HYDROELECTRIC RESERVOIRS IN PUERTO RICO

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ECOLOGICAL REVIEW OF HYDROELECTRIC RESERVOIRS IN PUERTO RICO

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Summary

A review of published literature and available data on the ecology of hydroelectric reservoirs and other lakes in Puerto Rico yielded various studies on unrelated elements in the aquatic ecology, but very few comprehensive investigations. The majority of the island-wide studies pertained to surveys on snails related to the parasitic disease bilharzia. A survey of 28 major lakes in 1976 showed that Biomphalaria glabrata had gradually been replaced from most of the lakes by Marisa cornuarietis and Tarebia granifera, two foreign snails which do not transmit bilharzia. Of the 17 lakes containing B. glabrata in 1956, only 8 remained infested in 1966 and only 5 in 1976, twenty years after the introduction of Marisa cornuarietis. Although the trend indicates that the lakes may be safe from transmission, a monitoring system is necessary before the lakes could be used for recreation.

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ECOLOGICAL REVIEW OF

Hydroelectric Reservoirs in Puerto Rico
by William R. Jobin, Frederick F. Ferguson, and Raymond A. Brom

1. Introduction

There has been an increase in the construction of hydroelectric reservoirs in the tropics, and the significant ecological changes caused by these reservoirs have often affected the ecology of local populations. This includes increases in parasitic Schistosoma, also known as Bilharzia.

The increased trend in hydroelectric projects has been exemplified by the Aswan Dam in Egypt, Kariba Dam on the Zambezi River, and Lake Volta in Ghana (Table 1). Recently, additional emphasis in Latin America was outlined by Mr. Antonio Ortiz Mena, President of the Inter-American Bank on May 19, 1975, in Santo Domingo.

The sectoral distribution of the loans authorized in 1974 reflected a trend determined by the global fuel and food crises. The hydroelectric capacity and food production are connected to the utilization of a common element essential to both sectors - water. For this reason, the Bank is particularly concerned with promoting the rational use of Latin America's vast water resources.

The total of $384.1 million of the Bank's 1974 loan portfolio helped increase power production in the region, making electric power the second largest individual sector. The approved loans were distributed as follows:

- $162.5 million to help finance hydroelectric projects that will promote power development, irrigation, and other farm improvement facilities in Costa Rica, Chile, and Ecuador.
- $93 million to increase hydroelectric potential, including rural electrification cooperative programs in Argentina and Ecuador.
- $95 million in binational credit to assist in financing the second stage of construction of the Salto Grande plant on the Uruguay River that will supply energy to Uruguay and the coastal provinces of Argentina.
- $33.6 million to build power distribution systems in Paraguay.

These bring the cumulative value of loans granted in this sector to $1.57 billion. Such resources are helping.

To finance the installation of 19.1 million kilowatts of power, of which 12.5 million kilowatts represent hydroelectric plants. The energy produced by these plants would require the consumption of 69 million barrels of oil per year with a value equal to 3623 million. Authorized loans are at hand.

Hydroelectric Reservoirs with Potential Impact on Human Health in Africa:

Lake Area, Country, Lake Dam Location, Health Problems When Full:
1. Egypt, Aswan on Nile River, Increased health potential, 5000 EleSayed, 1964.
2. Ethiopia, Tana Condar on Nile River, Ferguson, Rutz, 1970.
3. Ghana, Volta Akosombo on Volta River, Severe outbreak of Bilharzia, $500 Paperna, 1969.
4. Ivory Coast, Kos Nandana, Potential for Bilharzia, 1970.
5. Morocco, Lefttater, 1972.
6. Mozambique, Cabora Bassa Above Tete on Zambezi River, 2700, 1972.
7. Nigeria, Kainji New Bussa on Niger River, Bilharzia, 1300 Webbe, 1972.
8. Rhodonia, Melvaine Salisbury, Barnish and White, 1970.
9. Sudan, Jebel Aulia on White Nile River, 600 Abdel-Matek, 1972.

