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THE NATURAL ENVIRONMENT OF PUERTO RICO

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HISTORY AND DEVELOPMENT

The Island of Puerto Rico was discovered by Christopher Colombus on November 19, 1493. Sailing up from the Lesser Antilles and bound for Hispaniola, he came upon the Island on his second voyage to the New World. (Earlier explores likely had been there before, but Colombus - faulty a geographer but a competent navigator and cunning politician - made sure that all Europe heard about the land he had found.) The Island was then called Borinquén by the aboriginal Indians but Colombus re-named it San Juan Bautista in honor of St. John the Baptist. At the time of the discovery it was inhabited by peaceful Taino and Arawak Indians, both of the Brazilian-Guaraní group, but experienced invasion by the ferocious and warlike Caribs who were pushing north from the Lesser Antilles.

In 1508, King Ferdinand of Spain sent Juan Ponce de León to colonize the possession. He arrived with 50 armed men, an inhumane attitude towards the Island's 30,000 Indians, a thirst for gold and grand ideas of forming a Caribbean jewel for the crown of Spain. The first Spanish settlement was established at Caparra near what is now the city of San Juan, but was later re-located to the present site of Old San Juan and named Puerto Rico in allusion to Ponce de Leon's exclamation "Que puerto rico !" when he first landed there. It is conjured that some early colonial mapmaker exchanged the names "San Juan" and "Puerto Rico" in error, and hence-forth the Island became known as Puerto Rico.

The discovery of gold nuggets in some river beds led to the feverish establishment of one of the first colonial mining centers in the Hemisphere. The Indians were used by the Conquistadores to exploit these deposits and were mercilessly overworked. This and various epidemic diseases resulted in the fact that the Indians were virtually extinct by the middle of the 16th century. Thus the Spaniards turned to the slave market of West Africa for cheap labor, and Puerto Rico became an important slave trade center. The traffic grew to massive proportions and by 1765 some 50,000 Negroes had been brought in. As the Spanish were among the last to abolish slavery, it was not effectively halted till 1873.

Upon the exhaustion of the relatively small gold deposits, agriculture and trade became flourishing industries and Puerto Rico developed into one of the two great strongholds of the Spanish Main. Thus the need to fortify the city of San Juan became soon evident and construction of the fortresses "La Fortaleza" and "El Morro" begun in 1533 and 1539, respectively. Coveted by kings and pirates, this strategic island was attacked in 1595 by Sir Francis Drake; occupied for five months by English forces under the Earl of Cumberland in 1598; burnt and plundered by the Dutch in 1625 and suffered other sieges until the last futile attempt by the British in 1797.

In the 17th and 18th centuries, financial troubles developed. Puerto Rico was allowed to trade only with Spain; but French, Dutch, Danish and English traders smuggled in their goods. To remedy this situation, Spain permitted Puerto Rico to conduct free trade with foreign ships and also allowed immigration. But piracy continued to be a profitable enterprise, since Puerto Rico not only lay on the trade line of the Caribbean but also was the place were the gold and silver from Mexico was trans-shipped to Spain. "Freebooters", "flibustiers" and "buccaners" were the pirates of the Caribbean, and Captain William Kidd was the most famous of them all. But there were also "privaters" who plundered with the blessing of their souvereigns and were considered respectable.

In the 19th century some non-violent rebellions occurred on the Island and Spain was forced to give Puerto Rico the status of a province 1869. The liberal movement was crowned with more success when Spain granted autonomy in 1897. However, this newly acquired status was short lived. On July 25, 1898 - shortly after the outbreak of the Spanish-American War - U. S. troops landed at Guánica on the south coast. The Spanish surrendered, and in December of the same year the Treaty of Paris ceded Puerto Rico to the United States.

The Jones Act of 1917 granted Puerto Ricans U. S. citizenship, but not the right to vote in national elections. Still the Island had little political freedom. The governor and all the other top officials were appointed by the President of the United States. Circumstances improved under the dynamic leadership of Luis Muñoz Marín who became the first elected governor in 1948. In 1952, Puerto Rico became a Commonwealth with a representative goverment and voluntarily associated to the United States by means of a compact which the voters of Puerto Rico approved at the polls. Recent developments indicate a strong pro-statehood movement and many believe that Puerto Rico will eventually become the 51rst. state of the U. S. A.

