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Ecology of Biomphalaria glabrata and Marisa cornuarietis in Lakes of Puerto Rico. By William R. Jobin, Angel Laracuente, Roberto Mercado, Virgenmina Quinones, and Raymond A. Bronn.

INTRODUCTION

The ampullarid snail Marisa cornuarietis has displaced Biomphalaria glabrata, the intermediate snail host of bilharzia, from many of the 28 man-made lakes of Puerto Rico. These lakes were reservoirs created for irrigation, hydroelectric power, and domestic water supply (Figure 1). The biological process of displacement was gradual and occurred over a 20-year period. The purpose of this study was to examine the ecology of these lakes and determine what factors were most important in the competition between the two snails. In addition, the information should assist in evaluating the potential for using cornuarietis in other countries, and in designing or evaluating proposed irrigation and hydroelectric reservoirs in the tropics. This information is especially important in Africa where new reservoirs have invariably resulted in increased bilharzia transmission or caused other health problems (Table 1).

Lake Carraizo in Trujillo Alto, Puerto Rico was constructed as part of the San Juan water supply and also generates electric power. Unfortunately, it also receives poorly treated sewage from upstream communities and thus contains heavy aquatic plant populations and other undesirable conditions.

TABLE 1: HYDROELECTRIC RESERVOIRS WITH POTENTIAL REACTION ON HUMAN HEALTH IN AFRICA

Lake	Area	Country	Location	Health Problems	When Full	Reference
Aswan	5000	Egypt	On Nile River	Potential health problems in lake	1964	
Tana	-	Ethiopia	Gondar on Blue Nile	-	1970	Ferro, Rute
Volta	8500	Ghana	Akosombo on Volta River	Severe outbreak	1969	"

Bilharzia on West Shore. Ivory Coast, Kostu Banden Potential for Webbe, 2974 Bilharzia. Voraceo Tafilalet Poe. 1872 Mozambique Cabora Bassa 2700 Webbe, 2972 Nsgerta Kainji ‘New Bussa on Bilharzia 1300 Webbe, 1972 Niger River! Erosion increasing. Zimbabwe Metlvaine Salisbury Persistent Bilharzia and focus shift, 1970 Sudan Jebel Aultya On Nile 600 Abdel-Halek Roseires River 1972 Sennar 200 Uganda Victoria Owens Falls Onchocerciasis study, 1975 Zambia Kariba On Zambezi Bilharzia 5250 Mira, 1969 River transmission on Zambian shore. Kafue Katue 3100 Dazo and Biles, ‘Course.

MATERIALS AND METHODS

The ecological studies began in 1975 with preliminary reconnaissance surveys of all 28 reservoirs, followed by 3 years of intensive studies on the 6 most important hydroelectric reservoirs, and occasional observations on another 6 reservoirs which represent the wide range in sizes and conditions of man-made lakes in Puerto Rico (Table 2). The reservoirs were surveyed for snail populations, coliform bacteria, general water quality, algae populations and productivity, dissolved oxygen distribution, temperature, and clarity of the lake waters. Records were obtained on fluctuations in the water level and on incident solar radiation. The sampling methods and analyses used were standard for such ecological surveys and a detailed record of all data is available (1).

The six hydroelectric reservoirs studied in detail were Lakes Caonillas, Carraizo (Loiza), Dos Bocas, Carzas, Cuayo and Prieto (Figure 2). These studies began in January 1976 and ended in September 1978 with a total of 49 separate lake surveys, averaging 2.7 surveys per year, per lake. The additional six reservoirs, given occasional surveys between December 1975 and October 1978 were Lakes Carite, Cidra, Guajataca, Matrulles, Patillas, and Toro. They were surveyed a total of 16 times in the 3 years, about once a year. The remaining 16 reservoirs not included in these studies were surveyed only once, in 1975 or 1976, collecting information.

For snail populations and detailed water quality (2).

