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NATIONAL SPELEOLOGICAL SOCIETY

The National Speleological Society is a non-profit organization devoted to the study of caves, karst, and allied phenomena. It was founded in 1940 and is incorporated under the laws of the District of Columbia. The headquarters of the Society now are located in Huntsville, Alabama. The Society is affiliated with the American Association for the Advancement of Science.

The Society serves as a central agency for the collection, preservation, and dissemination of information in fields related to speleology. It also seeks the preservation of the unique faunas, geological and mineralogical features, and natural beauty of caverns through an active conservation program.

The affairs of the Society are controlled by an elected Board of Governors, which appoints national Officers. Technical affairs of the Society are administered by specialists in fields related to speleology through the Society's Biology Section, Section on Cave Geology and Geography, Social Science Section, and Research Advisory Committee.

Publications of the Society include the quarterly *Bulletin*, the monthly *News*, an annual *Speleo Digest*, *Special Publications*, and the *Caving Information Series*. Members in all categories except Family receive the *Bulletin* and *News*.

A library on speleological subjects is maintained by the Society at its office. Material is available to Society members at a nominal fee to defray the cost of handling and to others through inter-library loan. An extensive file of information on caves of the United States is maintained by the Society and currently is housed in Reston, Virginia.

The Aguas Buenas Caves, Puerto Rico: Geology, Hydrology, and Ecology With Special Reference to the Histoplasmosis Fungus*

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EXTRACTO

El área cárstica de Aguas Buenas, la que está localizada al oeste de la ciudad de Caguas y al sur del Municipio de Aguas Buenas en Puerto Rico, se ha desarrollado sobre dos pedazos aislados de la caliza Aguas Buenas del Cretaceo inferior, la que es base de la Torrecilla breccia. El desarrollo cárstico se caracteriza por los sumideros, ríos subterráneos y cavernas; así como por el acentuado desarrollo de características cársticas menores sobre la superficie de la caliza, principalmente "spitzkarren". Esta área cae dentro de la zona de bosques húmedos subtropicales, recibiendo approximadamente 1700 mm de precipitación anual. Los meses de mayor lluvia son: mayo agosto y septiembre. Generalmente, marzo es el mes de menor precipitación. La temperatura promedio es de 22.4° C.

Las cuevas principales de Aguas Buenas que han sido delineadas y estudiadas comprenden dos sistemas de pasajes distintos: el inferior, donde pasa un río; y el pasaje superior, o seco. Este último, se desvía un poco al sur del pasaje inferior. Se ha propuesto para su desarrollo turístico, una parte del pasaje superior de las cuevas. Existe un pasaje corto no delineado, al sur de los pasajes ya estudiados y delineados. Otra cueva se halla localizada en la parte oeste del mismo sistema. Esta tiene aproximadamente 400 mts. de largo por la que pasa un río con sistema de sifones en ambos extremos. La relación de esta cueva con el sistema principal aún no se ha determinado.

El área de drenaje del sistema completo de las cuevas de Aguas Buenas es de 5.6 $kms.^2$. Una porción de esta área está en parte sobre rocas volcánicas, otra sobre caliza, por lo que los ríos superficiales desaparecen cuando alcanzan la zona caliza. La infiltración directa en la superficie de la caliza a través de largas grietas es muy rápida. Los valores promedios de la razón de precipitación a escorrentía sobre el área de captación indica que la cueva conduce un mínimo de 350,000 m^3 (90 x 10^6 galones) de agua anualmente. Esta agua se une al Río Caguitas que abastece de agua al pueblo de Aguas Buenas. Por lo tanto, debe evitarse cualquier posible fuente de contaminación a este recurso.

Aunque la zona de vida del bosque donde se encuentran las cuevas de Aguas Buenas se caracteriza por el uso intensivo de la tierra, hay todavía una gran cantidad de mogotes boscosos en las colinas empinadas y los acantilados cerca de las cuevas, además de una vegetación húmeda en las entradas a las cuevas.

Se han recogido cerca de 52 especies de animales en estas cuevas. Aproximadamente el 60% de las especies y subespecies identificadas son endémicas en Puerto Rico. También la mayoría de estos organismos son troglófiles. Los murciélagos son una excepción, ya que salen de éstas para alimentarse de insectos, del néctar de las flores y frutas. La principal fuente de energía para la cadena alimenticia dentro de las cuevas, es proporcionada por las heces fecales de los murciélagos.

De la población de murciélagos de las cuevas de Aguas Buenas, los insectívoros (probablemente la mitad de los que habitan estas cuevas), juegan un papel importante en el control de insectos vectores de enfermedades a los residentes del área y probablemente más allá de éstos. Debido a que los murciélagos poseen selección de habitáculos, las cuevas de Aguas Buenas representan para ellos el más importante, sino el único sitio para alojarse en el este central de Puerto Rico. Por lo tanto, si se destruyen estos habitáculos, directa o indirectamente puede tener esta medida, unos impactos ecológicos y probablemente económicos adversos.

Se sabe que las cuevas de Aguas Buenas contienen el hongo *Histoplasma capsulatum*. Aproximadamente, el 20% de la población adulta de Puerto Rico ha tenido histoplasmosis, de acuerdo a estudios realizados por médicos y micólogos mediante el uso de pruebas en la piel con histoplasmina. Además, desde 1963 los estudios del suelo han demostrado la presencia del hongo en varias áreas de la Isla, notablemente, en las cuevas de Aguas Buenas. Se han registrado con frecuencia, brotes de la enfermedad en las personas que visitan estas cuevas.

Los focos epidémicos de la histoplasmosis, se han relacionado, algunas veces, con los habitats de murciélagos, pero en realidad, el papel ecológico que juegan los murciélagos con la histoplasmosis no es bien conocido aún. Con frecuencia se malinterpreta este papel, debido a que no hay evidencia científica sobre: si los murciélagos son los vectores iniciales de la enfermedad o si solamente son otras víctimas.

En Puerto Rico aún no se han realizado experimentos para el control y erradicación de la histoplasmosis. En un estudio, aplicaciones repetidas de una solución de formalina al 3% al suelo, aparentemente elimina al hongo. Como la formalina es altamente tóxica, particularmente a los organismos inferiores, y debido a que el drenaje de las cuevas de Aguas Buenas también se utiliza para abastos de agua se requerirá estudios detallados antes de aplicar esta técnica de erradicación.

La reinfección del guano acumulada por las esporas de histoplasma, causantes de la enfermedad, y que son transportadas por los murciélagos, es un problema que debe resolverse si las cuevas van a ser comercializadas. Así, se debe encontrar una vía para eliminar los murciélagos solamente de aquellas áreas de la cueva a ser usada por los turistas. De una revisión de los métodos usados para el control de los murciélagos, se concluye que, el único medio real y al presente disponible, es sellando las entradas a las áreas turísticas con sedazos plasticos, dejando aperturas no mayores de 5 mm. Los murciélagos podrán entonces moverse sin daño de esta área y anidar en otra porción de la cueva. Por supuesto, quedaría aún el problema de residuos de hongo en el guano del piso de la cueva. Esto requerirá futuras investigaciones.

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Introduction

Background and Purpose

For a number of years, the municipality of Aguas Buenas has been interested in developing the Aguas Buenas Caves as a recreational facility and tourist attraction. In 1968, the municipal government sponsored a study of the cave system and an evaluation of its commercial potential by the National Speleological Society. This report concluded that the Aguas Buenas Caves, while not unusual, could be commercialized if the disease-causing histoplasmosis fungus could be eliminated.

A bill, *P. del S. 385* (see Appendix), was introduced to the Senate of the Commonwealth of Puerto Rico in 1973 to organize an advisory board and to appropriate funds for the purchase and development of the Aguas Buenas Caves. It is the purpose of this report to summarize the existing knowledge on these caves, to add such new knowledge as is deemed pertinent, and to advise the Senate of the Commonwealth of Puerto Rico on the feasibility of their proposal.

Location

The Aguas Buenas karst is a small area of well-developed karst features located in the Central Mountains of Puerto Rico, west of the city of Caguas and south of the town of Aguas Buenas. The larger features can be seen in the northwestern corner of the U.S.G.S. topographic map for the Caguas, Puerto Rico, quadrangle (Fig. 1.). The area is marked by several deep sinkholes (about 50 m deep), sinking streams, and a large, integrated cave system. The Aguas Buenas Caves are well-known in Puerto Rico and their location is shown on some of the gasoline dealers' road maps of the island, even though the cave has no tourist facilities *per se*. The cave resurgence, which is frequently visited by picnickers, has the approximate coordinates W66° 06' 30",N 18° 14' 01".*

Climate

The Aguas Buenas karst area is located in the subtropical moist forest zone (Ewel and Whitmore, 1973). The mean basin elevation is approximately 415 m above sea level. Precipitation varies

* The coordinates reported by Thayer (1968) are in error.

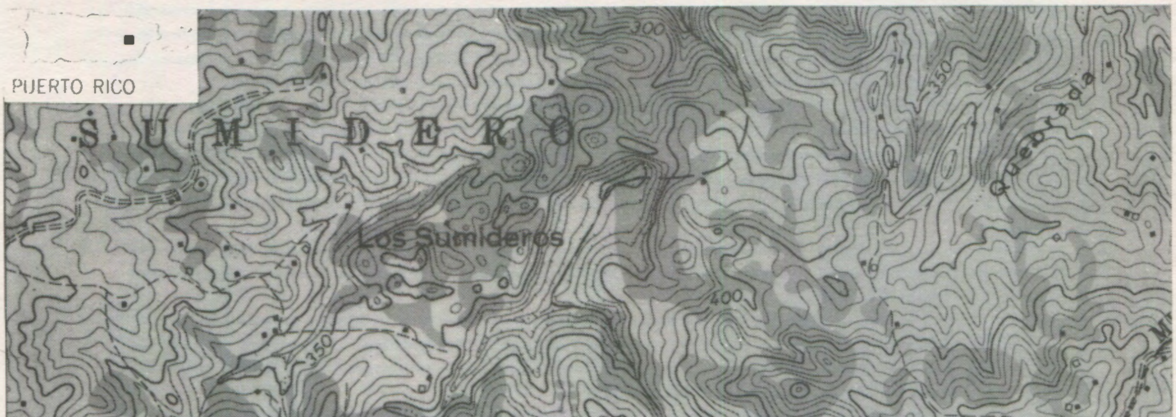


Fig. 1. Topography of the Aguas Buenas karst area (U.S.G.S., 1964). Contours are in meters.

seasonally, with peaks in May and in August-September; the driest month of the year is normally March (Black & Veatch and Domenech & Assoc., 1971). The average annual precipitation in nearby Cidra, at approximately the same elevation, is 1700 mm and the average annual temperature is 22.4° C (Calvesbert, 1974, pers. com.).