Puerto Rico was one of the poorest of the Spanish colonies and even some 25 years ago it was known as "the pesthole of the Caribbean". Today, while there is still poverty, it is rapidly decreasing and may be largely wiped out by 1975. This change was brought about by the daringly conceived "Operation Bootstrap", on outgrowth of governor Muñoz Marín's scheme of economical and social reconstruction. The success was remarkable. Aided by tax excemptions, there are now more than 2,000 factories in operation as compared with a few hundred in 1940. Today, the manufacturing sector accounts for about 1/4 of the Island's gross national product.

Because of this steady economic growth and rising standard of living, trade has become an important industry. On a per capita basis Puerto Ricans buy more from the United States than any other important market, more even than Canadians. The Island's purchases from USA amount to about $2 billion a

year, and the United States spend approximately $1.5 billion annually for Puerto Rican produce and goods. Tourism has become the Island's third-ranking industry and attracts some 1 million visitors a year spending about $220 million. Agriculture once the Island's mainstay now only accounts for about 10 percent of Puerto Rico's GNP, signifying the change from a predominantly agrarian economy to an industrial one. As a result, Puerto Rico's gross national product has increased from $225 million in 1940 to about $4.7 billion in 1970. In the same period, the per capita income rose from $120 to about $1,600.

Puerto Rico's racial make-up is diverse. By pedigree, the islander is in large measure Spanish. But although the Arawak Indians ceased to be a separate ethnic group in the 16th century, there remain a few traces of Indian blood. African influence is evidenced by the fact that about 10 to 15 percent of today's population are Negroes. Other races were added as the centuries went by: From Haiti came French families in 1801, from Louisiana about 100 Roman Catholic Americans; refugee Spanish royalists arrived from Venezuela, and a large group of Irish Catholics came from Philadelphia.

The Island's population was about 1 million in 1900 and now numbers 2,700,000; but the annual growth rate decreased from 20 percent in 1949 to about 1 percent today. About half of the Puerto Ricans live in rural areas and it is noteworthy that about 1.5 million persons are younger than 35 years. The population density is 786 inhabitants per square mile (303 inh./sq. km.) and Puerto Rico is thus one of the most densely populated countries of the world.

The culture of Puerto Rico is dominated by the heritage of Old Spain, and Spanish influence is strongly reflected in architecture, music, art, literature, and religion. About 80 percent of the population are considered Roman Catholic. But customs from the U.S. are readily absorbed and combined with some that are native to the island. Thus, the Puerto Rican is neither Spaniard nor American, though the cultures of both have left their marks. By instinct he is Puerto Rican, and so is his culture.

There is a saying that when the Spaniards came to a new territory they built a church and a fort, and when the North Americans came they built a school. There is a considerable degree of truth in this for, in 1899, the rate of illiteracy was more than 80 percent and was still 69 percent in 1940. Today more than 95 percent of school-age children attend classes and the rate of literacy is 95 percent. Perhaps the best indication of Puerto Rico's enthusiasm for education is the fact that the government spends 30 percent of its total budget on education - a proportion larger than that of most any other country in the world.

PHYSIOGRAPHY

Puerto Rico is the smallest and easternmost island of the Greater Antilles and lies at approximately 18°15' N latitude and 66°30' W longitude; about 2,500km. (1,600 mi.) SE of New York and some 1,600 km. (1,000 mi.) ESE of Miami. The Island is roughly rectangular; about 180 km. (113 mi.) east to west and maximally 56 km. (35 mi.) north to south, comprising 8,860 sq. km. (3,421 sq. mi. - 2.1 million acres). It is surrounded by the Atlantic Ocean to the north, which reaches its greatest depth of 8,510 m. (27,922 feet) in the Puerto Rico Trench some 145 km. (90 mi.) north of the Island, and by the Caribbean Sea to the south (see Fig. 1).