Table 2. MAJOR LAKES OF PUERTO RICO

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The basic equipment for the surveys included a mobile laboratory with appropriate vehicles and boats for continuous monitoring of the lakes, usually in remote mountain regions. The mobile laboratory used in these surveys included living accommodations for a crew of four as well as laboratory facilities for chemical titration and bacterial analyses (Figure 3). Two boats were used on the lakes, a 12 foot aluminum Jon boat for shore sampling and an 18 foot fiberglass boat with a small crane and winch for deep-water work (Figure 4). The availability of this equipment and the mobile laboratory made it possible to gather much more information on each lake than had been previously feasible. In the past only one-day expeditions with easily transported row-boats were possible due to the long trips involved from San Juan. With the new equipment, the surveys lasted a week and up to 4 men could work full-time on each lake. Sampling stations were established with marker buoys in each lake, usually at each major tributary, in the main body of the lake near the dam, and in any major branches in the lake. Each lake survey lasted four days, allowing for three 24-hour photosynthesis rounds using two light and two dark bottles at each station to determine changes in dissolved oxygen due to photosynthesis and respiration. The four bottles were suspended in a wire rack about 0.5 meters from the surface and the bottles were changed approximately the same time each day. An initial oxygen determination was made at each station every day as well. Also, the water temperature

0.1 m below the surface, the depth of visibility of a Secchi disk, and the water depth at the station were recorded each day. One liter samples were taken once during the week at each station for measurement of

Algae and chemical quality. The parameters measured later in the central laboratory were color, turbidity, hardness, chlorides, nitrogen, phosphates, and iron. Also, samples were filtered through millipore paper, fixed, and examined microscopically. Coliform samples were filtered and cultivated in the field by the standard Millipore technique and counted visually after 2 hours of incubation in a portable incubator at 34°C. Snail surveys were conducted from boats and on foot, making a complete shoreline inspection and scooping at 10 or 20-meter intervals with wire mesh dippers. When the bilharzia snails were found, they were held in a strong light for 3-4 hours to detect cercarial shedding, and later crushed and examined microscopically if found negative on the first examination. Water levels in the lakes during the surveys were obtained from records of the Water Resources Authority and the Aqueduct and Sewer Authority. Wind records and cloud cover were obtained from unpublished reports of the Federal Weather Bureau.

Small launch on Lake Dos Bocas in Utuado, Puerto Rico. This boat and an aluminum Jon boat made it possible to survey the larger lakes fairly quickly.

Results: The initial reconnaissance surveys of 1975 and 1976 were conducted primarily to ascertain the presence or absence of Biomphalaria glabrata and to select six reservoirs for intensive study in the subsequent three years. In this first survey of the 28 reservoirs, it was determined that B. glabrata was present only in Lakes Carite, Carralzo, Dos Bocas, and Garzas. However, Lakes Caonillas, Prieto, and Guayo were added to the first since they were interconnected with them by tunnels and overflow spillways. Also, Lake Carite was not a hydroelectric reservoir anymore, thus it was placed in the second set of six lakes which were selected for occasional study because they typified the many types and purposes of reservoirs throughout the island, giving a general representation of all 28 reservoirs. Water quality in an additional 1%

The estimation of lakes was derived from a single set of samples taken from the tributaries and near the dam, which were usually taken at all points on a given reservoir during the same week. The remaining two reservoirs were not sampled for chemical quality as Lake Coamo has been abandoned due to sediment accumulation, and Rio Blanco reservoir was merely a small dam on the Blanco River with virtually no storage volume. Two brackish lagoons, Cartagena and Tortugero, were also exempted from the sampling because they were coastal lagoons, not man-made reservoirs.

2. Five Major Reservoirs

The data from the intensive studies on the major reservoirs were analyzed in detail in terms of the Dos Bocas Hydroelectric system (Lakes Caonillas, Dos Bocas, and Garzas) and the Lajas Valley System (Lakes Cuayo and Prieto). The data for the sixth reservoir, Lake Carratzo which is part of the San Juan Water Supply System, will be presented separately.

Lake Caonillas conditions in the main body were represented by Stations A, B, and E, which generally had no significant differences between them, thus the data were combined (Figures 5 and 6). However, the turbidity decreased approaching Station A near the dam, probably due to sedimentation. Thus, turbidity at Station A was always lower than at Stations B and E. The number of blue-green algae was comparatively high at Station E in October 1976, while the green algae were few in number. Also, in June 1977, high concentrations of iron coming in from the Jayuya River raised the iron concentration at Station E considerably.