Potential evapotranspiration, as computed by the Thornthwaite method, for the eastern interior area of Puerto Rico is 1190 mm. There are no pan evaporation records in this area, but at Adjuntas, in the western interior mountains, the long-term value is 1300 mm/year (Calvesbert, 1974, pers. com.). Because the high proportion of subterranean drainage probably reduces both the evaporation and transpiration markedly, these figures are only maximum limits for this area.

Geology

Stratigraphy and Structure

The classicial karst area of Puerto Rico is developed on the off-lapping sequence of Tertiary limestones deposited on the north flank of Puerto Rico's Central Mountains (Monroe, 1968). The Aguas Buenas karst, however, is far removed from this area. It is developed on two separate outcrops of the Aguas Buenas limestone, which occurs as small, isolated lenses of reef limestone in east-central Puerto Rico. The Aguas Buenas limestone is the basal member of the Early Cretaceous (Albian) Torrecilla breccia, which is otherwise principally volcanic tuff-breccias, lava breccias, tuffs, lavas, and volcanic conglomerates (Briggs, 1969). The maximum total thickness of the Torrecilla breccia is 2,050 m, but the Aguas Buenas limestone generally occupies less than 60 m of this section (Briggs, 1969). However, in the area under consideration, the vertical extent of karst development indicates a possible thickness of 90 m (Thayer, 1968). An earlier study named equivalent strata in the adjacent Comerio Quadrangle "Formation K", with the Aguas Buenas limestone as the basal member (Pease and Briggs, 1960)*. The sequence was then thought to be Upper Cretaceous.

The major portion of the Torrecilla breccia was deposited under marine conditions, as indicated by rudist, gastropod, and crinoid fossils in the Aguas Buenas limestone member (Berryhill; *et al*, 1960; Briggs, 1969) and crude pillowing in some lavas (Briggs, 1969). The Aguas Buenas limestone was unconformably deposited over volcanic rocks assigned to Formations A, C, and J (Briggs, 1969), probably as a reef fringing a volcanic island (Berryhill; *et al*, 1960) or, possibly, in a shallow sea. The reefs of Aguas Buenas limestone indicate a brief hiatus in the volcanism (Briggs, 1969), as carbonate deposition and rapid clastic influx are generally mutually exclusive.

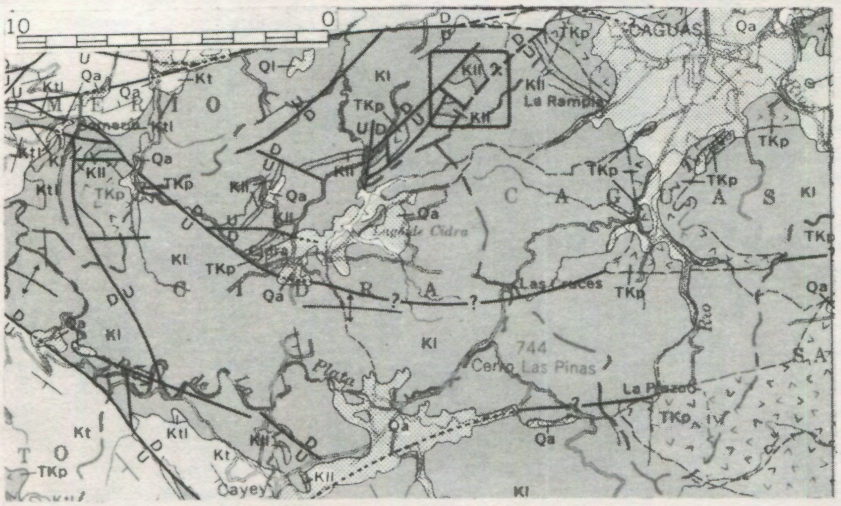
The northwestern and southeastern margins of these two outcrops are probably bounded by faults; in addition, a fault separates the two blocks. However, the other contacts appear to be depositional (Briggs and Akers, 1965). Dikes of volcanic rock occur frequently within the limestone. When they cross the cave passages, they act as structural controls of the passage trend, the volcanics being essentially invulnerable to the solution process which formed the cave. Figure 2 is a geologic map of that portion of east-central Puerto Rico in which exposures of Aguas Buenas limestone occur (taken from Briggs and Akers, 1965). No reports have been published on karst development on the other outcrops of this same limestone, but an inventory of caves in Puerto Rico compiled by the Department of Natural Resources indicates that several caves occur on the outcrop just southeast of Comerio (Martinez, 1974, pers. com.).

Karst Development

The dense tropical vegetation which generally covers the karst areas in Puerto Rico, combined with the steep, or vertical, slopes associated with the development of sinkholes, renders a portion of this terrain inaccessible for most practical purposes. However, in the Los Sumideros area numerous trails exist, generally kept open by frequent local visitors to the caves. In the area to the south, the terrain may best be traversed by walking in along the rivers.

Where bare limestone surfaces are exposed, they are generally characterized by a dense development of sharply pointed spires and intervening pits (spitzkarren), on the order of 20 cm from bottom to top. On steep slopes, such as on the walls of sinkholes, this development may be intensified and the spires may be on the order of 1 m tall. Above the Don Julio Entrance to the main Aguas Buenas Caves, there is a thin (about 1 m) roof of limestone and here the downward solution of the small pits has penetrated completely through the roof, providing several scenic skylights.

Larger scale karst features are also well developed in this area; most can be seen on the topographic map (Fig. 1). On the southern edge of the southern outcrop of limestone, there are a series of



Qa—alluvium.
Ql—landslide debris.

Kt—tuff ss, sltst, brc, cgl, lva, tuff.
Ktl—ls lenses.

TKp—plutonic rocks.
Kl—lva, lva brc, tuff, tuff brc.
Kll—Aguas Buenas Ls

Fig. 2. Geology of a part of south-central Puerto Rico showing outcrop areas of Aguas Buenas limestone (Briggs and Akers, 1965). Square indicates approximate area of Figure 1.

* Thayer (1968) incorrectly cites Pease and Briggs (1960) as placing the Aguas Buenas limestone in Formation J.

sinkholes (called *sumideros* in Puerto Rico). One short river disappears into a small crack in one of the larger sinks. Immediately north of these sinks, there is an elongated ridge of limestone. The aforementioned river passes below this ridge and emerges on the other (north) side from a small cave (Fig. 3). Here it again flows on the surface, over the volcanic rocks which separate the southern and northern blocks of limestone. Thayer (1968, p. 4) states "However, the stream pattern mentioned above suggests that there is at least surface continuity" between the two limestone outcrops. Since the stream emerges and flows overland to the northern area, where it again sinks, this statement is believed to be unsubstantiated.

The northern limestone outcrop (immediately surrounding the words "Los Sumideros" on the topographic map) is thickly pitted with sinkholes. The highly dissected remnants of a ridge of limestone mark the center of the outcrop area. It is within the northeastern portion of this ridge that the main Aguas Buenas Caves (Fig. 4) are located. The main Aguas Buenas Cave System is described in the National Speleological Society report *Field Trip to the Aguas Buenas Caves* (J. Gurnee, editor, 1968) and, also, by Beck (1973), from whom the following description is quoted (pp. 146-147).

Fig. 3. Small cave passage where the stream flows under the southernmost, and most upstream outcrop of limestone. (Photo by B.F. Beck).

"Although known as the Aguas Buenas Caves (plural), all the various entrances interconnect in a unified system of passages. There are two main passage systems, one an upper level, dry system, and the other a lower level system through which a river presently flows. The two levels, however, are not superimposed one over the other, rather the upper level is distinctly to the south of the lower one. One sloping crosspassage interconnects the two. Interestingly, the two main passage systems curve together at each end of the system where they also interconnect. Thayer (1968) postulates that the two levels were produced by a rejuvenation of erosion caused by the deepening of the external drainage or tectonic uplift."

"The upper, dry system of passages can be entered from a number of different openings, most of them toward the eastern end of the cave. Apparently because of the many entrances this portion of the cave is known as *Cueva Clara* (Light Cave); this portion of the cave is also the most densely littered and vandalized. The more western portions of the upper level make up a long, large 'avenue' through which one can virtually stroll with very little effort. The floor is clay and guano and the ceilings and walls are frequently decorated with massive speleothems which appear to have undergone some resolution and are also frequently coated with guano. The bat population in these passages is quite significant and small forests of sprouting seedlings of the Maria Tree (*Calophyllum brasiliense*) can frequently be observed under their roosts. In contrast to the eastern end, this portion of the cave is known as *Cueva Oscura* (Dark Cave). At one place in this passage two pits drop to a lower passage which later connects to the river system. At the western end of the upper passage, after passing through a large room with a sizeable bat colony, a long slope leads down into the river passage. In this area two very pretty waterfalls may be seen."

"The lower river passage is much more difficult to visit and is correspondingly less littered and vandalized. It can be entered by way of the upper passage or from its resurgence. It could also conceivably be entered through several skylights which drop approximately seventy-five meters to the river. The river course generally occupies only a portion of the passage and the sides are either slippery boulders or guano and mud banks. Most of the passage can be walked or waded through as the water is not, in my personal experience, over five feet deep and is generally only knee-deep. Upper level passages and alcoves are frequent and these are generally occupied by large bat colonies."

Commercialization will be confined to the *Cueva Oscura* section of the upper, dry passage system.