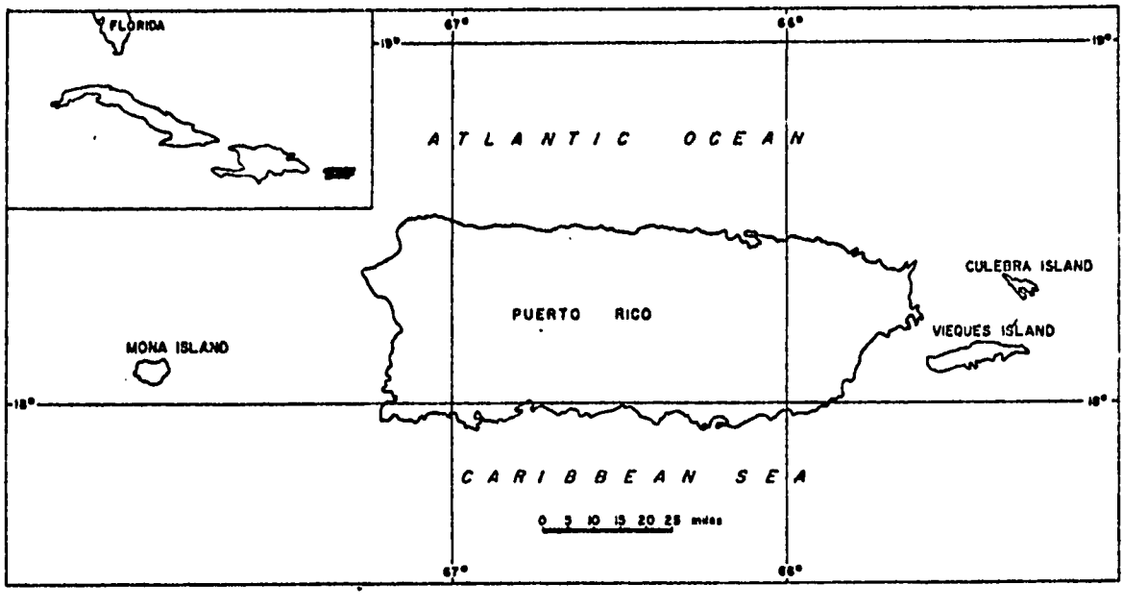


Fig. 1 - Principle Islands of the Commonwealth of Puerto Rico

Christopher Colombus is said to have described Puerto Rico to the Queen of Spain by crumbling a piece of parchment. The analogy seems appropriate, for montainous terrain covers more than 80 percent of the Island. The highest peaks rise to 1,338 m. (4,389 feet) in the Cerro de Punta and 1,065 m. (3,493 feet) in the El Yunque.Only about one-fourth of the total land area has slopes of 15 percent or less, a fourth ranges in slope from 16 to 45 percent, and the remaining half is even steeper.

The Island's main water divide extends E-W, but is considerably displaced to the south. Thus, the rivers heading to the Atlantic Ocean are better fed and have greater erosion force than those flowing into the Caribbean Sea. In total, some 50 non-navigable streams flow into the surrounding seas.

Mitchell (10) distinguished seven physiographic units that all contain a variety of landforms:

1 - The Monadnocks are the highest peaks of the central mountain ranges, namely the Cordillera Central, the Sierra de Luquillo, and the Sierra de Cayey. These summits rise above the altitude of the St. John Peneplain.

2 - The St. John Peneplain is the main skyline feature of the Cordillera Central and reaches highest elevations of about 750 to 800 m. (2,400 to 2,600 feet). During lower and middle Miocene the peneplain sloped gradually to sea level, but was uplifted in the upper Miocene. Since then it has undergone severe dissection, therefore only scattered remnants of the old peneplain are preserved today.

3 - The Caguana Peneplain, lying at an avarage altitude of 470 m. (1,500 ft.) is less conspicuous than the St. John Peneplain and originated during a later erosion cycle predating a further regional uplift.

4 - The Foothill Zone is the region adjacent to the southern flanks of the central mountains. It varies in elevation from 120 to 490 m. (400 to 1,600 feet) and has a hilly and sometimes rugged relief.

5 - The Interior Lowlands comprise those of Caguas, Cayey and Coamo. They are flat basins within mountainous areas and owe their presence to particular structural and lithological conditions.

