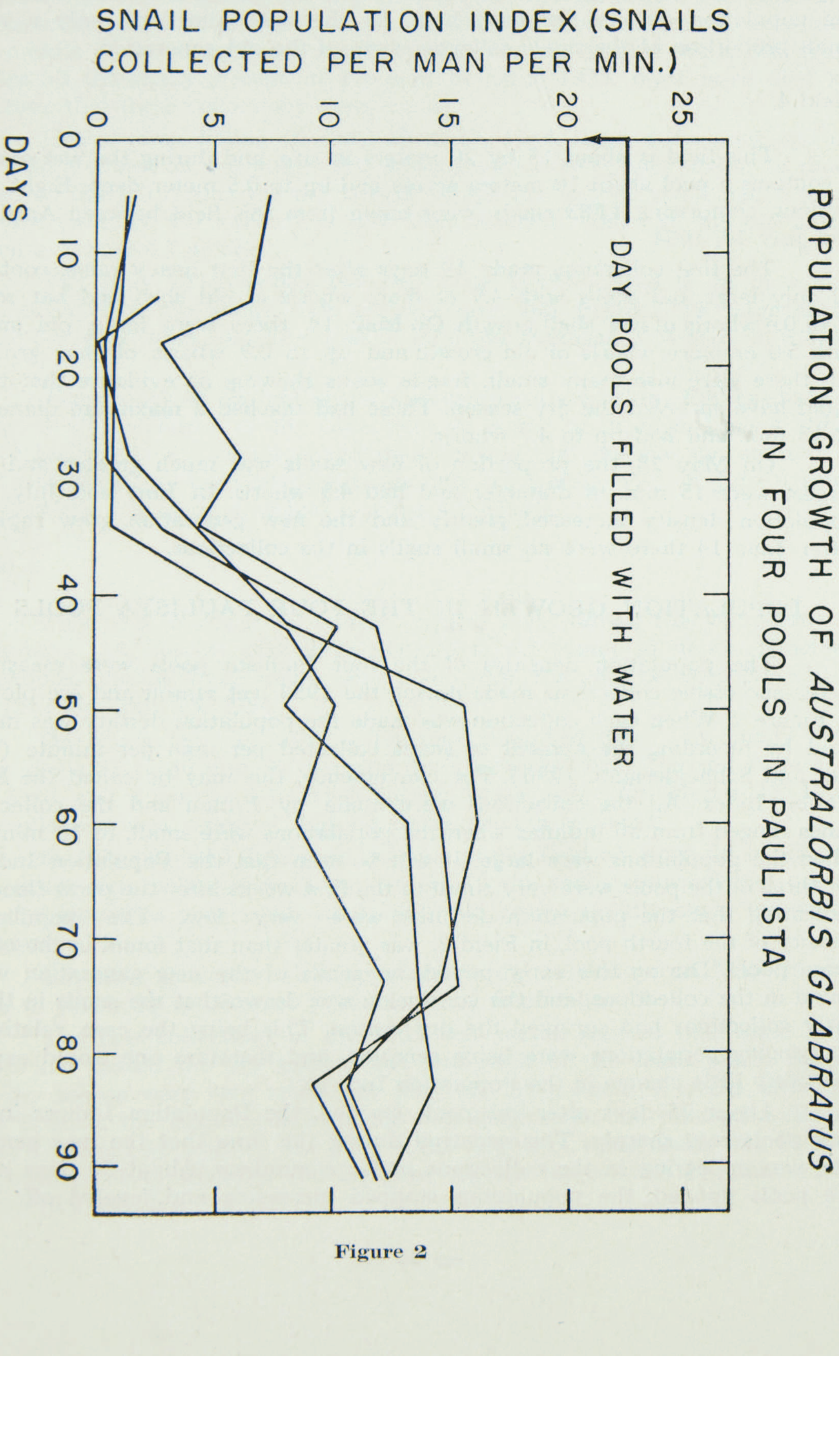
POPULATION GROWTH OF *AUSTRALORBIS GLABRATUS* IN FOUR POOLS IN PAULISTA
SNAIL POPULATION INDEX (SNAILS COLLECTED PER MAN PER MIN.)
0
5
10
15
20
25
DAYS
0
10
20
30
40
50
60
70
80
90
DAY POOLS FILLED WITH WATER

Figure 2

average population increase for three of the pools was about 10 to 15 fold, while the increase for the remaining pool was about 2 to 3 fold.