Station D represented the inflow from the Jayuya River and C represented the Vivi River, with some minor differences between them. The Jayuya River Station had more algae and diatoms, higher algal productivity, and a higher iron concentration. However, the phosphate and nitrate concentrations in the Jayuya River Station were slightly lower than at the Vivi River Station.

Figure 5. Lake Caonillas, the largest lake in Puerto Rico in terms of volume, discharges into

Bocas is part of a hydroelectric generating system.

Figure 6 shows the location of sampling stations on Lake Caonillas.

The main stations A, B, and C showed the trends with time and lake level (Table 3). The lake's level dropped to about mean sea level (M.S.L.) in the summer of 1977, then rose abruptly from September through November, declining again during the winter of 1978 in a fairly simple pattern (Figure 7). The water quality showed no unusual variations except for a high pH in September 1977 at the low lake level with a low respiration rate. The inflow from September to November diluted the concentration of chlorides, hardness, iron, and color, as expected. However, nutrients and phytoplankton did not change very much. Coliform bacteria counts averaged 4000 per 100 ml for the four sampled periods, indicating fairly heavy contamination. In January 1978, the water was quite clean, with a mean of 730 coliform per 100 ml. During the other three sampling periods, the counts ranged from 3000-5000 per 100 ml.

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Figure 18 shows Lake Dos Bocas as part of the hydroelectric generating system.

Lake Dos Bocas is the principal hydroelectric station in Puerto Rico (Figure 8). Although the geographical variation in water quality was not extreme, Station C is the only representative station for the entire lake due to the differences in Station B affected by the Arecibo River and Station D affected by the combined flows from the Limon River and the discharge from the Caonillas turbines (Figure 9). Seasonal variations in water quality at Station C near the dam were minor, likely affected mainly by large rainstorms. The lake was maintained between 87.8 meters and 90.2 meters above sea level during the two years of observation, a fluctuation range of less than 2.5 meters (Figure 10). This reservoir generates fairly continuously at maximum head, utilizing the upstream reservoirs for storage. At Station C, the water was the cleanest and clearest with the lowest coliform bacteria counts on the lake and the highest phytoplankton. The phytoplankton were apparently limited by very low nutrients (Table 6). The Secchi disk could be read at a mean depth of 1.34 meters; the water became more turbid and colored during the rainy season. There was sharp oxygen stratification at a depth of 5 meters with virtually no oxygen at deeper levels and 6 to 7 mg/l above that depth. However, the stratification was not caused by a thermocline but more likely due to good vertical mixing in the upper layer and a high benthic oxygen demand (Figure 11).

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Lake Dos Bocas, situated in a system of seven hydroelectric power stations, is the lowest lake for generating power in Puerto Rico.

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1. "Best Experiences Yet"

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"Sincerely, Karen John, University of Sofia, Area 1.
Page 26
Sugar Mill in Norway executed at 920654 cows at - 9261. 'SvZuvve' was the survey on 3rd day of the quarter.
Page 29
Lake Guayo
Lake Guayo, one of the most attractive lakes in Puerto Rico, is located near Castañer. Stations C and D represent the main portion of the lake while Station A was the entrance for the Guayo River and Station B the entrance of the Cidra River. (Figure 15). Nutrients were generally low except in May 1978 when the Total Phosphates rose to 0.08 mg/l, accompanied by a drop to zero nitrogen. This followed a period of extremely clean water during the Winter of 1978 (Table 6). The lake was

quite full with a stable level at about 945 M from September 1977 through June 1978. The previous year however the lake had fluctuated severely dropping to 1410 ft or 430 M in August 1976 and rising to 1460 feet or 445 M in December 1976, a range of 15 M (Figure 16). The level dropped again in July of 1977, but only to about 1430 feet or 436 M.
Page 30
Figure 15
Location of Sampling Stations on Lake Guayo.
LAKE GUAYO ° oo TK GRAPHICAL, SCALE
Page 31
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Page 33
Lake Prieto
This lake is one of the smallest studied, and was relatively..."

"Polluted. Station A near the dam was the most representative station (Figure 17). Nutrients were relatively high with a mean total phosphate concentration of 0.02 mg/l, nitrogen of 0.33 mg/l, and iron of about 1 mg/l (Table 7). Color and turbidity were also high, and the Secchi Disk depth was only 0.5 m. The lake level was quite steady at the level of the overflow to the diversion tunnel, as the overflow has a very large capacity in comparison to the mean flow of the Prieto River, thus lake level was not recorded.