From the very large, easternmost sinkhole (see Figure 1), another cave, previously undescribed, conducts the sinking river to where it merges with the lower, river passage of the main cave, at the sump marked by a question mark on the cave map (Fig. 4). This passage was not included on the original map due to time limitations (Gurnee, 1968), but is currently being mapped by the senior author and associates. On the westernmost end of the ridge, there is an upper level cave complex from which a pit approximately 20 m deep

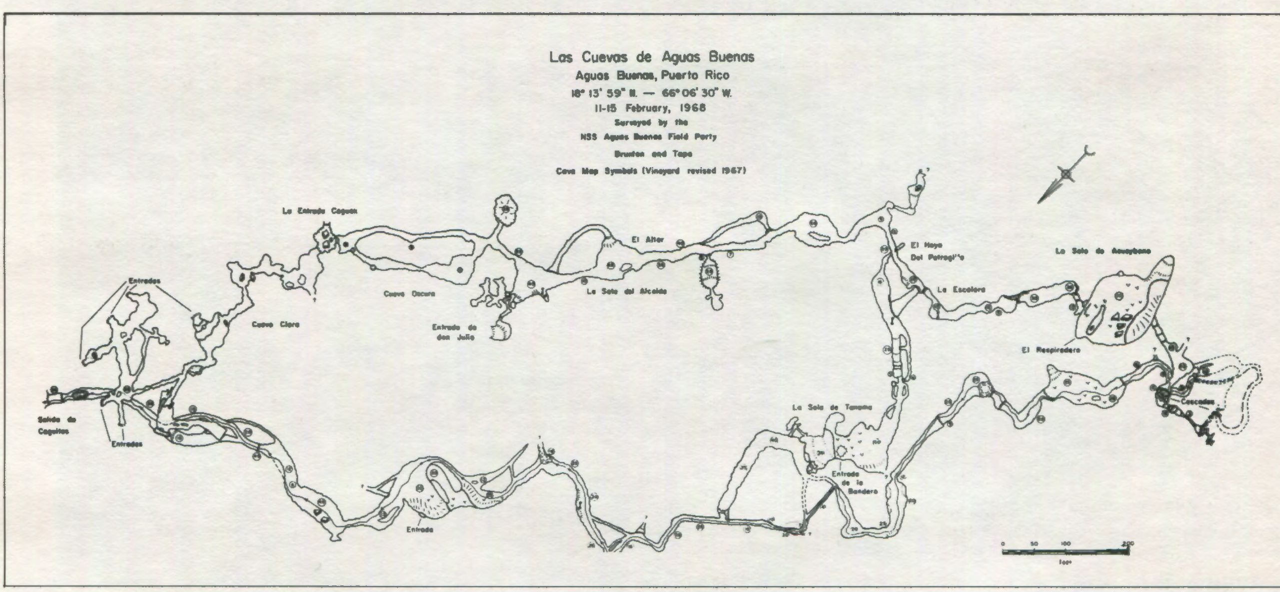


Fig. 4. Map of the Aguas Buenas Caves (Gurnee, 1968).

drops to a flowing stream. This stream emerges from a sump, flows approximately 400m in a generally eastward direction, then enters another sump.

The senior author and the local chapter of the National Speleological Society are presently exploring this system in detail. The approximate path of the unmapped portions of the cave is shown on Figure 5.

Thayer (1968) hypothesizes that cavern development ante-dated the surface topography and he states that "sinkhole topography cannot appear until subsurface solution cavities enlarge to the point of collapse" (p. 9). Sinkholes develop both by gradual solution and by collapse, as well as by several other mechanisms (see Jennings, 1971, pp. 121-125 and Fig. 36). Both solutional and collapse sinks appear to be present here. Sinkholes such as the one at the upstream end of the main cave system appear to have evolved by solution simultaneously with the subterranean solution which formed the cave. On the other hand, the hole which penetrates the roof of the *Sala de Tanama* (see Fig. 4) may be due to upward stoping of the roof of this very large room. Because this hole intersects the land surface high on the ridge, collapse appears to be a preferable mechanism for its formation. It can be readily seen from the previous discussions and the various maps (Figures 1, 4, and 5) that the entire karst area has developed a single, integrated subterranean and surface drainage system (see *Hydrology*, below).

Hydrology

Figure 5 is a map of the drainage area for which the resurgence of the Aguas Buenas Caves is the outflow. This encompasses an area of 5.6 km² (2.15 miles²) and includes several perennial streams. Although several portions of the drainage occur underground, these are discrete conduits and generally have characteristics similar to those of their surface counterparts. The drainage pattern, including the cave passages, is dendritic. The resurgence is the trunk and local base level. The stream flowing from the resurgence may be considered third order, when the total drainage pattern is evaluated.

Precipitation which falls on the limestone infiltrates rapidly through the multitude of solutionally enlarged joints and, on a larger scale, through the many sinkholes. Precipitation which falls

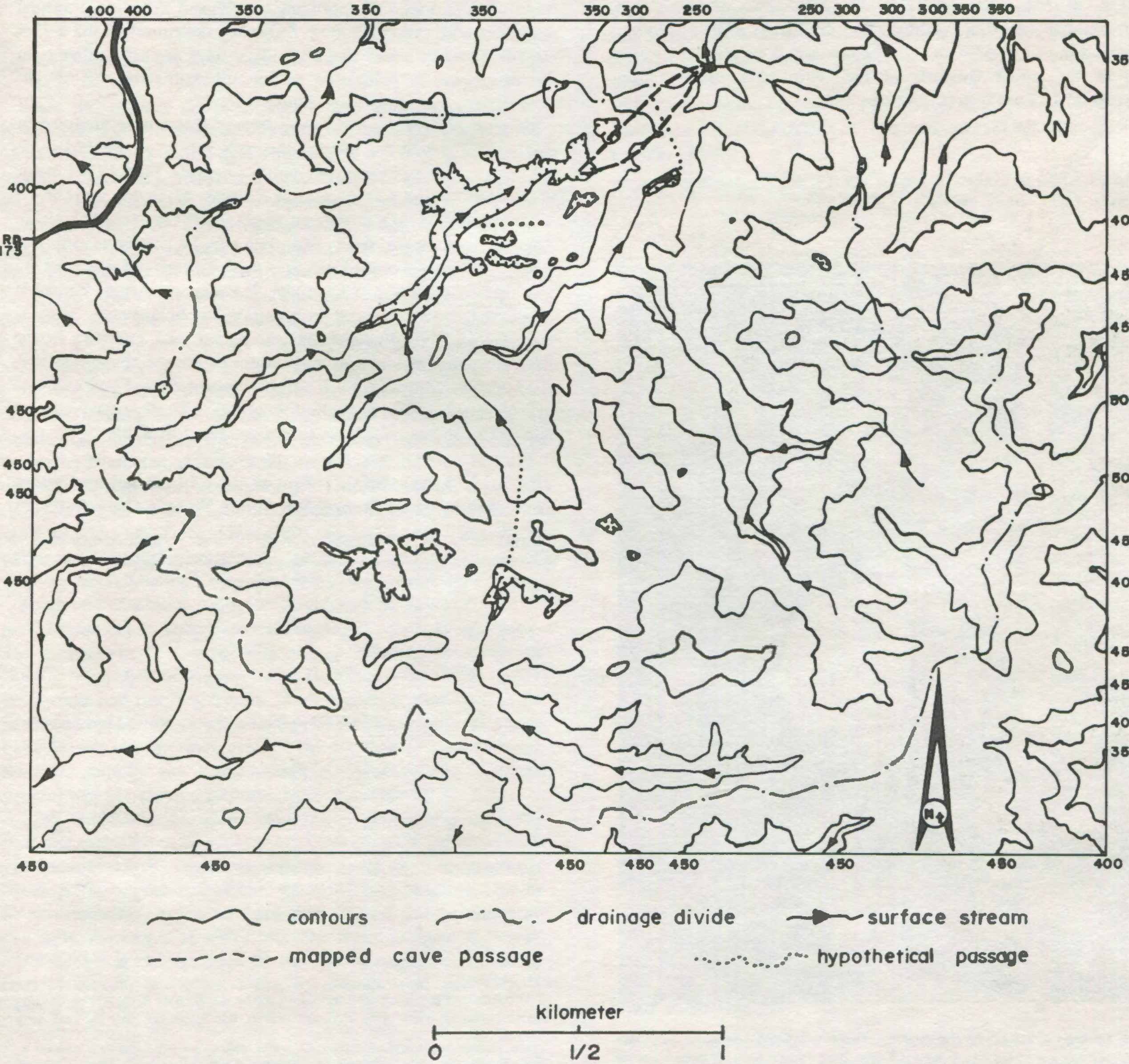


Fig. 5. Hydrology of the Aguas Buenas karst area. Base map is the U.S.G.S. topographic map for the Caguas, Puerto Rico, quadrangle, 1964. Contours are in meters.

on those areas of the basin underlain by volcanic rocks runs off overland to the surface streams. All the streams begin to sink very soon after crossing onto the limestone and rise again when they cross back onto the volcanics. The final resurgence occurs near the lowest surface exposure of the limestone-volcanic rock contact.

On January 3, 1974, outflow at the resurgence measured 1.85 m^3/min*. The water was clear and not in flood. Precipitation had occured on several days, so that base flow is probably somewhat less than this figure. Because of the small size of the basin, the rapid infiltration into the limestone, and the tropical rain pattern, the system is subjected to short duration, high velocity, peak discharges. These probably occur within five hours of the onset of heavy precipitation. This type of flash flood involves large volumes of water, is capable of transporting very coarse debris, and may prove a serious hazard to anyone working in the smaller passages of the lower levels of the cave system. On January 24, 1974, at approximately 10:30 a.m. I was working at the resurgence of the cave. It had been raining since early morning and the resurgence was in flood, flowing approximately 7 m^3/min (visual estimate) of turbid, brown water. At approximately 11:10 a.m. I heard an instantaneous increase of the noise of the water flow. When I glanced at the cave entrance, the flow had increased to approximately 15 m^3/min, more than double its earlier volume. Later that morning, after the rain had ceased, I watched the water level in the upper sinkhole of the main cave system drop approximately 7 cm in less than one hour.

