Bull. Org. mond. Santé
Bull. Wld Hlth Org. } 1965, 33, 163-175

An Analysis of Age-Prevalence Data by Catalytic Models

A Contribution to the Study of Bilharziasis

NELSON G. HAIRSTON [1]

The analysis of age-prevalence curves obtained from bilharziasis surveys is not usually carried out to the maximum depth the data allow for. With a view to obtaining greater value from the available information, the author analyses age-prevalence data for three common human schistosomes by Muench's catalytic models. The two-stage model is found the most appropriate. Use of this model assumes constant rates of becoming positive and of becoming negative. Two separate analyses are required, one for the first few years of life of the human host and one for the remainder. Satisfactory fits to the data are obtained only when the proportion of older people who remain positive is determined. This proportion varies with the intensity of transmission.

The calculated rates of becoming positive agree very well with rates obtained by observing originally negative children for 12 months or longer.

The parameters in the model are used in interpreting data from skin-test surveys. It is concluded tentatively that in order to be positive by the skin test, a person must have had both sexes of worms at some time in the past and to be carrying living female worms or to have been exposed recently to female cercariae.

It may become possible to use the model to predict the entire age-prevalence curve from data on children, thus saving much effort in parasitological surveys.

Surveys performed to discover the prevalence of bilharziasis are normally carried out in such a way that the relationship between prevalence and age may be reported. It is generally agreed that comparisons between two or more areas are more meaningful if the data are presented in this manner than from a simple statement of the over-all percentage positive. When the data are presented in graphic form, the initial upward slope with age and the age of maximum prevalence are regarded as important features. Most publications on the subject have not pursued the interpretation of these age-prevalence curves beyond the few self-evident observations that can be made.

Muench (1959) has pointed out that, if a few assumptions and simplifications can be permitted, the data may be analysed to reveal some very interesting points which are not obvious from a simple inspection of the graphs.

The purpose of the present communication is to analyse data from bilharziasis surveys using Muench's methods, and to point out some of the conclusions that can be drawn from the analysis.

THE ASSUMPTIONS AND THE DATA

Muench presents a number of different models, and points out that the choice among them depends upon the assumptions that appear to be permissible from the data. Naturally, these assumptions should not violate any other known facts pertaining to the disease. The most fundamental assumption in the method is that the epidemiological situation has remained the same for the length of life of the oldest age-group considered, so that it is assumed, for example, that persons 10 years old at the time of the survey have the same prevalence as those 30 years old had 20 years before the survey. The next assumptions are linked with this one in that it is assumed that the rate of acquiring the disease remains constant for long periods during the life

[1] Professor of Zoology, University of Michigan, Ann Arbor, Mich., USA.

FIG. 1
OBSERVED AGE-PREVALENCE OF *S. JAPONICUM* INFECTION IN COASTAL DIVISION, PALO LEYTE, PHILIPPINES

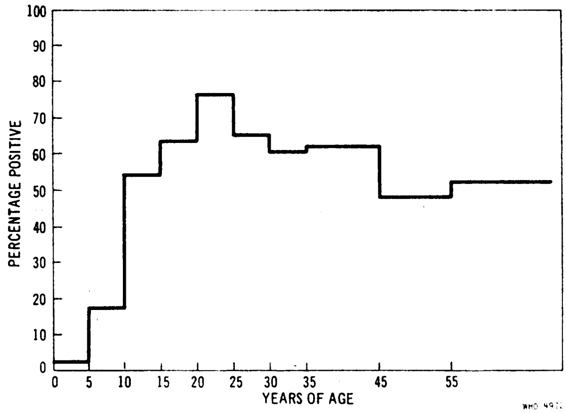
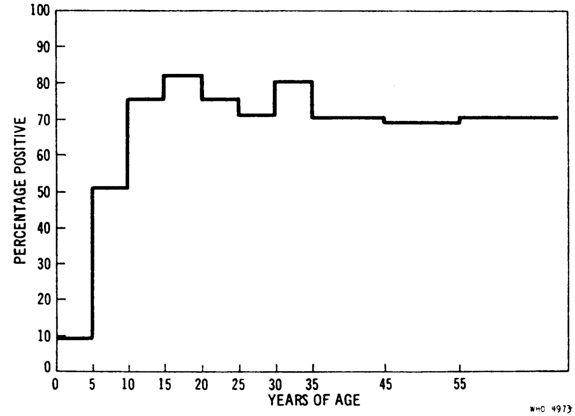


FIG. 2
OBSERVED AGE-PREVALENCE OF *S. JAPONICUM* INFECTION IN INLAND DIVISION, PALO, LEYTE, PHILIPPINES



of the host, if not throughout his life. For some of the models, it is further assumed that evidence of having had the disease disappears at a constant rate among those who are positive.

An examination of a fairly typical set of age-prevalence data, those from the coastal division of Palo, Leyte, Philippines, (Fig. 1) shows that the prevalence of *Schistosoma japonicum* infection rises to a maximum at 20-24 years and then declines gradually. The decline can be shown to be significant statistically, indicating that some individuals must lose the infection and not acquire it again. Any alternative explanation would require that older people never had become as heavily infected as the 20-24-year-olds. This seems unreasonable, in view both of the previous history of eastern Leyte and of the experimental data on immunity (Vogel & Minning, 1953). Data from the inland division of Palo (Fig. 2) indicate a more rapid increase in prevalence, and a peak prevalence that occurs five years earlier than on the coast and is somewhat higher. It is easy to conclude that trans-