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36 Snail Populations

Snail populations in the 5 major hydroelectric reservoirs showed the strong interaction of Marisa cornuarietis with Biomphalaria glabrata, with the eventual disappearance of the latter from all reservoirs except Lake Prieto (Table 8). By the third and fourth quarters of 1978, only Lake Prieto contained B. glabrata, while all others contained M. cornuarietis. The B. glabrata in Lake Prieto were usually infected with M. cornuarietis (Figure 18). Schistosoma mansoni

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Figure 18. This muddy shore on the northern bank of the Linn"

River was the last habitat of Biomphalaria glabrata in Lake Dos Bocas. Large numbers of Marisa cornuarietis were also present here. Glabrata was not found again after late 1976.

39 Water temperatures were recorded each day during the photosynthesis surveys. These measurements were taken at each station 10 centimeters below the surface. These surveys usually occurred during mid-morning, a time when water temperatures approximate the mean daily temperature in Puerto Rican lakes.

The 11 am temperature has been found to closely approximate the mean daily temperature (Jobin and Ferguson, 1976, PRNC Report #201). Hourly graphs of temperature for each survey make it possible to estimate the mean monthly temperatures for the 5 lakes, using the 11 am value (Figure 19). As expected, the highest mean temperatures occurred in Lake Dos Bocas which is closest to sea level, and the lowest temperatures occurred in Lakes Garzas and Prieto, the highest lakes of the group (Table 9).

The water temperatures in the lakes reached minimums between December and March, the cool dry season, but maximum temperatures occurred any time between June and November (Figure 20). By using the seasonal curves for water temperature for each lake, it was possible to estimate the temperature range for breeding of M. cornuarietis (Table 10). Many cases of the ampullariid snail were found at temperatures from 23.0°C to 25.0°C, but no eggs were seen at lower temperatures of 18.0°C or 19.7°C, nor were they seen at higher temperatures of 25.2°C, or 26.0°C. This indicates the optimal range for M. cornuarietis may be somewhat lower and narrower than the range for B. glabrata which is 20° to 30° with a maximum at 25°.

Comparison of Annual Mean Temperatures and Spillway Levels at 5 Major Hydroelectric Reservoirs in Puerto Rico:

Annual Mean Spillway Temperature (°C), Elevation (in Feet and Meters)

Coonittas: 22.5°C, 826252 ft
Dos Bocas: 26.6°C, 29590 ft
Garzas: 22.4°C, 736 ft
Guayo: 28.0°C, 171448 ft
Prieto: 22.0°C

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Table 10: Months during which eggs of Marisa cornuarietis were observed in lakes of Puerto Rico, 1975-1975. Mean Temperature in Egg masses, Lake, Month, Centigrade Degrees of Marisa (estimated):

Dos Bocas, Mar 78, (2.9), Not seen

Dos Bocas, Dec 76, 26.0, Not seen

Garzas, Feb 78, (9.7), Not seen

Garzas, May 78, (24.2), Many

Garzas, Jun 77, 25.0, Many

Garzas, Dec 77, 23.0, Many

Guayo, Jun 77, (25.2), Not seen

Prieto, Jun 78, 23.0, Many

Prieto, Mar 75, 18.0, Not seen

Prieto, Jul 77, 25.0, Not seen

Secchi Disk Measurements: The depth at which a Secchi disk is no longer visible gives an indication of the depth of the photic zone, the depth which light penetrates significantly to cause algal productivity. There were significant geographical variations in Secchi depths between stations, only the average was calculated for each lake survey. The clearest lake was Lake Guayo with visibility up to 3.6 meters (Table 11). However, 3 of the lakes had visibilities less than 1 meter, Lakes Caonillas, Dos Bocas, and Prieto. The lowest visibility was in Lake Prieto (0-10 m). Significant variations occurred in the depth of visibility during the various seasons of the year. Minimum visibilities occurred during the Second Quarter (April, May, June) in Lakes Caonillas and Garzas, but during the Fourth Quarter (October, November, December) in Lakes Dos Bocas and Prieto. Maximum visibilities occurred during the Fourth Quarter for Lakes Caonillas and Garzas with no particular pattern in the others. The periods of low visibility correspond to the two rainy seasons but it was not clear why Caonillas and Garzas should have their best visibility during these same rainy periods.