* Flow measured by Lawrence J. Mansue, U.S.G.S. Water Resources Division, by standard U.S.G.S. methods. See Fig. 6.

Fig. 6. Lawrence J. Mansue (Water Resources Division, U.S.G.S.) measures water flow at the resurgence of the Aguas Buenas Caves. Note vertical solution runnels on the limestone blocks in the background. (Photo by B.F. Beck).

The average annual discharge of the basin may be calculated from the annual precipitation, the evapotranspiration, and the basin area. Groundwater outflow through the volcanics is undoubtedly negligible. Evapotranspiration must be accounted for, but much of the flow occurs as the short duration, high volume pulses mentioned above, which generally coincide with periods of high humidity, the actual evapotranspiration is probably less than either the potential evapotranspiration (as calculated by the Thornthwaite method) or the pan evaporation. By utilizing a computer correlation of long-term hydrologic records with the various climatic parameters, Black & Veatch and Domenech & Associates (1970) derived a graphic relationship between the mean annual runoff/mean annual precipitation ratio and the basin climatic index. They were also able to derive a relationship between basin climatic index and mean annual precipitation at various elevations. Thus, utilizing the mean annual precipitation and the mean basin elevation, one can determine the basin climatic index, and from the basin climatic index one can determine the ratio of runoff to precipitation on an annual average. For the Aguas Buenas Cave drainage area, the annual precipitation averages 1700 mm/yr and the mean basin elevation is approximately 415 m; this yields a basin climatic index of approximately 90 and an average annual runoff/rainfall ratio of 0.365†. Summing the runoff (0.365 x 1700 mm) over the basin area (5.6 km^2) the average annual outflow from the resurgence is calculated to be approximately *350,000 m^3 (90 million gallons)*, as a *minimum*.

Water samples from the Aguas Buenas Caves were analyzed in the field to determine the approximate values of the carbonate parameters. pH was measured with a Chemtric Type 40 pH meter buffered to 7.0 and 4.0; the sample was then titrated to a pH of 4.5 with 0.01639N H_2SO_4 to determine alkalinity (Brown; *et al*, 1970). CO_2 was calculated from this data (*ibid.*). Temperature was measured with a standard mercury thermometer and dissolved O_2 was measured with a YSI Model 51A oxygen meter. Electrical conductivity was measured with a standard field meter. Samples were collected in dissolved oxygen bottles and analyzed in the laboratory for calcium and magnesium by atomic absorption with a lanthanum additive (*ibid.*). Samples were collected and analyzed at the resurgence and in the bottom of the sinkhole at the upstream end of the main cave. These values are listed in Table 1.

TABLE 1. Approximate values of the carbonate parameters and other selected factors for Aguas Buenas Cave water.§

Parameter	Upstream Sink	Resurgence
PH	7.9	7.9
Alk ($CaCO_3$)	150 ppm	110 ppm
Ca	41 ppm	32 ppm
Mg	9 ppm	13 ppm
CO_2	3 ppm	2 ppm
Temp	21½° C	20½° C
EC (cond)	210 Micromhos	260 Micromhos
O_2 (dis)	8.3 ppm	9.2 ppm

† This relationship was not determined for karst basins. Because of the factors affecting evapotranspiration which were discussed earlier, this figure can only be used as a minimum limit.

§ Field analyses were performed in coöperation with Lawrence J. Mansue, Water Resources Division, U.S.G.S.

Utilizing saturation curves for $CaCO_3$ in the presence of magnesium (modified from Picknett [1972]), it appears that both waters are unsaturated with respect to $CaCO_3$. According to these approximate calculations, the upstream waters may be slightly closer to saturation than those at the resurgence. However, if the total hardness is considered, combining both calcium and magnesium, the values at both sites are similar: 140 ppm upstream and 135 ppm at the resurgence. It is also interesting to note that the conductivity of the water and, thus, the total dissolved solids in the water increase significantly during its flow through the cave. This probably is due to the leaching of the large guano deposits therein.*

Julio Morales, the owner of the land which encompasses the main Aguas Buenas Caves, pumps water to his house from the uppermost end of the river in the main cave, on the north side of the sinkhole. An analysis by the Puerto Rico Aqueduct and Sewer Authority showed this water to be satisfactory for domestic consumption. More important, however, the cave stream is one of the principal tributaries of the Caguitas River, which is the main supply for the town of Aguas Buenas. Any possible pollution of this valuable source of water is, therefore, of great importance.

Biology

Life Zone and Surface Flora near the Caves

Since the regimen of precipitation and temperature in the subtropical moist forest zone where the Aguas Buenas Caves are located is nearly ideal for agriculture, it is within this zone that human use of land is most intense and varied. Original or very old forest is seldom found in this life zone except for areas in which the terrain is very steep and irregular and the soil unsuitable for agriculture. The continuous karst topography of northwest Puerto Rico, as well as the isolated karst in the Aguas Buenas area are such exceptions. One of the characters that makes these karst areas so noticeable from the air is the density and canopy height of their forest, in comparison with the surrounding pasture and second-growth scrub.

The Aguas Buenas cave area has, however, been relatively more accessible than most of the northwest karst. Thus, the original forest was lumbered more thoroughly and agriculture more frequently attempted on some of the steep slopes and marginal soils of this area. This would explain the presence, on some of the lesser slopes and sinkhole bottoms of numerous introduced tree species, such as African Tulip (*Spathodea campanulata*), Breadfruit (*Artocarpus altilis*), Immortelle (*Bucayo spp.*), Flamboyant (*Delonix regia*), Guamá Venezolano (*Inga quaternata*), and others.

Much of the original "mogote" vegetation is, however, still in evidence on the very steep slopes, cliffs and hilltops in the cave area. This includes the Cupey or Wild Mamey (*Clusia rosea*) and the Wildfig ("Jaguey") (*Ficus spp.*) with their characteristic liana-like aerial roots and spiraling trunks. Other common trees include the hardwooded endemic Quiebra-hacha (*Thoninia striata*), María or False Mamey (*Calophyllum calaba*), the Sweetpea or Guamá (*Inga laurina*), and the two "Yagrumos": the trumpet-tree (*Ceropia peltata*) and Matchwood (*Dydymopanax morototoni*).

In the moist alluvium along the streams leading into and away from the caves, the Rose-apple (*Eugenia jambos*) is quite common in the undergrowth. Tree ferns (*Cyathea spp.*) are also frequently found. At the bottom of the sinks, where the river enters and leaves the system, cool, dense air has combined with the mist produced by the rapid movement of water over the rocks to form a "cloud forest". This is characterized by the dense, epiphytic growth on trees of mosses, liverworts, ferns, bromeliads and, probably, a number of orchids.

* Because of its small size and general accessibility (as compared to other karst areas), this basin would be an ideal area in which to study the processes of limestone solution in a tropical environment. Such a study would have considerable scientific merit.

Most of the birds near the cave entrances are also found in many other locations in Puerto Rico. Some of the less common or more interesting species included the brightly colored Tody (*Todus mexicanus*), the Puerto Rican Bullfinch (*Loxigilla portorincencis*), and the Puerto Rican Lizard Cuckoo (*Saurothera vieilloti*). Green Herons (*Butorides virencens*) are fairly common near the streams in the area.

The Cave Fauna

The invertebrate list, unless otherwise specifically referenced, is taken from Peck's (1974) study of Puerto Rican cave fauna, which verified and added to earlier work done on the Aguas Buenas Caves by Fenton (1968). The vertebrate list is taken largely from notes and a key to the Chiroptera of Puerto Rico graciously lent to us by Fenton (1973, pers. com.).

As yet unstudied and, therefore, unlisted are the bacteria, protozoans, and other microorganisms. These live primarily in the decomposing bat guano on the cave floor; they sometimes also live in cave water where there is some stagnation. Also largely unlisted are the insect ectoparasites of bats found in association with much of the cave fauna. For the most part, these have not been studied with specific reference to the Aguas Buenas Caves. However, as parasites, they also play an important role in the food web of the caves.

The terms defined below are used in the list to denote the degree of an animal's specialization or restriction to cave life. (Moore and Nicholas, 1964):

Trogloxene ("cave guests"): Species which may spend some time in caves but which are not able to complete their life cycle there. Bats, which roost in caves but must feed on the outside, are the most obvious examples.

Troglophile ("cave lovers"): Species which are capable of living permanently in caves but which may also be found outside caves, usually in dark, moist environments.

Troglobites ("cave life"): which are species restricted entirely to caves, have so far not been recorded from the Aguas Buenas caves. They are usually blind and depigmented.

Notes on trophic levels of animals are also included:

Guano Scavengers feed on fungi and microörganisms found on the guano, as well as, in some cases, the undigested organic material in the guano itself.

Detritivores usually feed on plant materials such as wood, leaves, algae and soil carried into the cave by the stream.

Omnivores feed on a wide variety of plant and live or dead animal material.

Predators feed mainly on live animal prey.

Invertebrate List

PHYLUM *MOLLUSCA*

Class *Gastropoda*

1. *Subulina octona* Terrestrial snail
   Troglophile. Common on moist guano. Scavenger. Introduced.
2. *Pleurodonte caracolla* Tree snail
   Troglophile (?). Often found as shells, but occasionally alive, also. Usually feeds on algae and plant debris.

PHYLUM *ARTHROPODA*

Class *Arachnida* (Spiders and allies)

Order *Amblypygii*

3. *Tarantula fuscimana* Tail-less Whipscorpion (Guavá)
   Troglophile. Found in most caves in tropical America. Predator. Native.

Order *Schizomida*

4. *Schizomus portiricensis.*
Troglophile. Found commonly on damp guano. Predator. Endemic.

Order *Aranae* (Spiders)

5. *Psalistops corozali*
Troglophile. Predator. Native.
6. *Oligoctenus ottleyi*
Troglophile. Predator. Endemic to Puerto Rico and Mona.
7. *Nesticus pallidus*
Troglophile. Predator. Native.
8. *Modisimus montanus* A cellar spider or "long legs"
Troglophile. Predator. Endemic.
9. *Modisimus cavaticus* Cellar spider
Troglophile. Predator. Endemic.
10. *Loxosceles caribbaea* A spitting spider
Troglophile. Predator. Native.
11. *Theridon portiricense* A house spider
Troglophile. Predator. Endemic.