NOTES ON THE GROWTH RATE OF SNAILS FROM A NATURAL POOL.

Some of the data just presented attest to the rapidity with which *A. glabratus* may grow. Additional evidence concerning the growth rate of this species in the field was obtained from the study of a small pool in Espinheiro, Recife. The data are presented here as a supplement to the other records on snail growth.

The pool, about 5 meters in diameter and up to 0.5 meter in depth, became flooded in late April, 1953. Collections were made from the pool on May 7, 19, and 28. Examination of these snails demonstrated that every snail collected was a survivor of the dry season, and that a new snail generation was not yet appearing in the collections. Therefore, the snails in the three successive collections were samples from the same population, and the collections are comparable.

The mean diameters and ranges of the snails in the three collections were as follows:

May 7 Mean 10.0 mm. (S. D. 1.36) (162 snails)

May 19 Mean 12.7 mm. (S. D. 1.47) (275 snails)

May 28 Mean 15.4 mm. (S. D. 1.47) (241 snails)

Thus, in the space of 22 days, snails from the same population increased an average of over 5 millimeters in diameter. From unpublished records on *A. glabratus* taken from other localities in Recife, it is estimated that this difference in diameter represents a growth from about 4.8 whorls to 5.8 whorls or an average of about one whorl per snail.

OBSERVATIONS ON *A. GLABRATUS* LIVING IN HABITATS THAT NEVER DRY

Although they will not be reported here in detail, extensive observations were also made on *A. glabratus* living in bodies of water that never dry up. It was found that reproduction of the snails in these habitats was continuous throughout the year. However, there were marked fluctuations in the proportion of young to old snails and in the population density. These fluctuations did not appear to depend upon the season, temperature, or rainfall, and their cause is unknown. Occasionally, the snail population densities in certain habitats fell suddenly to a very low level. The causes for these population crises were not apparent but perhaps they resulted from epidemic disease among the snails, from chemical changes in the water, or from changes in turbidity, depth, or rate of flow. The coincidence of such a population crisis with the start of snail control efforts might be very misleading.

The life span of the snails in these habitats could not be determined, but there was no evidence that the snails lived longer than one year.

DISCUSSION

Although pulmonate snails are typically aquatic, certain species have long been known to be able to survive out of water for varying lengths of time. Some of the older literature on this subject, dating back about 100 years, has been reviewed by Shadin (1926), Mehl (1932), Cheatum (1934), and Precht (1939). Recently Shadin (1926) described observations on pulmonate and branchiate species living in temporary ponds in Russia. He found that some pulmonate species such as *Lymnaea palustris* and *Planorbis planorbis* could survive in habitats that were without standing water for almost 300 days of the year, including about 130 days when the dry pools were under snow. He found that the snails remained under dead grass, and some secreted a film in the shell opening which might have protected them from desiccation. He also noted that some of the snails buried themselves to a depth of 2 to 5 millimeters in the soil, but he did not specify whether these were pulmonate or branchiate snails.

Kolpakov (1929) conducted studies similar to these of Shadin and found that the pulmonates, *Planorbis corneus, P. planorbis, P. vortex, P. leucostoma, Lymnaea stagnalis,* and *L. palustris* were able to survive long periods out of water. He reported that *P. corneus* could bury itself in the mud to a depth of 1 to 5 centimeters, that some snails secreted a film in the opening of the shell, and that others crept under the protection of vegetation. However, some of the snails remained on the surface of the soil and were able to survive the dry season without any of these protective devices.

Mehl (1932) found that *Lymnaea truncatula* could live out of water in the field for 4-1/2 months, and Cheatum (1934) reported that 9 species of fresh-water pulmonates survived up to 62 days in a dry beach pool.

Precht (1939) reported that *Planorbis planorbis* lived up to 368 days and *P. corneus* up to 285 days out of water at high relative humidity in the laboratory. On the other hand, *P. vortex, Lymnaea stagnalis,* and certain other species lived only a relatively short time under these conditions.