Table 1: SEASONAL VARIATIONS IN MEAN OF SECCHI DEPTH, BY

Page 47 Table 12 Mean Shore Slope at High Water Level of 5 Major Hydroelectric Reservoirs in Puerto Rico (Taken from maps at scale of 1:20,000 with 10 meter contour intervals. Slope given is ratio of horizontal to vertical distance).

Lake Mean Shore Approximate Kilometers of Slope Shoreline by class of slope

From: Caonilas 2.3 1.0 Bocas 3.5 Garzas 0.0 3.5 Guayo 5.1 6.5 Prieto 3.021 1.0

Page 48 Seven Representative Lakes: Results from the annual surveys made on the 6 reservoirs of Lakes Carite, Cidra, Guajataca,

Matrullas, Patillas, and Toro were combined with data from Lake Carratzo to indicate the general range and variation of conditions in these representative reservoirs (Table 13). In general, the water quality conditions are not remarkably different, with Lake Carratzo representing the polluted extreme for Puerto Rico and Lake Matrullas, although highly colored, representing the least contaminated condition. All of the reservoirs, except Lake Matrullas and Lake Toro, supported large numbers of snails and usually 3 or 4 species at the same time (Tables 5 and 14). The most ubiquitous snail was the Ampullarid Marisa cornuarietis, which was found in all lakes except Toro.

The Thiarid snail Tarebia granifera was also very common and usually found in such large numbers that they defied counting (Figure 21). Biomphalaria glabrata, the planorbid snail which transmits Schistosoma mansoni, was found in five of the hydroelectric reservoirs, and in Lake Prieto, the snails were shedding the cercarial forms of the parasite (Table 8). Another parasite, Fasciola hepatica, which infects cattle in Puerto Rico, was found in Lymnaed snails in Lake Chora (Table 14).

All Biomphalaria glabrata recovered in the surveys were examined for schistosome infections, but observations on trematode infections in other snails were made only occasionally. In every instance, the numbers of B. glabrata recovered were very small and the snails were confined to a single habitat. These habitats were shallow with usually less than 0.1 meters of water, insufficient depth for N. cornuarietis. Except for Lake Carite, the habitats were always near the entrance of a tributary stream from a watershed known to contain a population of B. glabrata, suggesting they were recent arrivals washed in from upstream. In the exception on Lake Carite, the B. glabrata were found in a broad swampy overflow which often had only a trickle of water passing over it, insufficient for the establishment of a strong population of cornuarietis. Thus, these small habitats.

"Served as refuges for the last remnants of the B. glabrata populations. The total number of B. glabrata found in these places never approached 100 snails and usually fewer than 10 snails were found after intensive searching. The transitory nature of these remnant populations is further documented by the occasional absence of B. glabrata from these lakes during one or more of the surveys before 1978, despite extra searching when they were not encountered. In Lake Garzas, the planorbid snails were found only twice in 5 surveys, and in Lake Prieto 2 out of 4 times. This supports the hypothesis that they were snails washed in from upstream and unable to establish strong populations due to pressure from cornuarietis.

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Figure 21. Tarebia granifera was found in almost every lake, sometimes in uncountable numbers. It usually inhabited highly oxygenated water such as exposed shorelines, whereas Biomphalaria glabrata were found in quiet, private areas.

The final surveys in 1974 indicated that the long term trend of elimination of Biomphalaria glabrata by Marisa cornuarietis was continuing. The only lake containing B. glabrata at the end of 1978 was Lake Prieto. The planorbids had disappeared from the overflow of Lake Carite, from the bank of the Linbn River in Lake Dos Bocas, from the shallow pool at the entrance to Lake Garzas, and from the swampy fringes of Lake Carratzo (Figure 22). In each of these sites, large growing populations of Marisa cornuarietis were found. However, in Lake Prieto the Marisa cornuarietis were clearly being limited by shallow water, as the B. glabrata occurred in a swamp at the entrance of the river into Lake Prieto, where vegetation was thick, and water level was shallow.