Order *Acarina* (mites)

12. Unidentified species of the family Macrochelidae
Troglophile. Although found in guano, it may also associate with another cave organism, an insect, or a bat. Predator.
13. *Uropoda* sp.
Troglophile. Found in guano but known to associate with insects. Predator.

Order *Pseudoscorpiones* (Pseudoscorpions)

14. *Cheiridium* sp.
Troglophile. Predator.

Class *Crustacea*

Order *Isopoda* (Isopods)

15, 16, 17. Three unidentified species.
Troglophile. Found in moist guano. Scavengers or detritivores.

Order *Decapoda* (Crabs, shrimp, crayfish)

Family *Palaemonidae*

18. *Macrobrachium carcinus* Large freshwater shrimp ("camaron")
Trogloxene. Reported by Barry Beck from the lower river passage. Larval stages of this shrimp require salinity; thus, part of its life cycle must be spent in coastal waters (Erdman, 1972). Omnivore. Native.

Family *Atyidae*

19. *Atya innocuous* Small shrimp ("guabara")
Collected by George Drewry (1974) from the lower river passage. Trogloxene. Omnivore. Native.

Family *Pseudothelphusidae*

20. *Epilobocera sinuatifrons* Freshwater crab ("Buruquena")
Troglophile. Cave explorers may have mistaken this crab at inland locations for *Cardisoma guanhumi*, which is restricted to areas near the coast (Beck, 1973). Omnivore. Endemic.

Class *Diplopoda* (Millipedes)

21. *Iomus incisus*
Troglophile. Found on moist soil and guano. Detritivore or Scavenger. Endemic.

Class *Chilopoda* (Centipedes)

22. *Cryptops* sp.
Troglophile. Predator.

Class *Collembola* (Springtails)

23. *Paronella* sp.
Troglophile. Scavenger.

Class *Insecta*

Order *Blattaria* (Cockroaches)

24. *Pycnoscelus surinamensis* Field cockroach ("Cucaracha campestre")
Troglophile. Found worldwide in the tropics. Omnivore. Introduced.
25. *Anaplecta* (?) sp.
Troglophile. A new, as yet undescribed species of cockroach. Omnivore. Endemic.
26. *Pseudosymploce* sp.
Troglophile. New, undescribed species, first collected in the Luquillo Forest. Omnivore. Endemic.

Order *Orthoptera* (Grasshoppers and Crickets)

27. *Amphiacusta* sp. Crickets ("changa")
Possibly one or more undescribed species. Troglophiles (?). Detrivores.

Order *Dermaptera* (Earwigs)

28. *Carcinophora americana* "piquijuye" (Wolcott, 1948)
Troglophile. Omnivore. Native.

Order *Hemiptera* (True bugs)

29. *Rhagovelia* sp.
A waterstrider relative. Troglophile. Predator.

Order *Lepidoptera* (Moths, Butterflies)

Family *Tineidae* (clothes moths)

30, 31. Two undetermined species.
Troglophiles. Guano Scavengers.

Order *Coleoptera* (Beetles)

Family *Carabidae* (Ground beetles)

32. *Masoreus brevicillas*
Troglophile. Predator. Probably native.

Family *Leiodidae*

33. *Proptomaphaginus puertoricensis*
On damp guano. Troglophile. Scavenger. Endemic.

Order *Diptera* (Flies)

Family *Sciaridae* (Fungus gnat relatives)

34, 35, 36. Three undetermined species.
Troglophiles. Scavengers.

Family *Phoridae* (Humpbacked flies)

37. *Conicera* sp.
Troglophile. Scavenger.

Order *Hymenoptera*

Family *Formicidae* [*Ants*]

38. *Cyphomyrmex rimosus* A fungus ant
Troglophile. Scavenger or predator. Native.
39. *Ochetomyrmex auropunctatus*
Troglophile. Predator. Endemic.

A two-week investigation of the ecology of the invertebrates of the Aguas Buenas Caves was conducted in May, 1973 by Dr. S. Peck (Carleton University, Ottawa, Canada) as a field course in Tropical Cave Biology. At least a dozen additional invertebrates were discovered to occupy the cave, but full identifications are not yet available. These additions to the fauna and aspects of terrestrial invertebrate ecology will be presented in a later paper in preparation by S. Peck.

Vertebrate List

Class *Amphibia*

40. *Eleutherodactylus karlschmidti* A tree frog ("ranita cascada")
This frog is common along streams, especially near waterfalls, and probably migrates into caves in search of prey. Trogloxene. Predator. Endemic.
41. *Eleutherodactylus richmondi* Tree frog
Collected by George Drewry (1974). Probable trogloxene. Predator. Endemic.
42. *Leptodactylus albilabris* Mud frog ("sapito")
Tadpoles, in lower river passage, collected by George Drewry (1974). Trogloxene or troglophile. Predator. Native.

Class *Osteichthyes*

Family *Poecilidae*

43. *Lebistes reticulatus* Guppy
Common in shallow pools, lower passage. Collected by George Drewry (1974). Trogloxene, Predator. Introduced.

Class *Mammalia*

Order *Rodentia*

44. *Rattus* sp.
Rats are abundant in the caves, probably feeding on dead or captured bats, crabs, insects and garbage left by visitors. Trogloxene. Omnivore. Introduced.

Order *Chiroptera* (Bats)

(all cave bats are considered to be trogloxenes)

Family *Mormoopidae*

45. *Pteronotus fuliginosus* Small moustache bat
Listed by Starrett (1962) as *Chilonycteris fuliginosa inflata*, an endemic subspecies. Insectivore.
46. *Pteronotus parnellii* Parnell's moustache bat
Syn. *C. parnelli portoricensis*, an endemic subspecies (Starrett, 1962). Insectivore.
47. *Mormoops blainvillii* Leaf-chinned bat
Syn. *M.b. cuvieri*, endemic to Puerto Rico and Mona (Starrett, 1962). Insectivore.

Family *Phyllostomatidae* (Leaf-nosed bats)

Subfamily *Glossophaginae*

48. *Monophyllus redmani portoricensis* The Puerto Rican long-nosed bat
Primarily nectarivorous, but may also feed on insects. (Cockrum, 1962). Endemic subspecies. Omnivore (?).

Subfamily *Stenoderminae*

49. *Artebius jamaicensis* Jamaican fruit-eating bat
Roosts in both light and dark cave passages, as well as outside of of caves. Probably most abundant bat in the Aguas Buenas caves. Frugivorous. Native.

Subfamily *Phyllonycterinae*

50. *Brachyphylla cavernarum* St. Vincent fruit-eating bat
Similar in habits to *Artebius*, may roost in twilight zone of cave. Frugivorous. Native.
51. *Erophylla bombifrons* Brown flower bat
Listed by Starrett (1962) as *E.b. bombifrons*, an endemic subspecies. Reported by Fenton (1973) as nectarivorous and by Tamsitt and Valdivieso (1970a) as frugivorous.

Family *Vespertilionidae*

52. *Eptesicus fuscus* The big brown bat
May roost in twilight zone of cave. Listed by Starrett (1962) as *E.f. wetmorei*, an endemic subspecies. Insectivore.

Fossil Material

53. Fossil remains of an extinct ground sloth, *Acratocnus odontrigonus*, have been reported from the caves (Fenton, 1973).
54. The fossil tooth of a Hutia was collected by B.F. Beck from one of the new portions of the cave.

In summation, 52 living species of animals have been collected or identified from the Aguas Buenas Caves. There are in addition a large number of unidentified organisms ranging from fungi, protozoa and planktonic life to ectoparasites of bats and insects. Of those collected or identified, 37 are troglophiles and fifteen are trogloxenes, including the bats. There are no troglobites. The breakdown of trophic levels, excluding bats, is as follows:

Scavengers	—	9-14 species
Detrivores	—	2- 6 species
Predators	—	9-21 species
Omnivores	—	7 species

Of the bats, all of which forage outside of the cave, four are predators and four are either frugivores or nectarivores. One of the latter four may also be partly insectivorous. Of all identified species, including bat subspecies, 4 (11%) are introduced, 12 (32%) are native to Puerto Rico and elsewhere, and 21 (57%) are endemic, being found only in Puerto Rico.

The Cave Ecosystem

Most of the organisms in the Aguas Buenas caves dwell in complete darkness, disturbed only by the infrequent lamps and flashlights of spelunkers. In only a minor percentage of the area of the cave, near the entrances, can green plants obtain energy from sunlight through photosynthesis. Thus, the cave ecosystem depends almost entirely on energy imported into the cave already in organic form or, possibly, from chemo-autotrophic bacteria (see Caumartin, 1957). These sources are many, but undoubtedly the most significant source, probably accounting for over 90% of the energy, is the bat population. This population, numbering into the tens of thousands, forages nightly outside the caves for its fruit and insect food.

The useable energy that the bats bring into the cave ecosystem is contributed primarily in the form of guano (urine and feces). To a lesser extent, it is in the form of groomed-out hair, ectoparasites, and, finally, the bodies of the bats themselves as they fall moribund, die, and are decomposed in the cave. Another "guano component", in the sense of being brought in by the bats, are the uneaten parts of insects, fruits and seeds dropped onto the cave floor. Some of the seeds, especially those of the Maria tree (*C. brasiliensis*) which are brought in by *Artibius* bats (see Fig. 7), germinate below the bat roosts, sending a carpet of thin sprouts up from the guano pile (Beck, 1973).

Other sources of organic input, probably accounting for less than 10% of the total, include:

— Plant detritus, humus, and soil organisms washed in from the relatively small (5.6 km²) drainage basin above the caves, especially by floods during the rainy season.
—Green plant life, especially algae and mosses, growing in the entrance or the twilight zone.
— Incidental migrations of animals into the caves. These would probably include mongooses, cats, rats (which may also be regular trogloxenes), toads, snakes, flies, mosquitoes, and other visiting insects (as well as any guano, eggs, or larvae they may leave). Crickets may, like bats, regularly forage outside the caves and return to roost (Nicholas, 1966), but there is evidence that this is not the case in the Aguas Buenas Caves (Peck, 1974, pers. com.).