Olsen (1941, 1944) found that *Stagnicola bulimoides techella* could survive out of water for 169 days under field conditions and 158 days in the laboratory.

The fact that the pulmonate vectors of *Schistosoma mansoni* and *S. haematobium* could survive out of water was first pointed out by Barlow (1933, 1935) working in Egypt. He showed that *Biomphalaria boissyi* and *Bulinus truncatus* could survive the winter closure period of about 30 to 50 days, and he also noted that vector snails in the Sudan survive 2 to 7 months out of water. When he collected the Egyptian vectors from dry habitats and brought them into the laboratory, they lived a total of 4 *(B. truncatus)* and 6 *(B. boissyi)* months without water.

Gordon, Davey, and Peaston (1934) observed that *Biomphalaria pfeifferi* could live for a short period out of water and Annecke and Peacock (1951) reported that *Bulinus tropicus*, but not *B. forskali*, could survive out of water as long as 18 months under field conditions in the Transvaal.

In the Western Hemisphere, Brumpt (1941) was the first to note that *A. glabratus* could live out of water. Later, Barbosa and Dobbin (1952) reported that the same species could survive the long dry season in Northeastern Brazil. These latter authors' observations are confirmed and extended by the present report. Small numbers of snails in all five localities survived the dry season and repopulated the pools when the water returned. The studies reported here were not designed to produce detailed information concerning the conditions under which the snails are able to survive the dry season. Nevertheless, it was observed that living snails could be found at the soil surface in vegetation and among plant debris throughout the dry season, indicating that such locations provide sufficient protection for the snails. When the quadrats in Arruda were examined, it was noted that living snails were not found embedded in the soil, but that they were in cracks in the soil under debris and vegetation. Similar observations were made in the Paulista habitats. Some of the snails secreted fragile membranes in the shell openings. These membranes were always incomplete, but some snails had a series of them, one behind the other.

Although the observations made are not conclusive, the impression was gained that the snails probably do not purposely enter the soil in order to avoid the rigors of the dry season. As the habitats dried, the snails left stranded on the soil surface and in the debris showed no tendency to seek out places still covered with water, nor did they attempt soil penetration. The snails do not have a powerful foot, and they may actually be unable to drag the large shell over the dry soil or into the mud. Since the snails can survive the dry season at the soil surface under favorable conditions, it is not necessary for them to enter the soil for protection. The possibility remains that *A. glabratus* might be able to penetrate a short distance into very soft mud or soil under certain conditions. This subject which requires further investigation, will be dealt with in a later publication.

Some snails undoubtedly become buried in the soil by accident. For instance, they may be pressed into the soil under the feet of men or animals, or they may be covered by silt due to the shift of currents in a stream bed. Such buried snails may live there for a time, but they may not be able to extricate themselves. The recovery of snails from soil or mud is not proof that they penetrated there nor is it any indication that they can leave by their own efforts.

It should be noted that although the snails are able to live long periods out of water, this does not necessarily mean that they can withstand severe desiccation. The *A. glabratus* which survived the dry season in the habitats just described did so in locations which probably had a high relative humidity at all times. Therefore, the surviving snails probably did not lose a large amount of water during the dry season. Although it is not always clear from the descriptions in the literature, it appears that, at least in the majority of cases in which pulmonate snails have been found to survive for long periods out of water, they did so in situations that were relatively moist.

The ability of *A. glabratus* to live out of water for many months and to survive the dry season in Northeastern Pernambuco in the field has great epidemiological significance. The snails are able to inhabit temporary bodies of water which would otherwise be denied to them, and as a consequence, the number of potential foci of schistosomiasis is greatly increased.

The data presented here demonstrate that *A. glabratus* is capable of very rapid growth under field conditions. Small snails which survived the dry season always grew very rapidly, and even those taken in the first collections after the pools flooded had much new shell material superimposed on the old shells. The snails of the new generation grew so rapidly that by the middle of the wet season they had overlapped the size range of the previous generation. In all habitats the snails of the new generation approached maximal size with in the span of 4 months.