FIG. 3
OBSERVED AGE-PREVALENCE OF *S. MANSONI* INFECTION IN CONTROL DIVISION, EGYPT-49 PROJECT

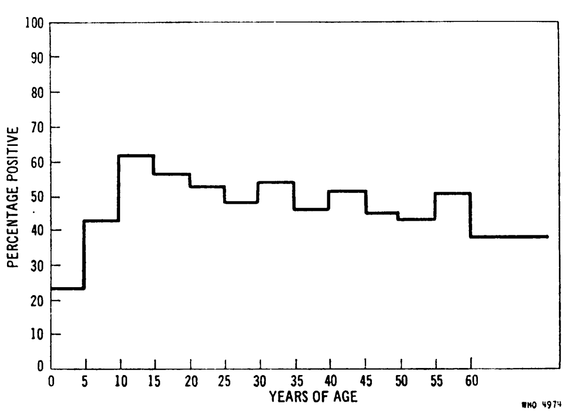


FIG. 4
OBSERVED AGE-PREVALENCE OF *S. HAEMATOBIUM* INFECTION IN CONTROL DIVISION, EGYPT-49 PROJECT

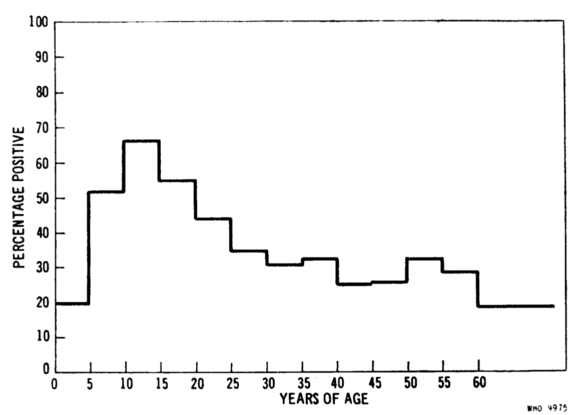


TABLE 1

PREVALENCE OF INFECTION WITH *SCHISTOSOMA JAPONICUM* BY AGE IN TWO DIVISIONS OF PALO, LEYTE, PHILIPPINES

	Age-group (years)									
	<5	5-9	10-14	15-19	20-24	25-29	30-34	35-44	45-54	≥ 55
Coastal division										
Number examined	131	143	122	88	76	57	58	108	73	67
Number positive	4	25	66	56	58	37	35	67	35	35
Proportion positive	0.031	0.175	0.541	0.636	0.763	0.649	0.603	0.620	0.479	0.522
Inland division										
Number examined	117	153	126	76	56	68	55	100	67	40
Number positive	11	78	95	62	42	48	44	70	46	28
Proportion positive	0.094	0.510	0.754	0.816	0.750	0.706	0.800	0.700	0.687	0.700

TABLE 2

PREVALENCE OF INFECTION WITH *SCHISTOSOMA HAEMATOBIUM* AND *SCHISTOSOMA MANSONI* BY AGE IN THE CONTROL DIVISION OF THE EGYPT-49 PROJECT AREA [a]

	Age-group (years)												
	<5	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	≥ 60
Number examined	379	359	303	208	144	171	156	133	114	94	93	42	101
Number positive for *S. haematobium*	75	189	201	114	63	59	48	43	29	24	30	12	24
Proportion positive for *S. haematobium*	0.198	0.526	0.663	0.548	0.438	0.345	0.308	0.323	0.254	0.255	0.323	0.286	0.238
Number positive for *S. mansoni*	89	154	187	117	75	82	83	61	58	42	40	21	38
Proportion positive for *S. mansoni*	0.235	0.429	0.617	0.563	0.521	0.480	0.532	0.459	0.509	0.447	0.430	0.500	0.376

[a] Mixed infections are included under the separate species.

mission is more intense inland than in the coastal division, but the measurement of the difference is not possible without a model.

Schistosoma mansoni in the control division of the Egypt-49 project [1] area shows a relationship between prevalence and age (Fig. 3) that is fairly similar to that of *S. japonicum* on the Leyte coast. Prevalence rises faster and comes to a peak earlier, but does not reach the maximum prevalence of *S. japonicum*.

Data on the prevalence of *S. haematobium* in the same area as *S. mansoni* (Fig. 4) show a curve of quite a different kind. The rate at which people become positive is great; the peak prevalence occurs early (between 10 and 15 years) and the decrease in prevalence after the peak is much greater than for the other two species. The numerical data on which these histograms are based are given by Pesigan et al. (1958) for *S. japonicum*; those for *S. mansoni* and *S. haematobium* are from the unpublished quarterly report for July 1963 of the Egypt-49 project. They are repeated here for convenience (Tables 1 and 2).

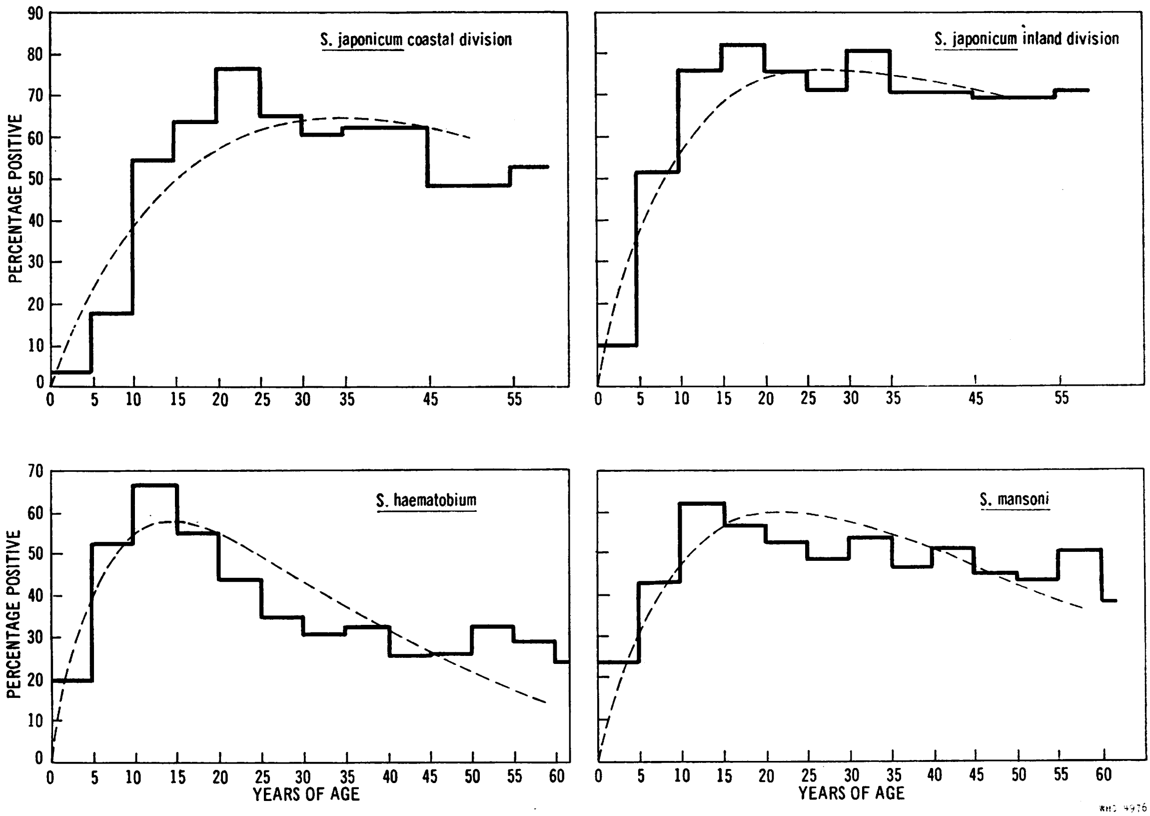
[1] Joint United Arab Republic/WHO/UNICEF Bilharziasis Control Pilot Project and Training Centre.