10. Uganda, Victoria Falls, Onchocerciasis, Caddy, 1975.
11. Zambia, Kariba on Zambezi River, Bilharzia, 5250, 1969.
12. Zambia, Kafue on Kafue River, 3100.

Miles of transmission and distribution lines are set to improve distribution systems in 2,392 communities. Our purpose in this report is to review existing data on hydroelectric reservoirs in the tropics, especially those in Puerto Rico, to highlight current problems and to identify future concerns. Our data from Puerto Rico derives from surveys on the ecology of Bilharzia and from records of Puerto Rican Water Authorities.

A. Hydroelectric Reservoirs in the Tropics

The tropical region which has experienced the greatest problems with Bilharzia in new hydroelectric impoundments is Africa (Table 1). The Bilharzia snails found most commonly in these African lakes have been of the genus Bulinus. Shallow papyrus swamps bordering Lake Victoria pose particular snail control problems. Sennar Reservoir has...

Clear water with adequate vegetation for the support of Bulinus, which was then regularly seeded into the Gertra Irrigation District (Sharaf El Din, 1955; Rahman and Sharaf El Din, 1961). At Lake Kariba, the problems of massive floating fern, Salvinia auriculata, threatened navigation and was a suitable habitat for snail vectors (Holm et al., 1969). Bilharzia posed a threat at Stavonga, an area designated for recreation and tourist development on Lake Kariba (Mirza,1965). The Volta Reservoir has a recurring problem of urinary bilharzia in fishing villages (Paperna, 1969). The same potential exists at Lake Nasser behind the Aswan Dam (Webbe, 1972). The transmission of bilharzia on these lakes is concentrated at local watering points and village shores; this simplifies control possibilities to some extent but leaves a clouded future because of the vast lengths of shoreline in lakes such as Volta. In the Western Hemisphere, the ecology of Biomphalaria glabrata has received considerable study in the natural lake of Venezuela and Brazil (table 2). In Lake Valenciana near Maracay, Venezuela, Biomphalaria is not common although there is massive colonization of Biomphalaria peregrina, a laboratory host of the schistosomes (Ferguson and Chrostowski, 1975).

Table 2: Major Reservoirs in Latin America with Potential Health Problems

Reservoir Name and Purpose of Reservoirs | Source of Information

1. Dominican Republic
2. Paraguay
3. Uruguay
4. Venezuela
5. Furnas in Minas
6. Gerais; Hydroelectric
7. Pampulha in Belo Horizonte, MG
8. Tres Marias in MG, Hydroelectric
9. Jupia-Tiha
10. Soteira 4.6 Megawatt Complex in Sao Paulo, Hydroelectric

11. Paulo Afonso on Sao, 3.8 Megawatt, Hydroelectric
12. Taveras on Yaque del Norte River, Hydroelectric and Irrigation
13. Bao in Cibao Valley, Hydroelectric
14. Acaray Hydroelectric
15. Salto Grande Regional Hydroelectric
16. Valenciana in Maracay, Natural

Reference: Pauling, E. (Interamerican Development Bank, 1975); Pauling, B. (1975); Speech by

President Joaquin Balaguer was, in 1975, alongside Dr. H. Ferrer Farta, a protector of the lake against pollution. The ecology of Lake Paspulha at Belo Horizonte, Brazil has been studied with regard to possible biological control of B. glabrata. In the Dominican Republic, Tyes and Maldonado (1969) showed special interest in the two hydroelectric reservoirs under construction at Tavares and Cibao. During the past decade, B. glabrata appeared to be absent from lakes of crater origin in Grenada, Montserrat, St. Kitts, and St. Vincent. The Cures Reservoir has been free of B. glabrata in numerous surveys of St. Croix water bodies since 1953. The municipal water supply reservoir of St. Kitts contained B. glabrata prior to molluscicidal elimination during 1958 (Sebastian et al., 1960). Several similar units in Grenada lacked the bilharzia snail during 1970 studies but contained large populations of B. straminea (Ferguson and Buckmire, 1974), which is a natural host for schistosomes in parts of Brazil and has proven to be a potential host in Grenada (Richards 1973). The observations of F.F. Ferguson and K.W. Buckmire; 46.8. Richards; 5scotchman; author's observations.