The reproductive potential of *A. glabratus* was found to be very great. Observations made during the dry season and in the first weeks after the pools flooded demonstrate that the snail populations become greatly depleted during the dry season, and that the number of snails in newly flooded areas is very small. Yet, during the first half of the wet season the populations in the pools became very large. In the first 35 days after the pools in the Paulista area flooded, the population indices remained very small, but in the next 15 to 25 days the indices increased very rapidly. The resulting population densities appeared to be maximal for the pools. Thus, it seems that within about 50 days the pools, which had harbored relatively few snails, had become saturated with snails.

It was noted that few, or no, new snails appeared to enter the populations of the pools after July 1. This could not be attributed to the failure of the larger snails to lay eggs, since eggs were numerous in at least one of the pools just before the absence of young snails was noticed. Apparently, either the embryos failed to develop or the very young snails died before reaching collectible size. Food supply was probably not the limiting factor here since this seemed to be present in abundance. Natural enemies may have destroyed the young snails. It is also possible that mature snails, if present in large numbers, inhibit, in some way, the development of young snails. This problem deserves special study.

The great reproductive capacity of the snails has a bearing on the problems of snail control. If a snail habitat is treated to kill the snails and some are not killed, the few survivors may repopulate the habitat within a few weeks. This emphasizes the need for highly effective control procedures and points to the great value of snail eradication. But it also means that interruption of transmission of schistosomiasis mansoni by means of snail destruction may require frequent treatments and constant supervision. Consequently, the cost of control measured may be very high in some localities.

On the basis of the observations described herein, it is possible to outline the seasonal cycle of *A. glabratus* in temporary pools in Pernambuco. Five pools furnished the data presented above, but many other typical habitats were also studied. Observations in these other habitats disagreed in no important way with the results obtained in the five pools used as examples. Therefore, the seasonal cycle to be outlined may be taken as typical for *A. glabratus* living under the conditions described.

The seasonal cycle is as follows: At the end of the rainy season, the snails are numerous, and most of them are usually large and mature. When the habitats dry and the snails are left out of water many die within the first few days or weeks. Some probably succumb from exposure to high temperatures and to drying while others are probably eaten by domesticated and wild animals. In any event, living snails are rarely found in exposed locations after the water disappears. Snails that are located in protected places when the water recedes may escape death, at least for a time. In the early part of the dry season, living snails are readily found under living plant material, under debris, and among the stems and exposed roots of plants. Here they are protected from the sun's heat, from excessive drying, and from predators.

As the season progresses more of the snails die and by the end of the dry season only a few snails may be left. The survivors may be small or large, but there is some indication that the smaller snails may be more successful in surviving the dry season.

When the water returns the few survivors grow rapidly, unless they are large already, and soon produce large numbers of eggs. The new snails so produced increase in size and in numbers and within 50 days after the first soaking rains, the snail population may be restored to peak density. After this time the population density remains relatively stable throughout the remainder of the wet season. The snails continue to grow but young snails may not be added to the population during the latter half of the wet season.

It is possible that an occasional snail may go through two dry seasons, but this was not observed. As a rule, snails present at the start of the wet season die during that season or soon after the start of the subsequent dry season. Most of the snails produced in May and June die during the following dry season and so they have a life expectancy of well under one year. Snails that survive the dry season might live up to 15 or perhaps 17 months.

The seasonal cycle of the snails in temporary habitats has an important bearing on the ability of these snails to transmit schistosomiasis. Barbosa and Coelho (1953) and Olivier et al. (1954) have shown that when *A. glabratus* with mature schistosome infections are taken out of water most of the snails die within about 20 days and that the survivors are no longer infected with the larval stages of the trematode. Thus, the snails surviving the dry season cannot be expected to have mature *S. mansoni* infections. However, Barbosa and Coelho (1955) have shown that immature *S. mansoni* infections in *A. glabratus* are not killed when the snails are kept out of water but merely stop developing until the snails are returned to the water. Therefore, snails surviving the dry season in habitats that dry annually may harbor immature infections which may rapidly complete their development when the water returns. Thus, at the start of the wet season, even though the snail population of a temporary body of water is small there may be a carry-over of immature infections. Consequently, some cercariae may be shed into the water within a short time after the water returns. However, development of new infections takes much longer. At least one month is required before snails of a new generation are present in the pool and about one month is required for the schistosome infection to develop after penetration of the miracidium. Thus, aside from infection which may be carried over in the immature state, at least one month must elapse before surviving snails can be infected and produce mature infections and about two months before snails of the new generation can transmit the disease. It is possible, then, that cercariae may not be produced by snails of temporary habitats until two months of the wet season have passed, except for the cercariae produced by snails that carried over immature infections. Since the wet season lasts only five to seven months transmission of infection to humans might occur only during three to five months of the year.