THE CATALYTIC MODEL

The simplest model that can be devised to describe data such as those presented must contain one

FIG. 5

COMPARISON BETWEEN OBSERVED AGE-PREVALENCE DATA FOR *S. JAPONICUM*, *S. HAEMATOBIUM* AND *S. MANSONI* INFECTIONS AND EXPECTED AGE-PREVALENCE CURVES CALCULATED FROM THE UNMODIFIED TWO STAGE-CATALYTIC MODEL



constant representing the rate at which the parasite is acquired and one representing the rate at which it is lost. It must be pointed out that a single means of detecting the presence of the parasite is used: the presence of eggs in stool or urine. Combinations of methods, including immunological techniques, would give a different and in some ways a more complete picture, but as a matter of fact would not permit so interesting an analysis.

Muench's model for the situation that apparently holds in bilharziasis is:

$$y = \frac{a}{a-b}(e^{-bt} - e^{-at}),$$

or, if b is greater than a:

$$y = \frac{a}{b-a}(e^{-at} - e^{-bt}),$$

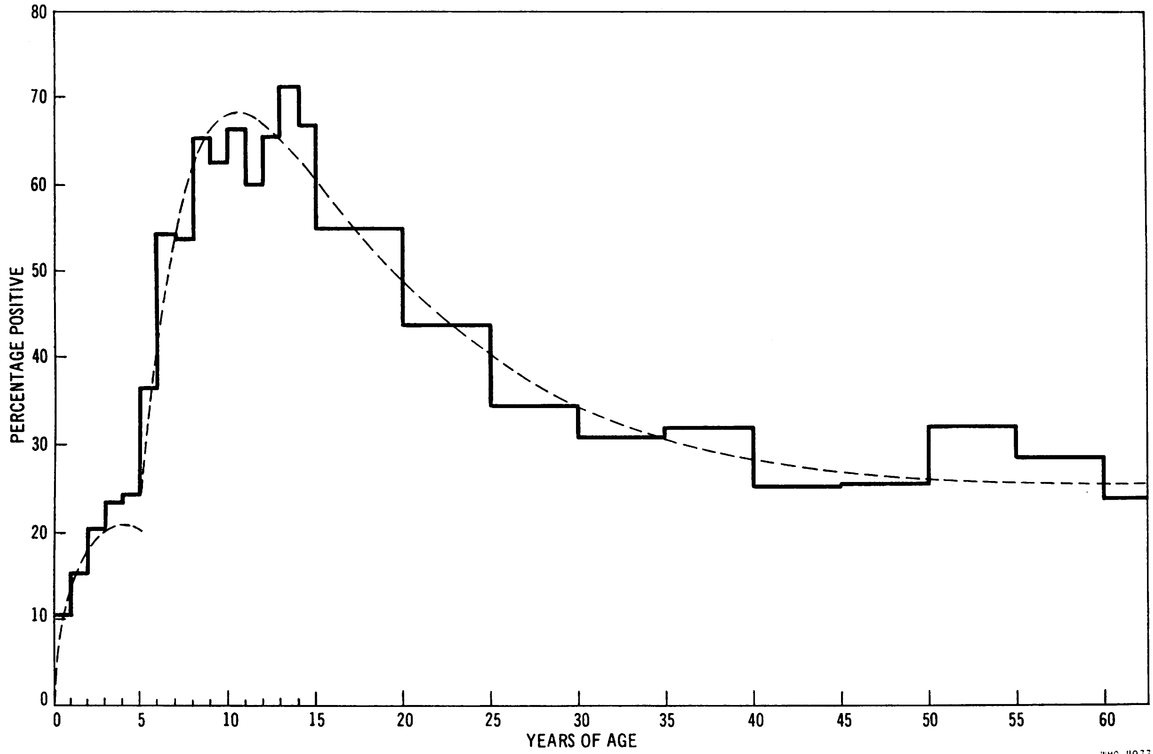
where a is the instantaneous rate of becoming positive per year; b is the instantaneous rate of becoming negative per year; e is the base of natural logarithms; t is time in years, and y is the expected proportion positive.

Muench gives the complete method for finding the constants a and b, including a nomogram, so that if one has his book only a knowledge of algebra is required. Mathematical tables are needed for solving the equation, of course.

The results of the calculations are disappointing (Fig. 5). None of the curves describes the data properly. There are several possible reasons for the poor fit. The most obvious reason is that the assumption of constant rates is incorrect. The model fits particularly badly at the extremes of age when one would expect exposure to differ from that in other age-groups. An examination of the data for *S. haematobium* is particularly revealing in this

FIG. 6

OBSERVED AGE-PREVALENCE OF *S. HAEMATOBIUM* INFECTION IN CONTROL DIVISION, EGYPT-49 PROJECT, WITH CURVES CALCULATED ON THE BASIS OF SEPARATE CATALYTIC MODELS FOR THE TWO AGE-GROUPS AND THE OBSERVATION THAT 25 % OF THE POPULATION DO NOT BECOME NEGATIVE OR ELSE REVERT TO POSITIVE



regard (Table 3). In this case, the prevalence is given year by year, and the sharp increase after 5 years is very apparent. This indicates that a separate catalytic model must be calculated for the first five years of life. From the way in which the nomogram is constructed, it is necessary to calculate the constants in terms of months, where so few years are used. This causes no difficulty because, in dealing with instantaneous rates, the conversion to years is simply a matter of multiplication by 12.

Calculations of the constants for the first five years of life yield values of 0.17 per year for a and 0.3 per year for b. The calculated curve is shown in Fig. 6. It falls below the observed points in the fourth and fifth years, a fact which reflects the likelihood that the change in rate of acquisition of worms is not abrupt, but is increasing during these two years, as would be expected.

It will have been observed that the curves in Fig. 5 also fit the data poorly for older people. Whereas the assumption of a constant rate of becoming negative requires that the curve descend continually with age after the peak, the data, in general, show a tendency to remain at a constant level during middle and older ages following a greater than expected drop shortly after the peak prevalence is reached.