6 - The Belted North Coastal Zone coincides with the outcrop area of the mid-Tertiary limestones along the north and north-western coasts. Subsequently to the emergence from the sea, a typical tropical karst topography was superimposed on these formations. This karst topography is characterized by cone-shaped hills and deep sinks.

7 - The Playas and Alluvial Plains are a series of broad, flat valleys, coalescing alluvial fans, deltaic deposits, marshes, and lagoons. This unit varies from virtually nonexistent to 19 km. (12 mi.) in width.

Figure 2 depicts occurrence and extent of these physigraphic-geomorphic units. The geomorphic development of the Island - in a somewhat hypothetical and highly schematic fashion - is shown on figure 3.

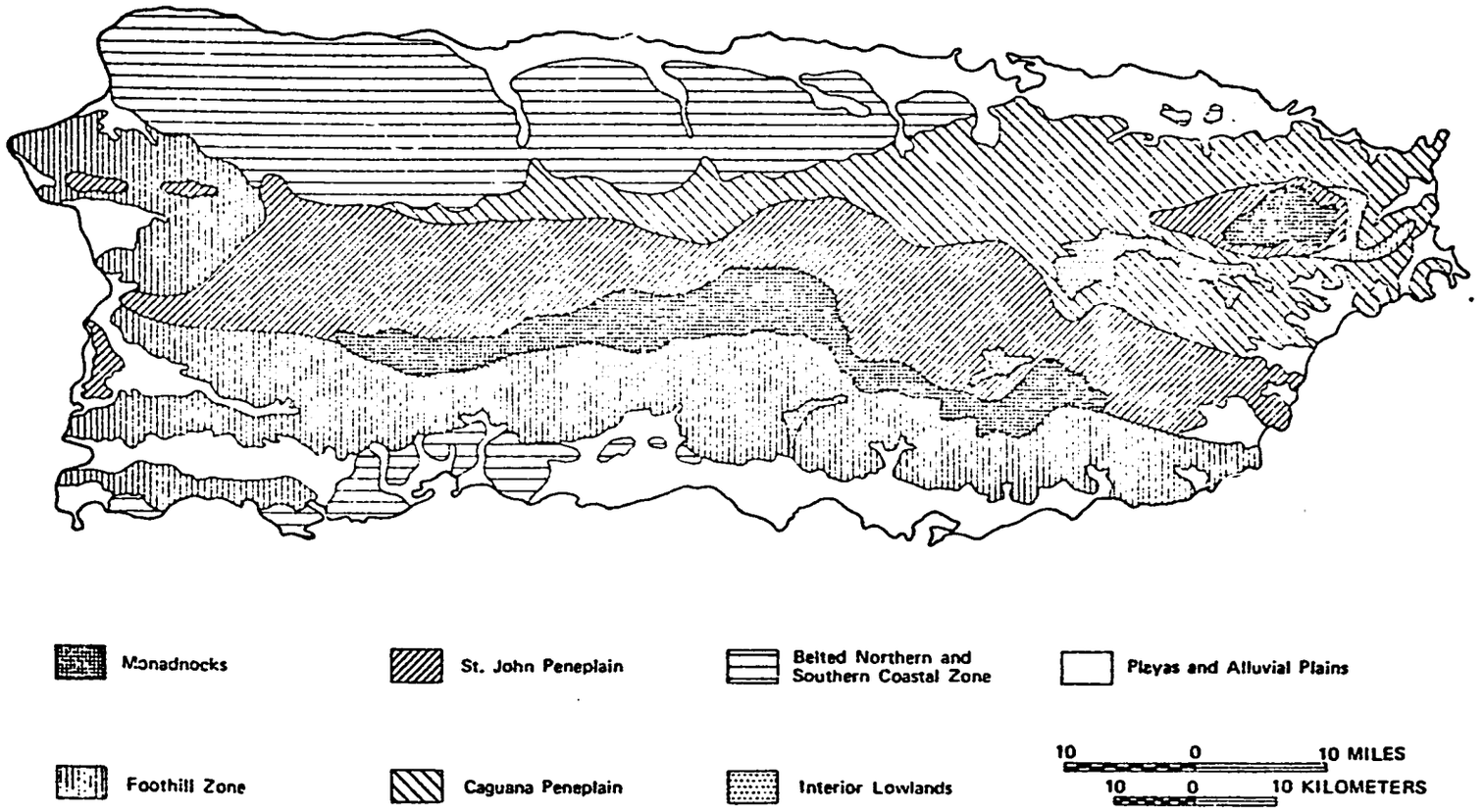
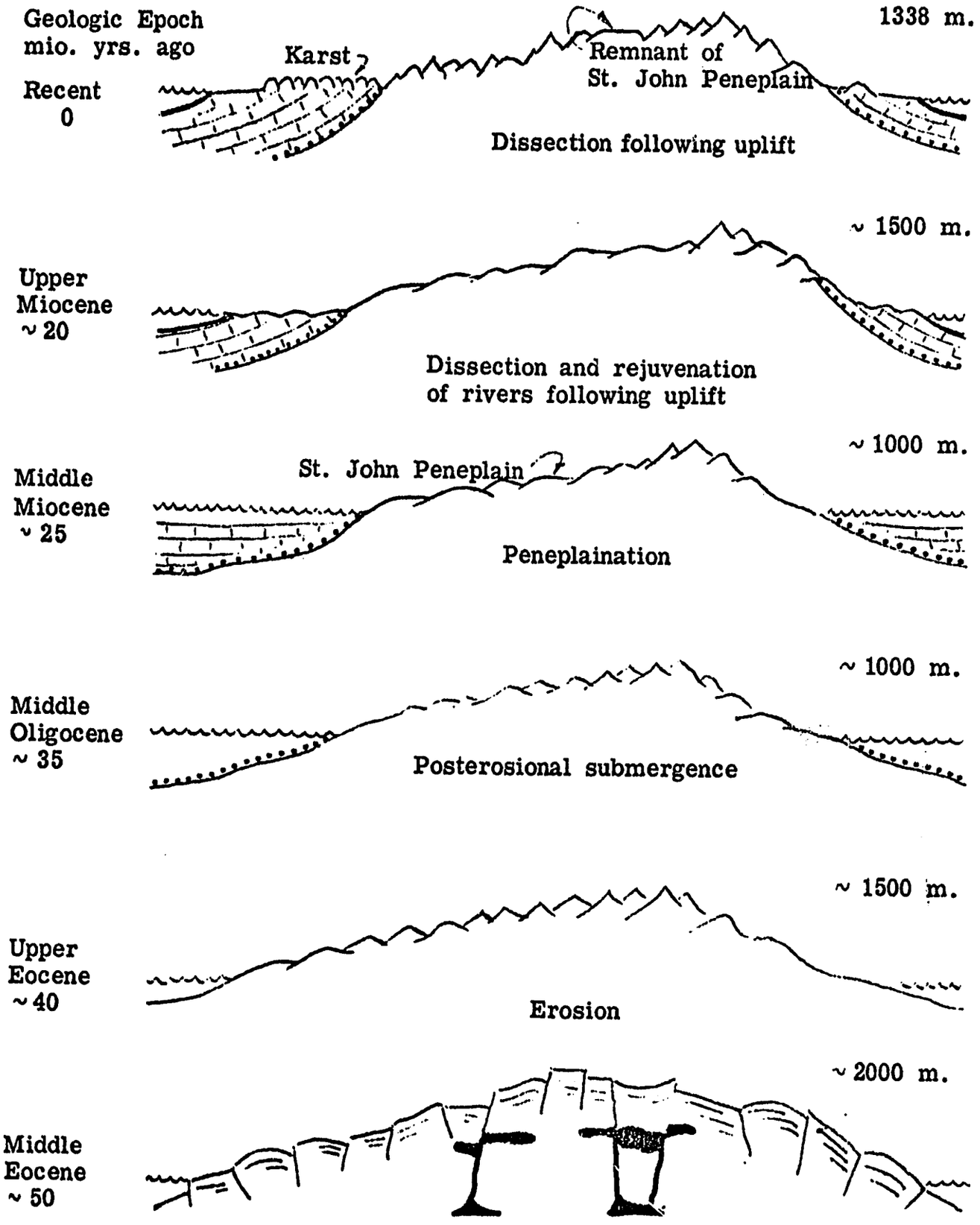


Fig. 2 - Physiographic - Geomorphic Regions of Puerto Rico (Beinroth, 1969)

Fig. 3 - Sketch Showing the Geomorphic Development of Puerto Rico,



CLIMATE

Much could be said about Puerto Rico's tropical marine climate, but this discussion is confined to the major climatic features.