Bat guano, which was intensively exploited years ago in Puerto Rico and Mona Island as a fertilizer, is rich in nitrogen and constitutes an excellent food source for the small invertebrates, molds, and fungi which form the basic level of the food web of permanent cave dwellers. This web, illustrated in Figure 8, accounts for the bulk of the biomass of the caves, excluding the bats themselves.

Fig. 7: *Artebius jamaicensis*, the Jamaican fruit-eating bat, a common resident of the Aguas Buenas Caves. (Photo by T.A. Wiewandt).

The bat population, then, forms the basis of the Aguas Buenas cave ecosystem. The bats are responsible, in one way or another, for nearly all the organic energy in the Caves (Figure 8). With reduction or elimination of this population, as may be contemplated with the development of the caves, we can expect, likewise, the reduction or elimination of most of the rest of the cave fauna. The lower, wet passages would, of course, continue to receive their minimal complement of inflowing detritus, which would support a small amount of life.

Destruction of the cave ecosystem and loss of the fauna would of course make the Caves much less interesting from a naturalist's point of view. However, most prospective tourist-visitors would not miss this aspect if they were never led to expect it, so that the absence of the fauna would not, necessarily, detract greatly from the prospect of the Caves being a success as a tourist attraction. If such destruction could be confined only to the limited part of the Caves to be regularly visited, the consequent limited loss of fauna might be acceptable if it should prove to be in the interest of public health. This limited alteration of the ecosystem is also likely to be much more practical than attempting the wholesale destruction of the bats and other cave fauna. The elimination of the entire bat population, as we shall see, would constitute an unacceptable natural and, probably, economic loss.

The most critical aspect of the biology of these caves from the standpoint of their proposed development is the bat population and the disease-causing fungus (*Histoplasma capsulatum*) which infects the bat guano. Of the bat species present in Aguas Buenas, only three species, *Pteronotus parmellii*, *Eptesicus fuscus* and *Artibeus jamaicensis* are known from previous studies to carry the *Histoplasma* fungus (Greenhall, 1965; Tamsitt and Valdivieso. 1970b). The degree to which *Histoplasma* is restricted to particular bat species apparently has not been studied, but there is no reason to doubt that the other bat species in Aguas Buenas also carry the fungus. Even if it were to be found that only a limited part of the bat population acted as a carrier of *Histoplasma*, it would still be necessary to contend with the primary problem, which is the general presence of spores throughout the bat guano accumulation on the cave floor. The fungus grows in this guano and the spores are distributed in the air as part of the dust raised whenever the guano is walked on or otherwise disturbed. Thus, sterilization or stabilization of the guano/soil of the cave floor, as well as control of the bats, must be considered in the control of histoplasmosis. A review of the Histoplasmosis problem follows this section.

Of the 13 extant species of bats known from Puerto Rico, eight have been identified from the Aguas Buenas Caves, (Fenton, 1973). At least five of these may be considered to be endemic subspecies (Anthony, 1925; Starrett, 1962; Choate and Birney, 1968). Although, to our knowledge, no population count has been made, casual observations on our frequent trips to all parts of the cave system indicate a population that numbers into the tens of thousands.

Bats, being largely nocturnal and colonial, are dependent on safe places to roost in large numbers during the daytime. The importance of a roost free from disturbance may be especially great for those species which undergo greatly reduced metabolism or torpor during the day, as well as for bats in nursery colonies where large numbers of newborn bats are clinging to the females. This fact frequently strikes cave explorers, whose very entrance into a room with a large roosting bat colony or nursery causes the demise of dozens of the bats as they lose their grip on their perches in the resulting commotion and fall to the cave floor. Since most bats have considerable difficulty taking flight from a non-perched position, they may have to crawl over the guano pile for a period of time, seeking an advantageous position for taking off. Torpid bats will have even more difficulty. The period spent on the guano pile is often a fatal one, as the myriad of insect larvae and other guano scavengers quickly swarm over the helpless bats, overwhelming and stripping them to a clean skeleton in a matter of hours. Although bats probably fall frequently enough under natural conditions, thus contributing to the "guano" input, outside disturbance to roosts caused by visitors results in a much larger number of bats being lost in this manner and may even endanger particular populations (Mohr, 1972).

Apparently, little study has been devoted to the questions of foraging range or roosting preferences for the species of bats recorded from Aguas Buenas. Three of these, *Artebius*, *Erophylla*, and *Monophyllus*, have been netted below canopy height in wooded and cleared areas in the Luquillo Forest, which has no known caves (Tamsitt and Valdivieso, 1970a). However the netting of bats in particular locations does not necessarily mean that the bats are roosting nearby. For example, in the southwestern U.S., the nightly insect-foraging flights of *Tadarida brasiliensis* (the Mexican free-tailed bat, also found in Puerto Rico, though not in Aguas Buenas) are known to extend as far as 50 miles from their cave roosts (Mohr and Poulson, 1966). On the other hand, Tamsitt and Valdivieso (1970a) stress the point that availability of roosting sites may be a limiting factor on bat populations. Thus, even if a surplus of food were available, bats might still not utilize the habitat due to lack of suitable roosting sites within the foraging territory. This is probably not true for bats such as *A. jamaicensis* and perhaps *E. fuscus*, which are not very restrictive in their selection of roosts, being found in houses, hollow trees, under palm leaves and in shallow, lighted caves as well as in the dark zones of large caves (Goodwin and Greenhall, 1961; Allen, 1967). However, for the other bat species in Aguas Buenas, particularly *E. bombifrons*, *P. fuliginosus* and *P. parnellii*, roost selectivity may be a limiting factor. That is, their roosting sites may be limited to caves, or they may find some other environmental feature of the Aguas Buenas

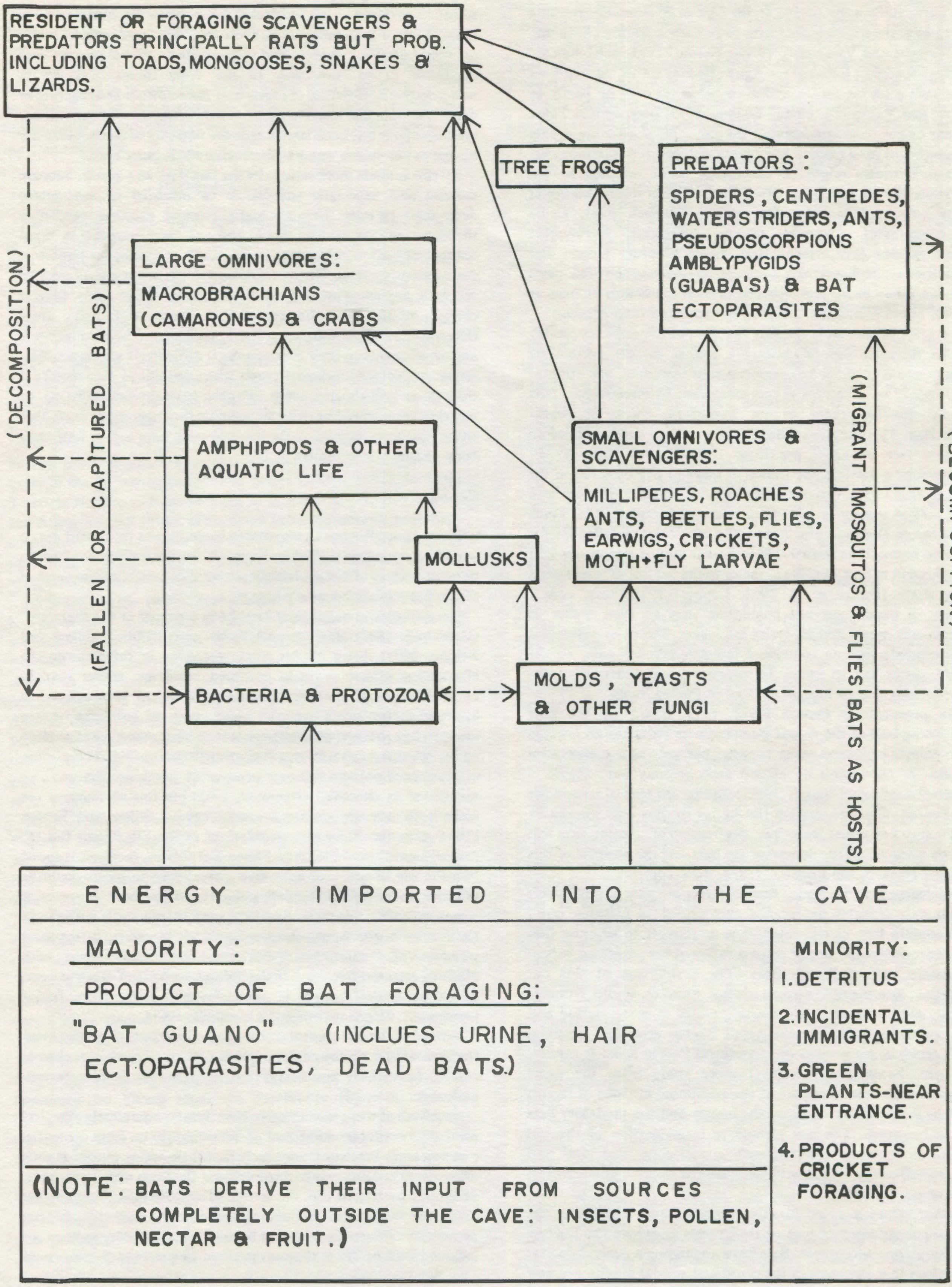


Fig. 8. Theoretical food web for the Aguas Buenas Caves (after Moore and Nicholas, 1964).

Caves particularly appropriate. In the case of *P. parnellii*, running water close to the roosting site seems to be such a feature (Anthony, 1925; Tamsitt and Valdivieso, 1970a; Fenton, 1973, pers. com.).