This observation suggests that a fraction of the population either does not lose the infection as readily as the majority or that they lack the ability to maintain any acquired immunity, with the result that they become reinfected sufficiently often to maintain a constant prevalence.

The data for *S. haematobium* suggest that about 25% of the population are involved in this process; for *S. mansoni*, the proportion seems to be about 45%. In the data for *S. japonicum*, an additional interesting point is seen. In the inland division of Leyte, where transmission is most intense, about 70% of the people seem to fall into the group which

TABLE 3

PREVALENCE OF INFECTION WITH *SCHISTOSOMA HAEMATOBIUM* AND *SCHISTOSOMA MANSONI* BY ONE-YEAR AGE-GROUPS IN THE CONTROL DIVISION OF THE EGYPT-49 PROJECT AREA

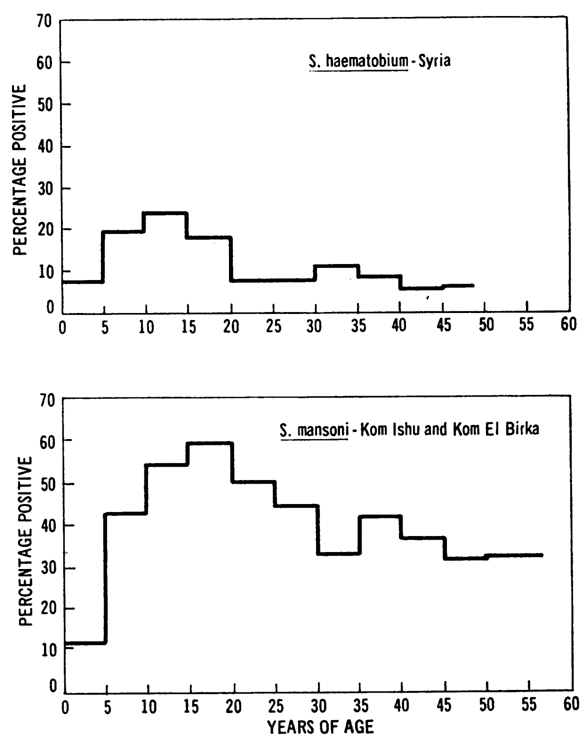
	Age (years)														
	<1	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Number examined	48	72	79	94	86	96	81	67	75	40	101	30	78	49	45
Number positive for *S. haematobium*	5	11	16	22	21	35	44	36	49	25	67	18	51	35	30
Proportion positive for *S. haematobium*	0.104	0.153	0.203	0.234	0.244	0.365	0.543	0.537	0.653	0.625	0.663	0.600	0.654	0.714	0.667
Number positive for *S. mansoni*	1	17	13	25	33	37	35	22	39	21	60	21	43	31	32
Proportion positive for *S. mansoni*	0.021	0.236	0.165	0.266	0.384	0.385	0.432	0.328	0.520	0.525	0.594	0.700	0.551	0.633	0.711

becomes reinfected; on the coast, the fraction seems to be considerably lower, possibly 50%, but the flattening occurs later and is not clearly defined. This suggests that the fraction reverting to positive is not fixed but depends upon the intensity of transmission. Such a phenomenon might have been anticipated, as the effectiveness of immunity is well known to depend inversely upon the size of the inoculum for a number of diseases. The same phenomenon appears to hold true for *S. haematobium* and *S. mansoni* (Fig. 7). In Syria, where transmission was very light, only about 7.5% of the population appear to revert to positive urines (Farooq—personal communication); in the Kom Ishu and Kom El Birka sections of the Egypt-49 project area, about 30% of the *S. mansoni* cases show the phenomena.

If the foregoing hypothesis is correct, the model should be modified to take care of it. This can be done by starting from the age at which the popu-

FIG. 7

AGE-PREVALENCE DATA FOR *S. HAEMATOBIUM* INFECTION IN SYRIA AND *S. MANSONI* INFECTION IN THE KOM ISHU AND KOM EL BIRKA SECTIONS OF THE EGYPT-49 PROJECT



lation reaches the prevalence indicated and treating the remaining data as though the prevalences reached were a fraction of the difference between that level and 100%.

Thus, in the data for *S. haematobium* in the control division, the postulated 25% is reached at about 5 years. For the next entry (5.5 years on the original scale, but 0.5 years on the new one), the observed prevalence is 0.365. This is 0.115 above the base line and represents $\frac{0.115}{0.75}$ or 0.153 of the possible distance from 25% to 100%. Successive recalculations were then made, year by year, for the remaining data up to 15 years of age, or a duration of 10 years. Estimation of the constants on this basis gave values of 0.3 for *a* and 0.1 for *b*. On solving the equation, the value must be multiplied by 0.75 to return to the original scale of 100% and then added to the base of 0.25 to give the expected proportion positive.

The results of this calculation fit the observed data extremely well (Fig. 6). It is emphasized that only the data from 5 to 14 years were used in calculating the parameters for the equation; the part of the histogram above 15 years was plotted after the calculations were made. It is further noteworthy that in a separate series of observations, made on the rate at which negative children became positive, the rate of acquisition of the disease is estimated as 0.33 per year for children over 5 years old. This is in good agreement with the estimate of 0.3 per year that is made using the catalytic model. Prevalence data for individual years of age are not available from Syria but the calculated constants from 5 years up indicate a rate of 0.125 per year for becoming positive and 0.35 per year for becoming negative. Note that the rate of loss of infection is comparable to that (0.3) for younger age-groups in Egypt, where the average number of female worms per positive individual would also be expected to be small. If people only become negative through the death of females, as suggested by the author (Hairston, 1965) then the rate of becoming negative should be the death-rate of female flukes raised to the power of the number of worms present. Thus, under this hypothesis, the death-rate of mated female *S. haematobium* must be at least 0.3-0.35 per year.

The age-prevalence data for *Schistosoma mansoni* show a less clear-cut break between the lowest age-groups and the rest of the population (Table 3). Moreover, the data for individual years of age fluctuate in a much more erratic way than do the data for *S. haematobium*, although the same number of people were examined and comparable proportions were positive, at least up to 15 years of age. Both lack of an obvious change in rate of becoming positive and the fluctuations in the percentage positive suggest that a peculiarity of sampling exists in the case of persons having *S. mansoni*—a peculiarity that is not shared by *S. haematobium* cases. Since the random sampling of people was very carefully planned, the best explanation appears to be that persons positive for *S. mansoni* are much less homogeneously distributed through the population than are those with *S. haematobium*, a suggestion that is borne out by the fact that mixed infections are much more common than would be expected from chance. This could be related to the distribution of the snail host, which occurs in scattered but very dense populations, in contrast to the snail host of *S. haematobium*, which is more widespread but not as numerous within a single habitat (Hairston, 1965). Whatever the cause, the above-mentioned peculiarities of the data for *S. mansoni* indicate caution in interpreting the analysis based upon the catalytic model.