Lying in the belt of trade winds, the Island is exposed to a considerable air flow that is relatively persistent from the east-northeast. (The control for this wind pattern is a high-pressure area known as the "Azores-Bermuda high" and the "equatorial depression". Seasonal shift of these areas is reflected in corresponding rainfall and temperature fluctuations.) Since the winds come from the broad reaches of the Atlantic Ocean they are moisture-laden, but when they are forced upward by the central mountains they precipitate much of the moisture they contain. As a result of this orographic effect, a large amount of rainfall occurs on the windward slopes, whereas the areas in the rainshadow receive substantially less. Because Puerto Rico is predominantly mountainous and the mountains have an irregular pattern, the annual rainfall shows much irregularity - see figure 5. Locally, convectional rains and breezes caused by the thermal land-water effect further contribute to this variation.

By the Thornthwaite system of classification (17), the climate of the northern, eastern and western coasts and the northern foothills is humid tropical; the central mountain ranges have a humid mesothermal or, in the highest areas, a wet mesothermal climate, while that of the southern foothill zone and the south coast is subhumid tropical or semiarid tropical - see figure 4.

Annual rainfall ranges around 510-635 cm. (200-250 inches) in the Luquillo Mountains to less than 76 cm. (30 inches) on the south coast. The distribution is uneven. The drier winter period is followed by moderate spring rains and a lull in the first part of summer. The later summer and fall typically is the wettest period, reaching a maximun in September and October - see figure 5.

The annual means of temperature average 25.6°C (78° F) in the coastal areas and about 22.2° C (72° F) in the uplands. While the variation in the monthly means is small, diurnal fluctuations are more significant and range from 7-10° C (12 to 18° F) throughout the year , see figure 6. The high temperatures in combination with the constant air flow cause high evapotranspiration. The total evaporation potential ranges from 125-200 cm. (50 to 80 in.) per year.

Hurricanes are a further major climatic feature of Puerto Rico. The massive circulation of moist air in these tropical storms causes intense rainfall in large amounts and results in great floods. Puerto Rico experiences hurricanes (whose centers touch the Island) on the average of about once every 25 to 30 years.

Since floods are also caused by hurricanes passing nearby, the frequency of severe floods is about every 5 to 6 years (3).

Climatological data for some representative sites are compiled in Table 1.