The data presented here have an important significance in the planning of snail destruction campaigns in seasonal habitats. Since the snail population density is very low in the first weeks of the wet season, this might be an excellent time to use a molluscicide against them. Its use at this time might reduce or even prevent transmission of schistosomiasis during the remainder of the wet season.

Since at least some of the snails survive the dry season in debris and vegetation at the soil level, clearing and burning of the vegetation and debris in temporary habitats during the dry season might be effective in reducing the number of surviving snails and might even eradicate them.

SUMMARY

The natural history of *Australorbis glabratus*, a vector of schistosomiasis mansoni, was studied in endemic areas of Northeastern Brazil. This part of Brazil has a marked seasonal rainfall cycle, with a rainy season lasting from March or April to July or August, and a relatively dry season lasting through the remainder of the year. As a result there are many temporary streams and pools which have water only during the rainy season. Nevertheless, *A. glabratus* survives in these temporary habitats passing the dry season out of water on the soil in the protection of debris and vegetation.

The seasonal cycle of the snail in these temporary habitats is as follows: The snails present at the end of the rainy season are left stranded out of water when the water level falls. A small proportion of these snails may survive the dry season if they are in favorable locations. When the water returns the snails rapidly produce a new generation of snails, and the population of the temporary habitats may reach a maximal level 50 to 60 days after

the first heavy rains. The snails grow rapidly and mature before the end of the rainy season. Under these conditions, the life span of most of the snails is less than one year, and the maximum life span is probably not more than 15 to 17 months.

In permanent bodies of water, the snails reproduce throughout the year, but there may be marked fluctuations in reproduction and in population density without known cause.

Since the population density of temporary bodies of water is lowest at the start of wet season, this may be the best time to attempt snail control by chemical means.

Transmission of schistosome infection by snails living in habitats that dry annually is, perforce, limited to a relatively short part of the year.

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SUMÁRIO

Foi estudado o ciclo biológico de *Australorbis glabratus*, conhecido vetor da esquistossomose em áreas endêmicas do Nordeste do Brasil. Nesta região existem duas estações bem pronunciadas, a estação chuvosa que vai de março ou abril a julho ou Agosto e a estação sêca que compreende o resto do ano. Em consequência, existem numerosos riachos e alagados que secam completamente durante a estação sêca. No entanto, *A. glabratus* sobrevive nestas coleções temporárias d'água, passando a estação sêca sob a proteção de resíduos ou vegetação.

O ciclo estacional de *A. glabratus* nestes criadouros temporários é o seguinte. Os caramujos que estão vivos ao fim da época das chuvas, ficam sob o solo quando a água desaparece. Em lugares favoráveis, uma pequena proporção dêstes moluscos consegue sobreviver à estação sêca. Quando chegam as chuvas enchendo os criadouros, os caramujos produzem ràpidamente uma nova geração e a população dêstes locais atinge o máximo aos 50 ou 60 dias depois das primeiras chuvas pesadas. Os caramujos crescem ràpidamente e estão maduros antes do fim da estação chuvosa. Nestas condições, a duração média de vida dos caramujos é menor do que um ano e a máxima não é superior a 15 ou 18 mêses.

Nos criadouros permanentes os caramujos reproduzem-se durante tôdo o ano, porém, por motivos desconhecidos, existem nítidas flutuações quanto à reprodução e à densidade populacional.

Desde que a densidade populacional dos criadouros temporários é baixa no início da estação sêca, esta seria a ocasião propícia de tentar o contrôle dos caramujos com moluscocidas.

A transmissão da esquistossomose por caramujos que vivem em coleções temporárias d'água está, òbviamente, limitada ao curto período durante o ano quando os criadouros estão cheios.

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