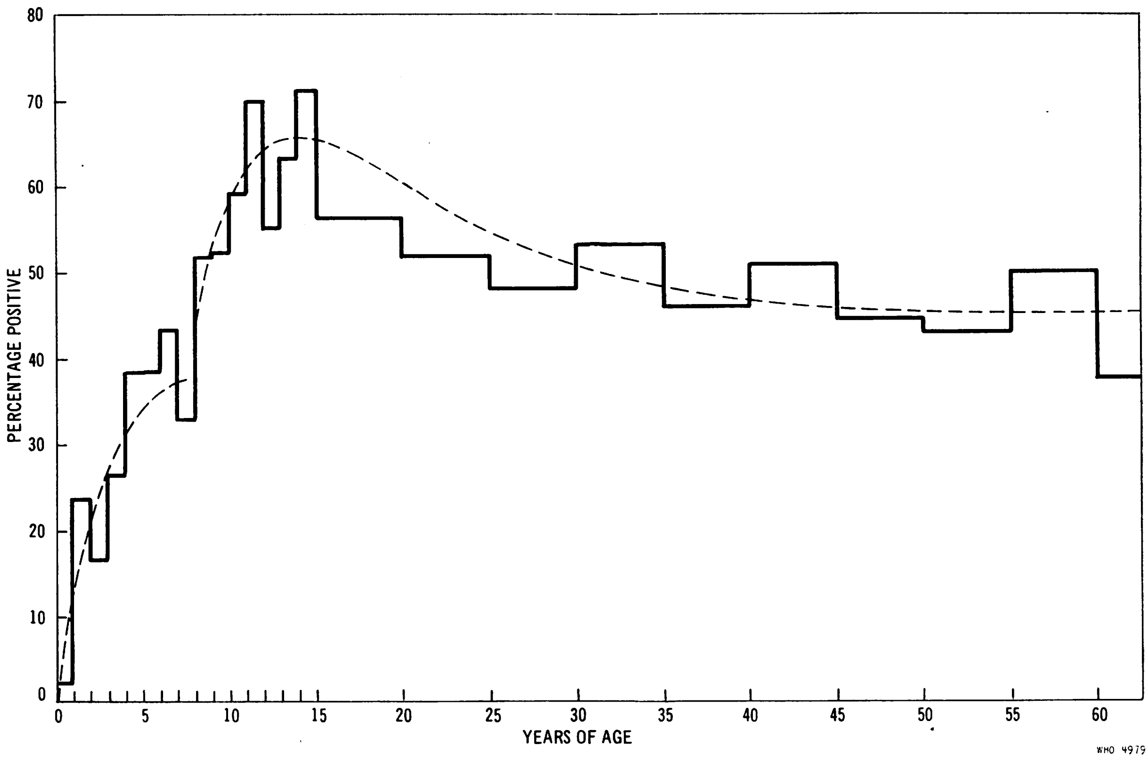
A change in rate of becoming positive seems to occur after 7 years of age. When the data from early years are used in calculating the constants in the model, a value of 0.13 per year is obtained for the rate of becoming positive, and 0.125 per year for the rate of becoming negative. In calculating the model for the rest of the age-groups, eye-fitting from the expected fraction positive of 0.375 at 7½ years indicates that about 45% should be positive at 8 years. Taking this as the starting-point, the second curve is based on a rate of 0.17 per year becoming positive and 0.16 per year becoming negative, with 45% of the people being able to be reinfected.

In spite of the difficulties, the model fits the data surprisingly well (Fig. 8), indicating that the calculated values contain some truth, and that the assumptions may be reasonably well founded.

Schistosoma japonicum presents additional difficulties which come from two different sources. The first difficulty is simply that data are not available on the fraction positive at each year of age but are lumped into five-year groups. This is critical in establishing the change in rate of becoming positive which occurs at around 5 years of age. The second difficulty is with the high and very variable fractions of the population that appear to revert to positive after becoming negative. The lack of detailed data for the early years of life prevents the calculation

FIG. 8

OBSERVED AGE-PREVALENCE OF *S. MANSONI* INFECTION IN CONTROL DIVISION, EGYPT-49 PROJECT, WITH CURVES CALCULATED ON THE BASIS OF SEPARATE CATALYTIC MODELS FOR THE TWO AGE-GROUPS AND THE OBSERVATION THAT 45 % OF THE POPULATION DO NOT BECOME NEGATIVE OR ELSE REVERT TO POSITIVE



of the expected percentage positive up to the level necessary for ca culating the rest of the curve, as was done for *S. haematobium* and *S. mansoni.*

For the coastal division of Palo, the prevalence is so low for the first five years of life that it can be ignored for present purposes. Calculating the values for the rest of the data, as though transmission started at 5 years of age, produces a reasonably good fit when a is 0.12 per year and b is 0.02 per year (Fig. 9). The agreement between the rate of becoming positive, estimated in this way, and that estimated from the rate at which known negative children become positive (Pesigan et al., 1958) is perfect. A satisfactory model for the inland division of Palo must await detailed data on young children.

DISCUSSION: POSSIBLE APPLICATION OF THE CONSTANTS

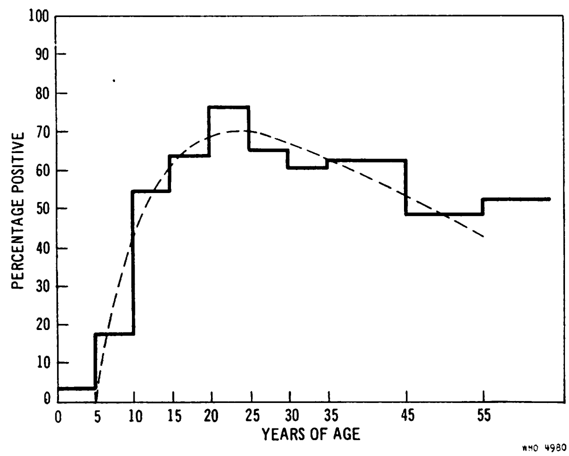
Interpreting the results of immunological tests