In Puerto Rico, there are 28 reservoirs which were constructed during 1913-1975 (Figure 2). Seventeen of these impoundments presently provide hydroelectric power (Table 3 and Figure 3), and some ecological information is available for each lake, generally related to studies on bilharzia. There are no natural lakes in Puerto Rico, except for the brackish lagoons of San Jose, Torrecillas, Pinon and the freshwater lagoons of Cartagena and Tortuguero (Reyes de Ruiz; 1971; Cendelas and Candelas, 1964; Marry and Aldrich, 1958; Harry and Cumbie, 1956). In addition to the major lakes, there are many small impoundments constructed for agricultural and fishing purposes. More than 800 standard USDA-SCS farm ponds are situated in the drought-prone central portion of the island. About 30 units have

The text has been surveyed for 2. glabrata, and although the snail was found in about half of the ponds, they are not usually important for transmission. Specially constructed night-storage ponds are used on the South coast for irrigation and 8. glabrata has been controlled in 100 of these ponds using Marisa cornuarietis (Rutz Tibeh et al, 1969). When comparing the ecology of such small impoundments with large man-made reservoirs, extrapolations of ecological parameters must be made with caution. It's important to understand why bilharzia snails are present or absent from watersheds contributory to hydroelectric impoundments. However, perusal of more than 300 titles of various reports on freshwater bodies in Puerto Rico indicates that ecological considerations affecting molluscan populations have been neglected (Cordero, 1969; Bogart et al, 1964). The most relevant reports for the study on lacustrine plankton include Candelas and Candelas, 1964, and that on hydrography of schistosomiasis (Crooks, 1967). Other reports make general references to the richness of the aquatic biota, including insects (Garcia, 1938; Klots, 1932; Martorell, 1945; Wolcott, 1948), birds (Biaggi, 1970; Danforth, 1925; Leopold, 1963) and fish (Erdman, 1972; and Ferguson, 1975). Terrestrial plants have been well studied (Odum and Pigeon, 1970; Britten and Hilson, 1930; De Otero et al, 1945; Velsz and Van Overbeek, 1950; Little and Wadsworth, 1964), and much is known about aquatic and semi-aquatic plants (Pratt, 1947, 1948; Reyes de Rutz, 1971). Both terrestrial snails (Aguayo, 1961, 1966; Van der Schalee, 1948) and freshwater snails have received definitive study (Abbott, 1952; Baker, 1945; Ferguson, 1958; Ferguson and Gerhardt, 1959; Ferguson and Richard, 1963; Harry and Hubendich, 1964; Hubendich, 1955; Parod, 1960; Reyes de Ruiz, 1971;

Richarda, 1965; Richards, 1964; Richards and Ferguson, 1962; Watlington, 1955).

Table: Rating of Hydroelectric Reservoirs in Puerto Rico by Power Production

Power Production (Kilowatts)	Present Volume (Million Cubic Meters)	Length of Shoreline (Kilometers)	Reservoir
20,000	1.60	161	Yahueca
-	0.60	4.0	Prieto
-	0.12	2.0	Oro Diversion to Prieto
18,000	14.65	39.47	Dot Bocas
17,600	-	60.46	Ceont tas
12,240	5.80	-	Cerzas
8,640	3.58	-	Macrutlas
2,600	24.67	-	Carraizo
1,920	-	222	Gutnes
-	0.79	68	Rio Blanco Loco
-	0.57	-	Jordan Diversion to Caonitlas Adjuntas
-	0.36	16	Pellejas

II. Impact of Reservoirs on Bilharzia Snails

In an attempt to assess the role of major reservoirs in the transmission of bilharzia, a complete survey was made of all lakes on the island between July 1975 and June 1976, in cooperation with the Department of Health. A five-man crew with a boat inspected the entire shoreline of each lake and identified all live snails. In addition, water samples were taken at each tributary and in the main body of the lake near the dam. The samples were analyzed by standard methods (APHA, 1973).