Of the bat species found in the Aguas Buenas Caves, *M. redmani* is primarily a nectar feeder and *E. bombifrons* may be partly so (Tamsitt and Valdivieso, 1970a; Fenton, 1973, pers. com.). These bats may be the most important or the exclusive pollinating agents for a number of local plants. Any plants with large, nightblooming, odiferous blossoms might be considered to be adapted to bat pollination (Novick and Dale, 1973). Puerto Rican species known to be bat pollinated include: *Crescentia* (Calabash tree), *Ceiba* (Silk-cotton tree), *Capparis* (Burro, Linguam), *Eucalyptus*, *Eugenia jambos* (Pomarrosa), and *Agave* (Century plant). Bat pollination or seed dispersal is mentioned by Buchanan (1972, pers. com.) as a factor in the reproduction of such familiar fruit trees as Caimito, Mamey, Banana, Soursop (Guanabana) and Almond.

Even more important is the fact that four of the eight species (*P. parnellii, P. fuliginosus, M. blainvillii,* and *E. fuscus*), accounting for up to one half of the bat population of the caves, are obligate insectivores. The quantities of prey consumed by insectivorous bats certainly qualifies them as an important check on insect populations. The Big Brown Bat (*E. fuscus*) can eat insects at an estimated rate of 1,000 per hour (Novick and Dale, 1973). Multiplied by a possible population of three to five hundred in the Aguas Buenas Caves, this one species would consume up to one and a half million insects in just three hours of foraging. The Texas population of *Tadarida brasiliensis* (the Mexican Freetailed Bat) is estimated to consume from 7,000 to 20,000 tons of insects per year and is thought to be a significant factor in the control of insect pests in that state (Davis; *et al*, 1962; Cooper, 1973, pers. com.). Tonnage of insects per bat population may go even higher in tropical areas, where activity cycles are longer. Moore and Nicholas (1964) estimate that an individual insectivorous bat eats, on the average, about half its weight in insects per non-hibernating day (bats probably do not hibernate at all in Puerto Rico).

Data provided by Fenton (1973, pers. com.) on the four insect-eating bats of the Aguas Buenas Caves indicates an average of two pounds of insects eaten per year per bat, as a conservative estimate. A population of 10,000 insectivorous bats (again a conservative estimate) would, then, consume ten tons of insects per year. Fenton, who has studied the Aguas Buenas bats intensively over the past few years, feels that "destruction of roosting sites will certainly bring about the demise of the bats and the removal of this predation pressure (on insects)" (1973, pers. com.).

Considering that the Aguas Buenas Caves are part of a relatively isolated unit of karst topography surrounded by volcanic rocks which contain few, or no, caves, it is reasonable to suppose that these caves shelter the largest concentration of cave-dwelling bats in the eastern half of Puerto Rico. The destruction of this bat population, as a possible disease control measure, would probably seriously reduce or eliminate several species of insect eating and plant pollinating bats from the Aguas Buenas area and, possibly, from a much larger portion of east-central Puerto Rico. It cannot, of course, be predicted without more study what the exact ecological or economic impact of the additional millions of insects would be if the balance between the insects and the predatory bats were to be upset. The loss of such a large portion of the bat population could have widespread, unfortunate ecological and economic effects, and it would seem unwise to take chances with this ecological balance.

Further, from a more strictly conservationist viewpoint, the wholesale destruction of bats or their roosts anywhere has become increasingly less acceptable. Bats have undergone a general decline in numbers in many parts of the world and several species are now or may soon be endangered (Mohr, 1972). The two chief reasons listed for this decline are insecticide poisoning and disturbance to roosting and nursery colonies by cave visitors (some of them scientists involved in bat research!) Although rabies is negligible as a direct factor in bat mortality, it constitutes a large indirect factor in their decline. Widespread public and official panic over bat-borne rabies, especially in the West Indies, has led to non-selective destruction of roosts and the resultant endangering of many bat populations. This destruction is apparently continuing, even though it has been shown that the majority of bat populations do not act as rabies vectors (Buchanan 1972, pers. com.).

All this is made more serious by the fact that, as a group, bats are delicate and especially susceptible to intended or inadvertent destruction by man. They are highly colonial, roosting together in the thousands, or even millions, and are, thus, exposed to rapid reduction by a few calamitous events, such as contagious disease or destruction of roosts. Their physiological tolerance ranges may be relatively narrow, thus making them susceptible to slight adverse changes in the microclimates of their roosts or foraging areas (Henshaw, 1972). On the other hand, their strong homing instincts and attachments to their roosts make it difficult, if not impossible, for most species to seek new roosts when conditions may require it (Moore and Nicholas, 1964). Flights to unknown roosting or foraging areas would be risky for animals that operate on such high energy budgets as bats (c.f.: insectivorous bats eating half their body weight in prey daily).

Bat Control

If the Aguas Buenas Caves were to be developed for tourist use, it would be necessary to find some means of controlling the bats as possible vectors of histoplasmosis without jeopardizing the survival of the bat population as a whole.*

Some studies of bat control have been reported in the literature: (Greenhall, 1965; Tamsitt and Valdivieso, 1970b; Laidlaw and Fenton, 1971). Most of this work was done in reference to the elimination of bat roosts in occupied buildings, rather than in caves. The use of nontoxic irritants or pesticides is mentioned as appropriate for small confined areas, such as buildings or tree cavities, but these would be inefficient in large, open areas or deep caves, requiring exhaustive and continual application. The placing of paper or aluminum foil over prospective perching sites was also mentioned as effective, (Greenhall, 1965) but this obviously is not esthetically appropriate for a tourist cave. Laidlaw and Fenton (1971), experimenting with populations of the Big Brown Bat (*E. fuscus*) as well as of the Little Brown Bat (*Myotis lucifugus*), found that the use of artificial light as a disturbance to roosts could be effective, reducing bat populations by 41 to 97 percent. However, it seems likely that this method will not work satisfactorily with two of the species in the Aguas Buenas Caves, *A. jamaicensis* (the most numerous of all the species in the caves) and *B. cavernarum*, both of which are known to dwell in the lighted portions of caves or even, in the case of *Artebius*, in open daylight under palm fronds (Anthony, 1925; Goodwin and Greenhall, 1961).

Several of the bat control studies (e.g. Greenhall, 1965) mention the eventual possibility of developing sonic or ultrasonic devices to control bats. This possibility certainly deserves further investigation.

Nearly all of these studies agree that the only completely effective, presently available means of eliminating bats from potential roosting areas involves the sealing off of their access routes. If such means were applied only to those areas of the caves which were to be developed for tourist use, the source of new *Histoplasma* infection might be eliminated without jeopardizing much of the bat population of the cave. It should be noted that, in order to keep out bats as small as *M. lucifugus* openings larger than 5 mm would

* As mentioned previously, bat control, in itself, does not deal completely with the histoplasmosis aspect. The critical problem is that of the residual *Histoplasma* spores in the guano accumulation. See "Histoplasmosis", this report.

have to be eliminated (Laidlaw and Fenton, 1971). In the Aguas Buenas Caves, *P. fuliginosus* and *M. redmani* are roughly comparable in size to *M. lucifugus*. However, the use of plastic screening should be sufficient to prevent the entrance of these bats into cave areas to be used by tourists. Thick plastic sheeting would probably be most appropriate for sealing off passages where the movement of spore-bearing guano dust from other parts of the cave must be restricted.

Histoplasmosis

Histoplasma capsulatum is still considered an imperfect fungus (a deuteromycete), because it does not reproduce sexually (Berliner, 1971), although Ajello, in 1969, isolated the perfect stage (Torres-Blasini, 1974, pers. com.). It is dimorphous; that is, it has a mycelian phase and a yeast-like phase, depending on the environmental conditions. It has the same general physiological, cytological, genetic, and chemical characteristics as other imperfect fungi. In the natural environment, it lives as a saprophyte, but it is pathogenic in man and other mammals. *H. capsulatum* is the etiological agent of the disease known as histoplasmosis, which is acquired by inhalation of the spores.

Cultures of the fungus from men and animals and, also, as isolated from the soil, suggest that histoplasmosis is endemic in 31 states of the 48 contiguous United States (Ajello, 1971). In Latin America, it extends from Mexico, at latitude 32° N, to Uruguay and Argentina. All grades of exposure to histoplasmosis have been encountered, varying from very low to almost 100% for adults in some humid tropical and subtropical areas, particularly in river valleys and deltas (MacKinnon, 1971).

As recently as the 1940's, histoplasmosis was considered very rare in Puerto Rico. Suarez; *et al*, (1951) performed the first survey utilizing the histoplasmosis skin test. On this occassion, they analyzed 1,055 persons, including veterans, soldiers, hospital employees, school children, and college students. Twelve and seven tenths percent of those tested were positive for histoplasmosis. Another study was made in 1955, by the U.S. Public Health Service, on a total of 1,611 elementary school children from all over the island. They separated the results by rural and urban zones, which were 14.7% and 5.2% positive, respectively (Torres-Blasini; *et al*, 1960).

In 1957, Sifontes tested 167 children under the age of six from the Pediatric Department of the Alejandro Ruiz Soler Sanatorium and 305 adults from the Cayey Sanatorium. He found that only one child tested positive for histoplasmosis but that 35% of the adults were positive, 70% of these intensely so (Torres-Blasini; *et al*, 1960). Moreover, between July, 1957, and February, 1958, Sifontes examined the x-rays of 1,097 persons who were negative to the tuberculosis test and found that 14% had pulmonary calcifications (Torres-Blasini; *et al*, 1960). These high positive results for histoplasmosis in Puerto Rico seemed to indicate that the disease occurs more frequently than was formerly suspected, from the distribution of the etiological agent.

Cox (1970) conducted histoplasmosis skin tests on 2,085 persons from the following institutions: the State Penitentiary and Institution for Young Men, the Psychiatric Hospital, and the Industrial School for Women. Of the total, 1,611 were men and 420 women; the tests were positive for 26 and 31%, respectively. From all the aforementioned histoplasmosis surveys, it can be extrapolated that the total positive incidence for adults in Puerto Rico is approximately 20%.