There are a number of problems associated with the search for schistosome eggs in excreta, and the results of surveys based upon even the best techniques have sometimes been viewed with suspicion because of the impossibility of being certain that no positive cases have been missed. This uncertainty has prompted intensive investigations of the possibility of using immunological reactions in diagnostic and survey work. It is clear from the results of these efforts that several tests exist which will give a higher proportion of positive results than will the examination of faeces or urine (Jachowski & Anderson, 1961; Kagan & Pellegrino, 1961). It is not clear, however, just what a positive test means in terms of the state of parasitization of the host. If the estimates made in the present paper and elsewhere (Hairston, 1962, 1965) are valid, then there is an array of groups of people with different states of parasitization which can be listed. Simplifying these somewhat, they are:

1. The group which has never been infected with parasites of either sex.

FIG. 9

OBSERVED AGE-PREVALENCE OF *S. JAPONICUM* INFECTION IN COASTAL DIVISION, PALO, LEYTE, PHILIPPINES, WITH THE CURVE CALCULATED ON THE ASSUMPTION THAT TRANSMISSION BEFORE 5 YEARS OF AGE IS NEGLIGIBLE



2. The group which has living parasites of both sexes, and which in theory should be positive on examination of stool or urine.

3. The group with living parasites of one sex only:

(*a*) those with one or more males;

(*b*) those with one or more females.

4. The group which has had living parasites of both sexes in the past and has been parasitologically positive but which is now negative parasitologically and presumably has only male worms or none at all.

Immunological tests could, in theory, give positive reactions to any or all of the last three groups. In the interpretation of surveys performed with such tests, it would be important to know which groups or what combinations of groups were being identified by the test concerned. With perfect parasitological data, group 2 can be identified, but no claims have been made that any immunological test distinguishes between groups 2 and 3 and 4.

The constants derived from the applications of the catalytic model appear to be helpful in solving this dilemma but the problem can only be handled on a statistical basis and the groups identified are different from those listed above. If the constants are correctly calculated, then the proportion of the population which has ever been parasitologically positive can be calculated as $1 - e^{-at}$, where a is the rate of becoming positive each year, t is time in years and e is the base of natural logarithms. This group will include those individuals positive at time t as well as those who have been positive and have become negative.

The group with female worms, mated or not, can be identified as the following proportion: $1 - e^{-m}$, where m is the mean number of female worms per person, estimated from the rate of acquisition and the death-rate of females (Hairston, 1965). The groups that have ever contained any living worms, mated or not, can be calculated from the same formula, using m as the average number of worms present, regardless of sex.

In one case for which data are available the comparison between these expected proportions and the results of skin tests reveal some very interesting points. This case is that of the coastal division of Palo, Leyte. The expected proportion stool-positive with age has been shown above and the calculated mean numbers of worms of each sex are given in Table 4. The mathematics have imposed an

TABLE 4

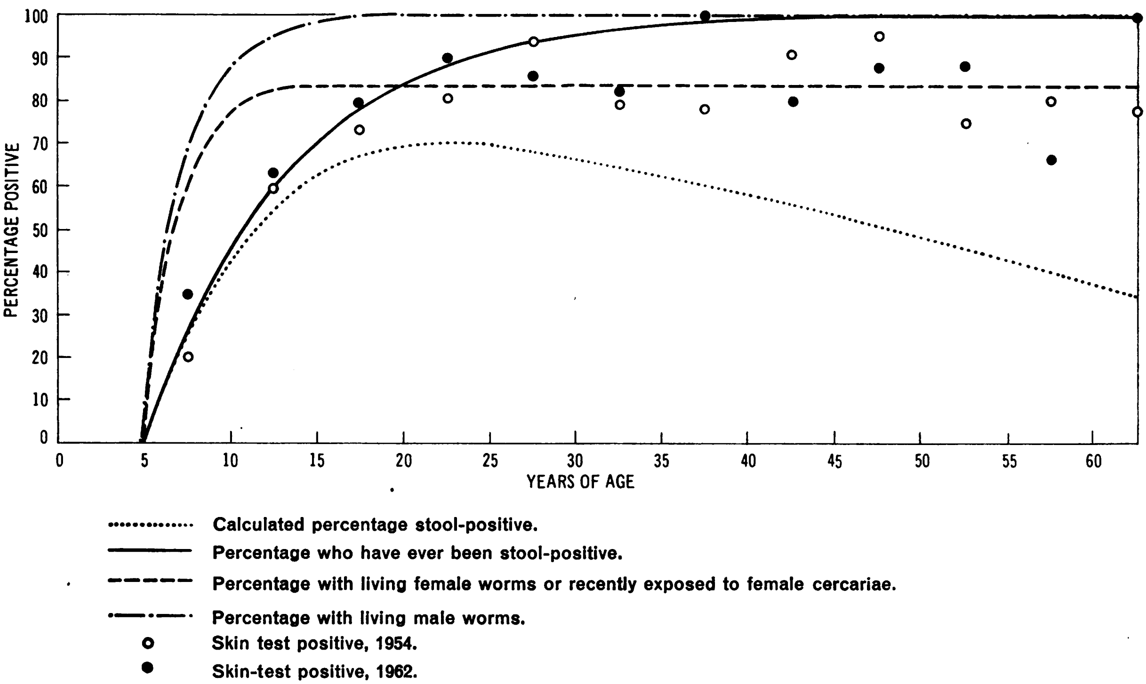
THE CALCULATED AVERAGE NUMBER OF MALE AND FEMALE *SCHISTOSOMA JAPONICUM* PER PERSON AT SUCCESSIVE AGES FROM 5 YEARS ONWARDS IN THE COASTAL DIVISION OF PALO, LEYTE, PHILIPPINES [a]

Age (years)	Average No. of male worms per person	Average No. of female worms per person	Proportion of females that are mated	Average No. of mated females per person	Average No. of females per positive person
5	0.08	0.080	0.077	0.006	1.005
6	0.48	0.479	0.381	0.182	1.094
7	0.88	0.839	0.585	0.491	1.265
8	1.28	1.130	0.722	0.816	1.463
9	1.68	1.350	0.814	1.099	1.647
10	2.08	1.507	0.875	1.319	1.800
11	2.48	1.616	0.916	1.480	1.916
12	2.88	1.689	0.944	1.594	2.000
13	3.28	1.737	0.962	1.617	2.058
14	3.68	1.768	0.975	1.724	2.098
15	4.08	1.787	0.983	1.757	2.123
16	4.48	1.799	0.989	1.779	2.143
17	4.88	1.806	0.992	1.792	2.150
18	5.28	1.810	0.995	1.801	2.156
19	5.68	1.812	0.997	1.807	2.162
20	6.08	1.813	0.998	1.809	2.163
21	6.48	1.813	1.000	1.809	2.163

[a] From 4 to 5 years, the rate of acquiring flukes is assumed to be 20 % of the rate from 5 years on. Calculations are based upon an instantaneous rate of 0.12 becoming positive per year and an instantaneous death-rate of 0.25 per year for female worms. No death of male worms is assumed.