The survey showed that only 5 lakes contained Biomphalaria glabrata, while 18 lakes harbored Marisa cornuarietis and 14 lakes contained eb granifera (Table 5). Four other species of aquatic snails were scattered throughout the lakes but in much fewer numbers than the first 3 species mentioned. Seven of the lakes harbored floating water hyacinth and generally large amounts of vegetation, but the other 23 had rather sparse quantities of vegetation. Although the lakes had fairly high turbidity and color, only 7 of them had significant levels of phosphates, indicative of sewage pollution or eutrophication (Table 6).

A. Previous Snail Surveys

In previous studies, only nominal attention was paid to the presence of B. glabrata in reservoirs during 1952-1954 (Harry and Cumbie, 1955; Harry and Aldrich, 1958; Harry et al., 1957; Pimentel and White, 1957, 1958, 1959). Cursory searches of Lakes Guajataca...

The following is the corrected text:

In Guineo, Dos Bocas, Patillas, Guayabal, and Coamo, there were several failed attempts to locate B. glabrata during 1952-1954. To clearly define the presence or absence of the snail in all reservoirs, a comprehensive survey was completed during 1956-58. A two-man team walked accessible shorelines and used a UV light to conduct the survey.

Table: Major Lakes of Puerto Rico, Snails and Vegetation, 1976

Lake Water General No.	Name	Bgt	Me	Tg	Pa	Ph	Ly	Tr	Hyacinth	Vegetation
1	-	x	-	-	-	-	-	-	-	Sparse
2	-	-	-	-	-	-	-	-	-	Sparse
3	Carite	x	x	-	-	-	-	-	-	Sparse
4	Carraizo	x	x	x	-	-	-	-	-	Abundant
5	-	-	-	-	-	-	-	-	-	Sparse
6	-	-	x	x	-	-	-	-	-	Moderate
7	-	x	-	-	-	-	-	-	-	Abundant
8	-	x	x	x	x	x	-	-	-	Moderate
9	-	x	x	x	-	-	-	-	-	Moderate
10	-	x	x	x	-	-	-	-	-	Moderate

From this first island-wide survey, it was determined that 17 of the lakes contained populations of B. glabrata (Table 7). The use of chemical molluscicides for snail control was avoided for the lakes because many of them also served as drinking water supplies. Thus, attempts were made, beginning in 1958, to employ Marisa cornuarietis as a competitor or predator snail to thus reduce the populations of B. glabrata. Additionally, observations were made on the encroachment of another suspected competitor snail, Tarebia granifera.

(Ferguson, 1973; Ferguson, 1975). Marisa cornuarietis was hand-scattered in batches of 50 or more at several points along the shore of each lake from 1958 to 1961. The concurrent spread of Tarebia granifera was apparently due to natural agents such as birds. Several other species of snails were seen in the reservoirs during this time in much smaller numbers, including Physa cubensis, Helisoma sp., Ferrissia sp., and Ampullaria or Pomacea, a foreign import (Watlington, 1955).

Ten years after the initial island-wide survey, a second similar study was completed on all the lakes, searching all the shorelines and listing the presence or absence of B. glabrata, Marisa cornuarietis, and Tarebia granifera, the three most common and profuse species. Due to the introduction of cornuarietis, this snail was stable in 15 of the lakes by 1966, while B. glabrata was found in only 8 (Table 7). Biological control of Biomphalaria glabrata by Marisa cornuarietis is a dynamic process, not an absolute change.

Snails are thought to be carried about on the muddy feet of birds and cattle, and the reservoirs are continually being reinfested by natural means from upstream colonies. Great losses of snails occur with constantly shifting water levels, determined by hydroelectric power generation and irrigation usage, as well as drawdowns for urban water supply. However, the stranding does not necessarily eliminate all the snails and they soon repopulate the habitat if conditions are favorable.