FIGURE 22. BIOLOGICAL CONTROL OF BILHARZIA SNAILS IN RESERVOIRS OF PUERTO RICO, 1956-1978. MARISA CORNUARIETIS BIOLOGICAL CONTROL AGENT. HOST OF

RESERVOIRS INHABITED BY SNAILS, 1958: YEAR OF SURVEY 54

Remaining 14 Lakes:

The remaining 14 lakes showed normal ranges of water quality, although the water had less color than the 12 reservoirs studied in detail (Table 15). None of the remaining 18 lakes contained populations of B. glabrata although M. cornuarietis, T. granifera, and many others were found (Table 16).

Table 1: Water quality of 14 reservoirs in Puerto Rico during a reconnaissance survey of 1975 and 1976 (3). Standard Units In mg/liter:

Lake No. of Samples | Color | Turbidity | Chlorides | Total Iron | Nitrate Hardness | Phosphates and Nitrite

Adjuntas: 3 | 7 | 2 | 0.2 | 0.2 | 0.2 | 168

Comerio: 4 | 8 | 1 | 0.3 | 0.1 | 0.5266

Comerio #2: 2 | 8 | 5 | 0.1 | 0.3 | 0.6 | 10

Guyabal: 6 | 5 | 8 | 0.1 | 0.0 | 0.0 | 0.0

Guineo: 5 | 203 | 0.0 | 0.0 | 0.0 | 0.0 | 2

Jordan: 2 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 157

La Plata: 5 | 5 | 16 | 0.0 | 6.2 | 0.2 | 0.0

Las Curias: 5 | 5 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0

Loco: 2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0

Luckett: 23 | 5 | 8 | 0.0 | 0.2 | 0.3187

Pellejas: 2 | 6 | 10 | 0.0 | 0.5 | 0.0 | 1

Toa: 2 | 0.1 | 0.6 | 0.0 | 0.0 | 0.0 | 30

Vivi: 2 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0

Yahuecas: 2 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0

Vaca: 1 | 0.2 | 0.2 | 0.0 | 0.0 | 0.0 | 14

Table 16: Snail Species in 14 minor reservoirs of Puerto Rico, 1976 to 1978.

Lake | Snail Species Present

Adjuntas: N/A

Comerio: N/A

Comerio #2: N/A

Guayabal: N/A

Guineo: N/A

Jordan: Present

Las Curias: N/A

Loco: N/A

Luckett: Present

Pellejas: N/A

Toa: Present

Vivi: N/A

Yahuecas: N/A

Key:

Bg = Biomphalaria glabrata

No = Marisa cornuarietis

Ty = Tarebla granifera

Pa = Pomacea australis

Ph = Physa cubensis

Ly = Lyanea columella
Tr = Troplcorbis riseii
The major portion of the data collected deals with the Lakes of the Dos Bocas Hydroelectric System (Table 17) and the Lajas Valley Irrigation and Hydroelectric System (Figure 23). Over the past 15 or 20 years, there have been general indications that the original focus of bilharzia transmission around the Dos Bocas Reservoir System has decreased significantly while the prevalence by...

Skin tests in the population near the reservoirs of the Lajas Valley System have held steady or increased (Table 1s).

TABLE 17: HYDROELECTRIC RESERVOIRS IN THE DOS BOCAS SYSTEM

Reservoir	Year of Construction	Municipality
Lake Dos Bocas	1942	Arecibo and Utuado
Lake Caonillas	1948	Utuado
Lake Jordan	1950	Utuado
Lake Pellejas	1950	Adjuntas
Lake Vivi	1950	Utuado
Lake Adjuntas	1950	Adjuntas

Figure 23: The Dos Bocas and Lajas Reservoir System in Puerto Rico, Atlantic Ocean, Caribbean Sea

4. ADJUSTED POSITIVITY FOR SCHISTOSOMIASIS OBTAINED FROM SKIN TEST OF FIFTH GRADERS IN PUERTO RICO, 1963, 1969, and 1976 FOR THE AREAS SURROUNDING THE DOS BOCAS AND THE LAJAS RESERVOIR SYSTEMS.

Watershed	1963
Dos Bocas System (Utuado, Jayuya, Adjuntas)	2.95
Lajas System (Yauco, Guayanilla, Penuelas)	1.6
Upper Yauco, Castañer	2.5

*Adjusted for change in methodology from Kagan et al, 1966 (2). Corrected, Ruiz et al, 1973 (3). From Negron and Nazario, 1975 (4).