FIG. 10

S. JAPONICUM INFECTION IN COASTAL DIVISION, PALO, LEYTE, PHILIPPINES, SHOWING THE DIVISION OF INFECTED PERSONS INTO GROUPS ACCORDING TO AGE AND STATE OF PARASITIZATION[a]



[a] Curves are based upon constants calculated from the catalytic model and an annual death-rate of 0.25 for mated female flukes.

inconsistency that must be resolved. This is the estimate of the mean number of worms, particularly females, in older age-groups. Since less than 1% of the people above the age of 15 would lack male worms under the assumptions that have been made, it is clear that if females were really present, a larger proportion of people should be positive than is either observed or calculated from the catalytic model. It seems likely, therefore, that the worms are killed in the body before maturity and that the correct designation for " the proportion of people with live female worms " should be " the proportion of people with live female worms or recently exposed to female cercariae ".

With this reservation, consider Fig. 10. Four theoretical lines have been plotted. The lowest of the four is the expected proportion stool-positive at each age. As shown in Fig. 9, this is a good fit to the data. The remaining curves are calculated from the constants in this model. They represent the proportion that had ever been positive, the proportion with live female worms or recently exposed to female cercariae, and the proportion with living male worms.

In one of the villages in this area, skin tests were performed in 1954 using a locally prepared antigen. The data are shown as open circles in Fig. 10. In 1962, the same village was again surveyed by skin test, this time using the Melcher antigen. This antigen is somewhat more powerful, as shown by the position of the closed circles. The picture is complicated somewhat by the fact that partial snail control had been in effect for several years before the second survey, but the pattern of results from the two surveys is remarkably consistent. For the first 20 or 25 years of age there is excellent agreement between the observed proportion positive and the curve representing the proportion calculated to have been stool-positive at some time during their lives. After 25 or 30 years of age, however, both skin test surveys give results indicating an upper asymptote of 84%-88% positive, instead of rising to 100% with the theoretical curve. Since the proportion expected to have male worms rises to virtually 100%

before the age of 20, only the proportion with live females or recently exposed to female cercariae seems at all related to the observations. The relationship is remarkably close. The theoretical asymptote is at 83.7%. As noted above, the average proportions skin-positive after 25 years of age are 84.5% and 87.5% for the two tests. The tentative conclusion, which needs testing in a number of areas, is that two requirements must be met for a person to give a positive reaction to the skin test: the presence of mated worms, at least during some time in the past, and either the presence of living female worms or recent exposure to female cercariae. Alternative hypotheses do not seem to be tenable. If an appreciable fraction of the population were never exposed to the parasite, there should be no agreement between observed and calculated rates of becoming stool-positive. If an appreciable fraction of the infected individuals never became reactive to the antigen, the observed proportion skin-positive should fall appreciably below the proportion that are stool-positive during the early part of the curve. Although this happened to a slight extent with the local antigen (Pesigan et al., 1958), it did not happen with the Melcher antigen.

The tentative conclusion reached about the conditions necessary to be skin-positive seems to be the best hypothesis available for explaining the facts. It would have been difficult or impossible to reach this hypothesis without the analysis through the catalytic model. It is concluded that the model is a powerful tool in helping to solve some of the problems associated with the results of immunological tests. As surveys are done with the various other tests, similar analyses may help in interpreting the data.

The data from Egypt have been analysed in the same manner as those from the Philippines. The results are given in Fig. 11. The presence of two species of schistosome complicates the picture, especially in view of the fact that cross-reactions between antigens of one species and antibodies against the other are the rule. To take care of this problem, two additional lines have been calculated for each graph. These are the proportion of individuals who have ever had either infection and the proportion with living females of either species or recently exposed to female cercariae of either. It should be noted that very large numbers of individuals would have to be tested above the age of 14 before any statistically valid distinction could be made between 100% positive and the percentage expected to have living females. Nevertheless, the curves may be useful.

Reducing the amount of data required

It will be agreed by all who have participated in stool or urine survey work that a reduction in the number of persons to be examined is highly desirable. The relationship between the constants in the model and the shape of the entire age-prevalence curve suggests the possibility of just such a saving in effort. It has already been noted that the model produces excellent agreement with observations, even where the data cover only the first 15 years of life. One additional piece of information required is an estimate of the proportion of the older people who revert to a positive condition. Inasmuch as