Thus, the 20-year record of snail populations, concluding with the final comprehensive survey in 1976, is a summation of the biological interaction of these snail species in response to the dynamic nature of the lake habitats, and the various means of reintroduction of the snails. By 1976 the balance had shifted in favor of M. cornuarietis, which was found in 21 lakes, often in very large numbers (Table 7). At the same time, B. glabrata was present only in 5 lakes and in 3 of these less than... (Text ends abruptly)

100 snails were found after several days of searching by a five-man crew (Tables 7 and 8). In studies on small ponds, competition has often eliminated certain types of vegetation due to the large number of snails which have overlap. However, in these large lakes, although Marisa cornuarietis consumes some of the types of aquatic vegetation which shelter and feed Biomphalaria glabrata- 8), in general they have had no pronounced effect on weeds in the lakes during the 20 years observation. As in previous studies on farm ponds, the instances in which Biomphalaria glabrata and Marisa cornuarietis co-exist over a long period of time are those water bodies which contain large quantities of vegetation. This is confirmed by the observations from the Lakes in 1976 (table 5 and 5). The lakes harboring both species either had large masses of floating water hyacinth or high levels of nutrients which indicate extensive algae growths.

Fecal Contamination of Lake:

It should be emphasized that snails infected with the bilharzia parasite have been collected from only one lake, at two different sites on Lake Carraizo.

TABLES ANALYSIS OF PRESENCE OF BIOMPHALARIA GLABRATA AND MARISA CORNUARTETIS IN MAJOR RESERVOIRS OF PUERTO RICO, 1956-1976.

Biomphalaria glabrata, Marisa cornuarietis

Reservoirs 1957-61 1962-66-1976

1. Reservoir A + + +
2. Reservoir B + - +
3. Reservoir C - + +
4. Reservoir D + ND -
5. Reservoir E + + +
6. Reservoir F - + -
7. Reservoir G + ND +
8. Reservoir H - - +
9. Reservoir I + + ND
10. Reservoir J ND - +

Note:
"+" indicates presence,
"-" indicates absence,
"ND" indicates no data.

The "+", "-", and "ND" symbols represent presence, absence, and no data respectively.

12/13, 15/17, 21/28 - "12/17 surveyed = Snails absent + Snails present. ND = No data."

We are in Yabucoa and near San Antonio. At present, this lake is probably the greatest potential hazard in terms of Bilharzia transmission since it receives waste from the Capuas Treatment Plant and from several other sewage discharges from municipalities in the watershed. In addition, there are potential problems from the Villalba sewage discharge into Lake Cuyabal, the Utuado sewage discharge into Lake Dos Bocas, sewage from Comerio which enters the two Comerio reservoirs, and sewage from the Guavate prison colony which enters Lake Carite. There have also been many infected snails collected in the Jayuya river below the town, and there is a possibility that these snails could be carried into Lake Carite. Thus, the absence of the host snail from most of these reservoirs is a good indication that the lakes could eventually be developed for recreation, but careful monitoring will be required to make sure that the small and sporadic populations of B. glabrata which appear in the lakes are not carrying the Bilharzia infection.

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APPENDIX:

Figures 7-31. Maps and photos of lakes in alphabetical order.

Tables A1-A30. Data record of water quality samples from lakes in alphabetical order 1975-1976.

SPANISH TERMINOLOGY:

The maps contain several common Spanish words which are translated below:

Azo = Lake
Rio = River
Quebrada = Creek
Afluente = Tributary
Represa = Dam
N, B, O, S = North, East, West, South
Camino = Road
Ruta = Route
Carretera = Highway
Entrada = Entrance
Vertedero = Spillway

Figure 7. Map of Lake Adjuntas (LAGO ADJUNTAS)

The rest of the text is unreadable and appears to contain errors. Please provide a corrected version for translation.

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