The fungus *Histoplasma capsulatum* was isolated for the first time in Puerto Rico from a patient with histoplasmosis. A second case was diagnosed from a post-mortem culture of tissue sections in 1962. In the latter case, it was confirmed that the deceased had not traveled off of the island; thus, the fungus must have some specific habitat in Puerto Rico. Based on the previously mentioned clinical antecedents, a mycological soil study was commenced in 1963. The isolation of *H. capsulatum* from the soil in Puerto Rico posed certain problems of nutritional selectivity, because it is hypothesized that the local fungus is a different strain from that in the U.S. Nevertheless, in February, 1963, a sample taken from the *Cueva de los Panes* produced positive results for *Histoplasma* (Torres-Blasini and Carrasco, 1966a). Later, in 1965, Torres-Blasini and Carrasco (1966b), in a study of locations throughout the island, found *H. capsulatum* positive at two sites: the same *Cueva de Los Panes* and the *Cuevas de Aguas Buenas*.

Further evidence of the presence of the fungus in the Aguas Buenas Caves was found by the National Speleological Society expedition there in 1968 (Gurnee, 1968). The purposes of this study were:

A. To prepare a report on the geology, topography, biology, archaeology, and medical aspects of the cave;
B. To investigate the commercial possibilities of the cave for tourist development.

Following the visit, it was determined that all six of the visitors who were originally negative to the skin test were now positive. Two of these became seriously ill. In 1967, Russell Gurnee journeyed down the Río Tanama with two members of the U.S. Geological Survey from Puerto Rico and other participants. One of the Geological Survey employees contracted histoplasmosis and was hospitalized in serious condition for three months.

Of the 21 students participating in the Carleton University Field Course in May, 1973, all who had negative skin tests before converted to positive afterward. The seriousness of the illness ranged from that of a mild cold to being bedridden for a week (Peck, 1974, pers. com.).

More recently, an investigator from the Medical Center was bedridden due to histoplasmosis, which he contracted in the Aguas Buenas Caves. In another instance, Dr. Barry Beck, speleologist for the Department of Natural Resources, and his assistant, Alex de la Cruz, both contracted the disease in the aforementioned caves. It is possible, however that *Histoplasma capsulatum* may be found in the air whenever the conditions of climate and substrate are conducive to its presence.

Ecology of Histoplasma Capsulatum *and its relation to Bats*

As previously mentioned, the physiological, cytological, genetic, and chemical characteristics of *H. capsulatum* are similar to those of the other deuteromycetes. Nevertheless, no generalizations can be made with respect to the ecology of this fungus. Its habitat in bat and bird guano make it different from most of its class. Factors such as temperature and humidity are very important to the establishment of the fungus in a given region. A temperature of 32° C is considered optimum (Di Salvo, 1971).

The role that bats play in the ecology of this fungus is very important. The fungus has been isolated both from the feces of bats and from the tissues of New World bats (DiSalvo, 1971). Possibly, both environmental factors and the roosting places of the bats can affect the presence of *H. capsulatum*. Thus, the study of the cycle from fungus to soil to bat to soil will contribute to the understanding of the spread of *H. capsulatum* (DiSalvo; *et al*, 1970).

Twenty-five species of bats are recorded as hosts or as being infected naturally. Of these, three have been identified from the Aguas Buenas Caves in Puerto Rico: *Pteronotus parnellii, Artibeus jamaicensis* (see Fig. 7), and *Eptesicus fuscus* (Fenton, 1973, pers. com.). There is also evidence that the intestinal tissues of bats contain the yeast form of *Histoplasma*. Bats experimentally infected with the fungus have subsequently passed it in their feces. Although the infection was not acquired normally, it does demonstrate that bats are capable of spreading this disease. Possibly, the bats contract histoplasmosis the same as man. Thus, it is important to understand the physiology, migration, hibernation, and other habits of the bats to determine if the bats are original vectors of histoplasmosis or are only another victim. If the bats play an important role in the dissemination of histoplasmosis in nature, the migratory habits of these flying mammals would extend the dispersal of *H. capsulatum* beyond its natural foci. This also requires further investigation.

Clinical Manifestations of Histoplasmosis

Fungi associated with diseases in humans can be divided into those which affect only the skin (the dermatophytes) and those that are capable of infecting the deeper tissues of the body (the systemic fungi). *Histoplasma* is among the latter.

Histoplasmosis is caused by the fungus *H. capsulatum*. It may have a large variety of clinical manifestations. The respiratory infection can be mild or severe. It is generally not apparent and is also self-limiting. The progressive dissemination of the infection spreads through the reticuloendothelial system, causing fever, general malaise, hepatomegalia, esplenomegalia, anemia, and leucopenia.

As previously mentioned, this disease is cosmopolitan. There are areas of high incidence in the United States, particularly in the central Mississippi River Valley and in the Ohio River Valley. The clinical and epidemiological manifestations of hisplasmosis show distinct behaviors in different climates. Experiments with animals support the hypothesis that a high constant temperature in tropical lowlands, without seasonal variation, can contribute to the inhibition of some of the manifestations of the disease (Sarosi; *et al*, 1971).

Histoplasmosis can coexist with tuberculosis, which makes it more difficult to diagnose. These are three types of pulmonary histoplasmosis (Saliba, 1971a):

A. Acute Pulmonary form—an upper respiratory infection, like a "prolonged cold", which may progress to pneumonitis;
B. Disseminated variety—the disease may slowly progress to various organs, following dissemination by the blood stream, or it can be violent with a rapid clinical deterioration resulting in death; Characterized by fever and hepatosplenamegaly;
C. Chronic Cavitary Pulmonary Histoplasmosis—besides cavitation the disease may involve extensive infiltration, fibrosis, and calcification; this may have progressed from an initial pulmonary infection or it may represent a reinfection, similar to tuberculosis.

Of the three types of histoplasmosis, the chronic and disseminated forms are the most dangerous.

Control, Eradication, and Treatment of Histoplasmosis

More detailed studies are needed to guide the eradication of *H. capsulatum* from endemic zones. Such an effort requires the coöperation of various governmental agencies and centers of advanced studies, in Puerto Rico, for instance, the School of Medicine and the Laboratory of Tropical Mycology of the University of Puerto Rico.

In general, the control of any pathogenic agent or other organism means the intervention of man in determining environmental factors detrimental to said agent; this does not, necessarily, signify its total eradication or elimination. Intervention can also be of a preventive character; in this case, it can only resolve the problem partially. Spores of the fungus can be transported by various agents from one place to another, with the consequent establishment of a new site of infection.

One study (Smith, 1964) on the eradication of endemic foci of histoplasmosis has given very good preliminary results. The application of a 3% solution of formalin has, to date, been the only proven control in the fight against histoplasmosis.

There is no way of preventing the disease once contact has been made between man and the fungus; one acquires some immunity by having the disease (Lewis, 1973). To date, the antifungal agent most often used to treat severe infections of histoplasmosis is Amphotericine B, in doses of 0.5 gm and 3.2 gm, three times per week for approximately sixteen weeks (Saliba, 1971b). Dosage for the disseminated form of the disease is 0.5 mg/kg body weight, daily (Seabury, 1971).

Conclusions

1. Water infiltrates rapidly into the limestone through enlarged joints.
2. The Aguas Buenas Caves drain an area of 5.6 km^2 and provide approximately 350,000 m^3 (90,000,000 gallons) of potable water annually, a major portion of the water supply of the town of Aguas Buenas.
3. The bat population of the Aguas Buenas Caves is an important part of the local ecology, helping both to control insects and to pollinate plants.
4. Almost all the life inside the Aguas Buenas Caves is dependent upon the bat guano as the base of its food supply.
5. The fungus which causes the disease Histoplasmosis is definitely present in the Aguas Buenas Caves and is a serious health hazard.
6. Although the Histoplasmosis fungus lives in the bat guano, the removal of the bats will not necessarily eliminate the fungus.
7. The bat population of these caves is delicate and easily disturbed. Its loss would be a natural tragedy and quite possibly could cause economic harm to the surrounding area.
8. It would be detrimental to destroy any of the bats or to unnecessarily disturb their roosting areas, with the exception of excluding them from those portions of the cave which are to be developed.
9. Any chemicals used to eliminate Histoplasmosis from the guano most probably will rapidly contaminate the river which is part of the water supply of the town of Aguas Buenas. Chemicals which previously have been used for this purpose could kill all life in the portions of the cave which they reach, if not sufficiently diluted. There are not sufficient data available on the behavior of the various possible chemicals in this environment. Pilot studies must be made to ascertain dilution, evaporation, absorption, and biodegradation factors.

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Appendix

Summary of P. del S. 385

P. del S. 385 was presented on March 8, 1973, by Senators Rodriquez Torres, Deynes Soto, and Izquierdo Mora. The legislature has previously enacted other statutes dealing with scenic areas of island-wide importance and it is felt that the Aguas Buenas Caves may qualify in this category.

Section 1 authorizes the Recreational Development Company of the government of Puerto Rico to acquire the necessary land. Section 2 creates a consulting board to direct the planning, development, and operation of the caves. Section 3 states that all island government units may participate in this project, if they so desire. In section 4, the membership of the consulting board is detailed: the five members of the Board of Directors of the Recreational Development Company plus the Director of the Department of Tourism, the President of the University, the Secretary of Health, the Mayor of Aguas Buenas, and the Administrator of Parks and Public Recreation as President of the Board.

Section 5 gives the consulting board authority to work with other government agencies to develop and to operate the caves. Section 6 enables the consulting board to acquire funds, make contracts, and accept voluntary services and contributions, as required. Section 7 allows municipal governments and other participating agencies to assign funds to this project. Section 8 appropriates $25,000 from the general funds of the Commonwealth for the Secretary of Health to begin a program of eradication of the bats, rats, or any other elements of the fauna and flora which may be a detriment to public health during the fiscal year 1973-1974. It further assigns $275,000 to the Recreational Development Company to acquire the land and begin development, during the same year. In following years, the necessary funds will be assigned from the general Commonwealth budget. Section 9 states that the consulting board will be ruled by a majority vote of its members. Finally Section 10 states that this law will take effect as soon as it is approved.

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CONTENTS

PAPERS TO APPEAR IN LATER ISSUES