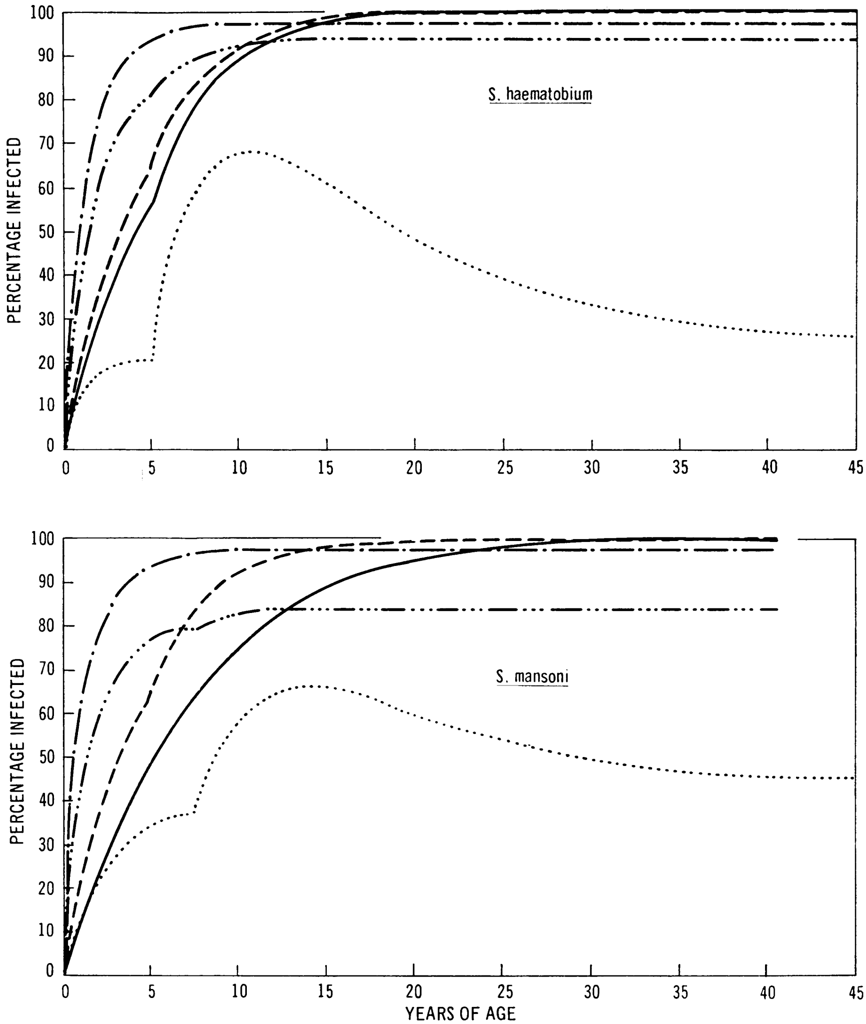
TABLE 5

COMPARISON BETWEEN THE ESTIMATED PROPORTIONS OF PEOPLE REVERTING TO A POSITIVE CONDITION OR NOT BECOMING NEGATIVE AND THE CALCULATED CONSTANTS IN THE TWO-STAGE CATALYTIC MODEL

Species and location	Proportion reverting to positive	Annual rate of becoming positive (young children)	Annual rate of becoming positive (older ages)	Annual rate of becoming negative (young children)	Annual rate of becoming negative (older ages)
S. haematobium, Control division, Egypt-49	0.25	0.17	0.30	0.30	0.10
S. haematobium, Syria	0.075	?	0.125	?	0.35
S. mansoni, Control division, Egypt-49	0.45	0.13	0.17	0.125	0.16
S. mansoni, Kom Ishu and Kom El Birka, Egypt-49	0.30	0.085	0.111	0.336	0.111
S. japonicum Coastal division, Palo, Philippines	0.50(?)	?	0.12	?	0.02

FIG. 11

***S. HAEMATOBIUM* AND *S. MANSONI* INFECTIONS IN CONTROL DIVISION, EGYPT-49 PROJECT, CALCULATED AS FOR FIG. 10 WITH THE ADDITION OF CURVES SHOWING PROPORTION OF PERSONS WITH EITHER PARASITE**



Calculated percentage with eggs in stool or urine.
Percentage who have ever had eggs in stool or urine.
Percentage who have been positive for either species.
Percentage with living female worms or recently exposed to female cercariae.
Percentage with living female worms or either species or recently exposed to female cercariae of either species.

this proportion appears to vary directly with the rate at which people become positive, data on the older segment of the population could be expressed in exact terms. In order to obtain a mathematical formula for *S. haematobium*, detailed data from at least one other urine survey would be necessary. This should have a transmission rate intermediate between those found for the Egypt-49 project and those found for Syria. For *S. mansoni* there is less confidence in the existing analyses and data on areas of low transmission rates are also needed. In the case of *S. japonicum*, the data probably exist in the files of the Philippines control project, since what is required is age-prevalence data for each year of life up to 15, plus complete data for a region of low transmission such as the endemic area in Sorsogon Province.

For all three species, the available estimates are given in Table 5. A sufficient expansion of this table might save a large amount of effort on future surveys.

ACKNOWLEDGEMENT

I wish to thank Dr M. Farooq, Senior WHO Adviser, for permission to use unpublished data from the reports of the Egypt-49 project and from his visit to endemic bilharziasis areas in Syria and Turkey.

RÉSUMÉ

Les modèles mathématiques proposés par Muench en 1959 ont servi à l'analyse de données relatives à la prévalence selon l'âge, chez l'homme, des différentes variétés de bilharziose.

L'utilisation de ces modèles est basée sur deux hypothèses: les tendances épidémiologiques restent identiques au cours d'un laps de temps correspondant à l'âge atteint par le groupe de population le plus ancien, et les taux d'infection nouvelle ou de disparition de la maladie chez l'homme restent constants, la positivité ou la négativité étant établie par les examens de selles ou d'urine. Il est nécessaire par ailleurs que ces données soient recueillies au cours de deux enquêtes distinctes, la première portant sur le groupe d'âge de 0 à 5 ans, l'autre sur les groupes d'âge supérieur.

Les calculs effectués au moyen du modèle mathématique sont en concordance avec les données épidémiologiques, à condition de déterminer la proportion des personnes âgées chez lesquelles les examens restent positifs. Cette proportion varie suivant l'intensité de la transmission. Les valeurs calculées des taux d'infection nouvelle correspondent de manière satisfaisante aux chiffres obtenus par l'observation, pendant douze mois ou plus, d'enfants initialement non infectés. Les paramètres du modèle permettent également d'interpréter les données recueillies au cours d'enquêtes utilisant les tests cutanés. La conclusion provisoire de l'auteur est que les tests ne sont positifs que chez les sujets qui, à un moment de leur existence, ont hébergé des schistosomes des deux sexes, et qui sont porteurs de parasites femelles vivants ou ont été exposés récemment à l'infection par des cercaires femelles.

L'emploi de ce modèle permettra peut-être de prédire l'allure de la courbe de prévalence de la bilharziose pour tous les groupes d'âge, à partir des données obtenues chez les enfants. Les enquêtes parasitologiques en seraient grandement facilitées.

REFERENCES

Hairston, N. G. (1962) *Population ecology and epidemiological problems.* In: Wolstenholme, G. E. W. & O'Connor, M., ed., *Bilharziasis*, London, Churchill, pp. 36-62 (Ciba Foundation Symposium)

Hairston, N. G. (1965) *Bull. Wld Hlth Org.*, **33**, 45-62

Jachowski, L. A. & Anderson, R. I. (1961) *Bull. Wld Hlth Org.*, **25**, 675-693

Kagan, I. G. & Pellegrino, J. (1961) *Bull. Wld Hlth Org.*, **25**, 611-674

Muench, H. (1959) *Catalytic models in epidemiology*, Cambridge, Mass., Harvard University Press

Pesigan, T. P. et al. (1958) *Bull. Wld Hlth Org.*, **18**, 345-455

Vogel, H. & Minning, W. (1953) *Z. Tropenmed. Parasit.*, **4**, 418-505