During the Second World War, construction began on a complex of six interconnected reservoirs near Utuado, a classic focus of schistosomiasis. Lake Dos Bocas is the largest of the six and receives the flow from turbines at Caonillas. Lake Dos Bocas also receives the flow from Lakes Jordan, Pellejas, Vivi, and Adjuntas (Figure 23). The population around Utuado was about 10,000 in 1960. Because of the relatively large contributing watershed and because it is now used primarily for short-term supplemental power generation, Lake Dos Bocas is maintained at a fairly constant level. The other lakes, however, are subject to large fluctuations, as was Dos Bocas before 1950.

The combined system generates about 63 million kilowatt hours per year. There is very little direct utilization of the water for irrigation. Although a survey in 1955 did not encounter S. gla in Lake Dos Bocas or in Lake Caonillas (Harry and Cumbie, 1956), a more detailed survey a few years later discovered a small population.

The population in Lake Dos Bocas at the mouth of the Limón River, the eastern tributary, as well as a few small colonies in swamps adjacent to the western tributary, the Arecibo River, is significant (Figure is absent). The lake was filled with floating water hyacinth and the thiarid snail Tarebia granifera (Ritchie et al., 1962). A regular inspection system was instituted on Lake Dos Bocas, Lake Caonillas, and Lake Adjuntas in 1956, demonstrating the presence of B. glabrata in Lake Dos Bocas from 1956 to 1976.

Primarily in the same small colony on the Limón River (Jobin et al., 1977). The planorbid snail was also found in Lake Caonillas as late as 1966, but it was not found after intensive searching in 1976. The two times Lake Adjuntas was surveyed, it did not contain B. glabrata. Lakes Jordin, Vivi, and Pellejas were not surveyed until 1976 because of their small size and inaccessibility. They did not contain B. glabrata in 1976 (Jobin et al., 1977). Lake Dos Bocas and Lake Caonillas contained enormous numbers of Tari 2 granifera in 1976, primarily on exposed red clay shores (Jobin et al., 1976). In the watersheds contributing to these lakes, the snails have been found in many places both upstream and downstream of the lakes, especially on the flood plains of the Vivi and Arecibo River near Utuado, in the Jayuya streams which contribute to Lake Caonillas, in the Limón River which contributes to the eastern branch of Lake Dos Bocas, and in the lower flood plain of the Arecibo River, below the entire system. Despite the presence of B. glabrata throughout the watershed, it was somewhat surprising that none of the lakes contained a significant population of the snails. The molluscan herbivores in Puerto Rican lakes are not generally subjected to significant predation by larger forms, thus their population dynamics are regulated by intra-species and inter-species competition for food and habitat space, by suitability of oviposition sites, by water temperatures and in the case of B. glabrata, by predation on eggs and young from M.

Cornuarietis. Other minor mechanisms of population regulation may be predation by fish, and other larger animals.

Snail death rates are functions of aging, diseases including parasitism, mechanical stress due to wave action, and perhaps chemical deficiencies, primarily oxygen. However, most lakes in Puerto Rico seem quite suitable chemically for snail populations. One snail, which is found infrequently, is apparently restricted by lack of suitable oviposition sites. Pomacea australis is found in large numbers only along the rocky shores of Lake Patillas, near the entrance of Rio Patillas and Rio Marin. It is found in small numbers in a few other lakes such as Carratzo, Carite, Cidra, and Guayo. This large snail lays its eggs on vertical faces above the water surface by crawling out at night, thus it needs rocks or other solid vertical surfaces which emerge above the water in lakes with fairly stable levels during the oviposition sites, since Bs glabrata and Marisa usually lay their eggs on vegetation or miscellaneous debris. Biagra nifera is ovoviviparous and coincidentally the most ubiquitous and numerous aquatic snail on the island, found in large numbers in all watersheds. The factors determining distribution and numbers of Lymnaea and Physa in the lakes are not understood. Their numbers are always few with no discernible patterns to their distribution. Perhaps the amphibious Lymnaea is affected by terrestrial conditions, and perhaps Physa requires high concentration of organic matter. Helisoma is absent from all lakes, apparently being very sensitive to contaminants and a very weak competitor against other snails under Puerto Rican conditions.

The most important determinants to be considered in general analysis of snail populations are the water temperature, food (peri-phyton), habitat volume, number of same species, and number of other snails. If one compares the reservoirs in the Dos Bocas System, where bilharzia prevalence has been declining steadily since the reservoirs were

The text appears to be a mix of coherent sentences and random characters, possibly due to a scanning or transcription error. The coherent part of the text could be fixed as follows:

"The construction of reservoirs in the Lajas System has led to an increase in the prevalence of bilharzia. Some ecological differences, possibly resulting from the construction, might be responsible for this. In the Lajas system, Biomphalaria populations have remained stable in Lake Prieto, usually infected with S. mansoni. However, planorbids have gradually disappeared from the Dos Bocas system, and no infections have been found in these species. The lakes of the Lajas System had significantly higher concentrations of hardness, phosphates, nitrates, and nitrites than the lakes of the Dos Bocas System (refer to Tables 19 and 20). The net productivity and the ratio of net productivity to respiration were lower in the Lajas System. However, other parameters, including coliform bacteria and phytoplankton populations, showed no significant differences. A second interesting comparison can be made regarding the suitability of lakes for Marisa cornuarietis, based on a comparison with Lake Guayo, which undoubtedly supports the largest and most productive population."

Unfortunately, the rest of the text is indecipherable. It might be best to obtain the original document or a clearer version to ensure accurate transcription.

On this day, 300"; Length 500, Serial number 90090" Take off at High Sea South at a temperature of 200°0 ; Speed 200, Altitude 2000-0; Old THO THO Take a break at Saxewdeous Teo, woe; Sem = SOT et eT Os 40r ort 1/6a at *os6y se ssoupaey ron eaoyag _ofeno ‘eau sezae) _se00g $0 _SeTTTUORD wanes sefer at Foxe works se00g s0q UT 246) sxoyoueses swoashs sefey pue worksks se00g og uF Saye] vosKiaq Szmr9urseY KaqTEND J9IeK UY £90u239)) FP UEOTITUOIS oz a1ae

6 Marisa cornuarietis in Puerto Rico, and Lake Caonillas which is very similar in many respects to Lake Guayo but which contains only a few M. cornuarietis, and sometimes none. While Lake Guayo had more nutrients than Lake Caonillas and a deeper photic zone, the net oxygen productivity at the surface of Lake Caonillas was twice the productivity of Lake Guayo, with similar ratios of oxygen productivity/respiration (Table 21). The higher oxygen productivity was confirmed by the high algae counts in Lake Caonillas. This suggests that algae is not as important for cornuarietis as is Littoral vegetation. With the flatter shoreline of Lake Guayo, deeper photic zone and higher nutrients, the amount of rooted shoreline vegetation was enormous, while in Lake Caonillas the steep shorelines and low nutrients produced virtually no littoral vegetation, with erosion of most of the shore.

Table 21 Comparisons of lakes as habitats for Marisa cornuarietis.

Parameter	Ideal Habitat for Marisa cornuarietis	Very poor Habitat for Marisa cornuarietis
	Lake Guayo	Lake Caonillas
Chlorides-ng/1 n ‘	Marcnessong/1 09	M950, we no
pH	7.8	7.5
Total Phosphates as P	0.03	0.01
Nitrates and Nitrites as Neng/t	0.10	0.06
Iron	0.06	0.13
Secchi Disk ne Ma	Turbidity 5.0	10 22 colors
Net Productivity mg/l 0,/day	0.7	1.5
Respiration-ng/} 0,/day	0.5	1
Coliform bacteria per 100 ml	aus 3975	
Blue-green algae per 100 al	4836	180
Green algae per 100 al	1160	
Diatoms per 100 al	ae 6m	
Flagellates per 100 al	178	170

70 References Preliminary da + Raymond Brown, et al, 1979 "Preliminary Results from a Survey of Water

"Quality in Some Puerto Rican Lakes", CER Report #15, Center for Energy and Environment Research, Caparra Heights Station, Puerto Rico.

2. Jobin, W. R. et al, 1977. "Biological Control of Biomphalaria Glabrata in Major Reservoirs in Puerto Rico". American Journal of Tropical Medicine and Hygiene, Vol. 26, 1011-1028.