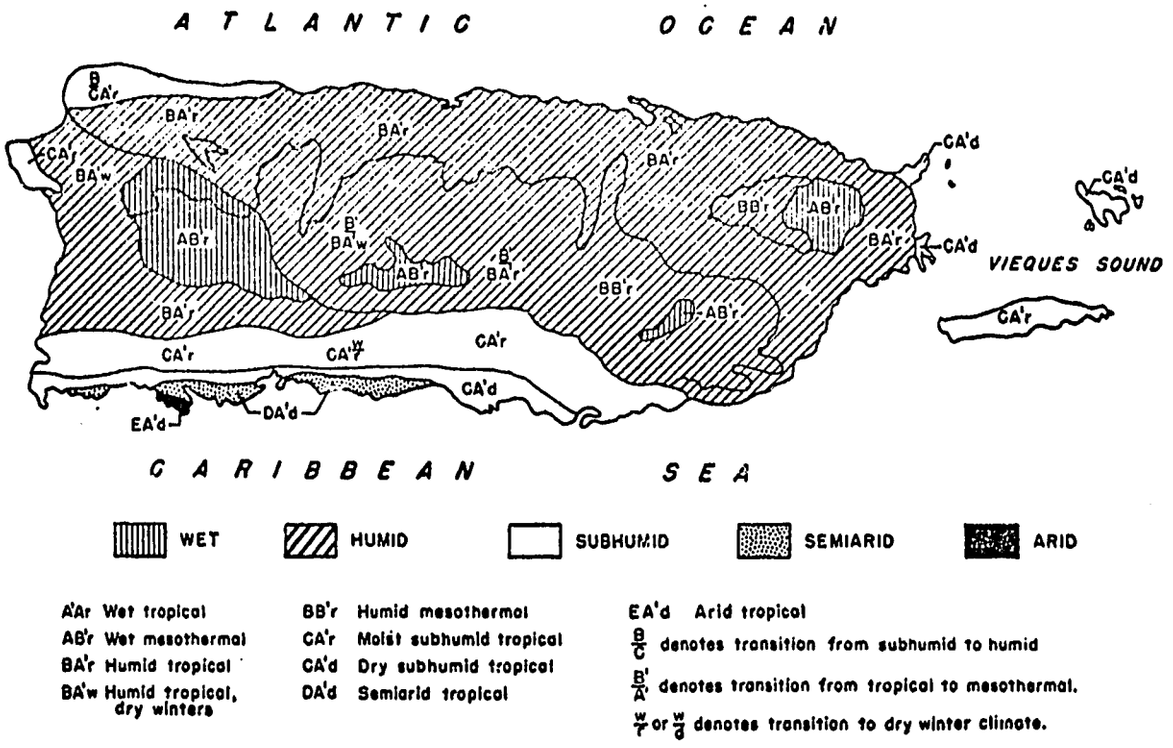


Fig. 4 - Climatic Map of Puerto Rico according to the Thornthwaite System of Classification. Source: USDA Yearbook of Agriculture, 1941

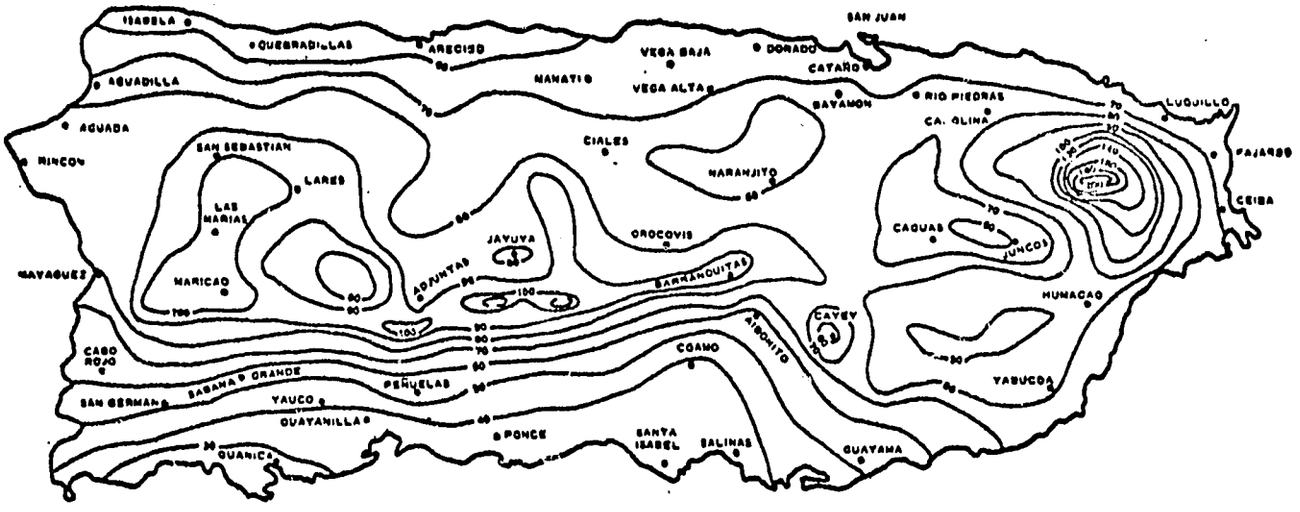


Fig. 5 - Mean Annual Rainfall (inches) in Puerto Rico
Source: P.R. Water Resources Authority

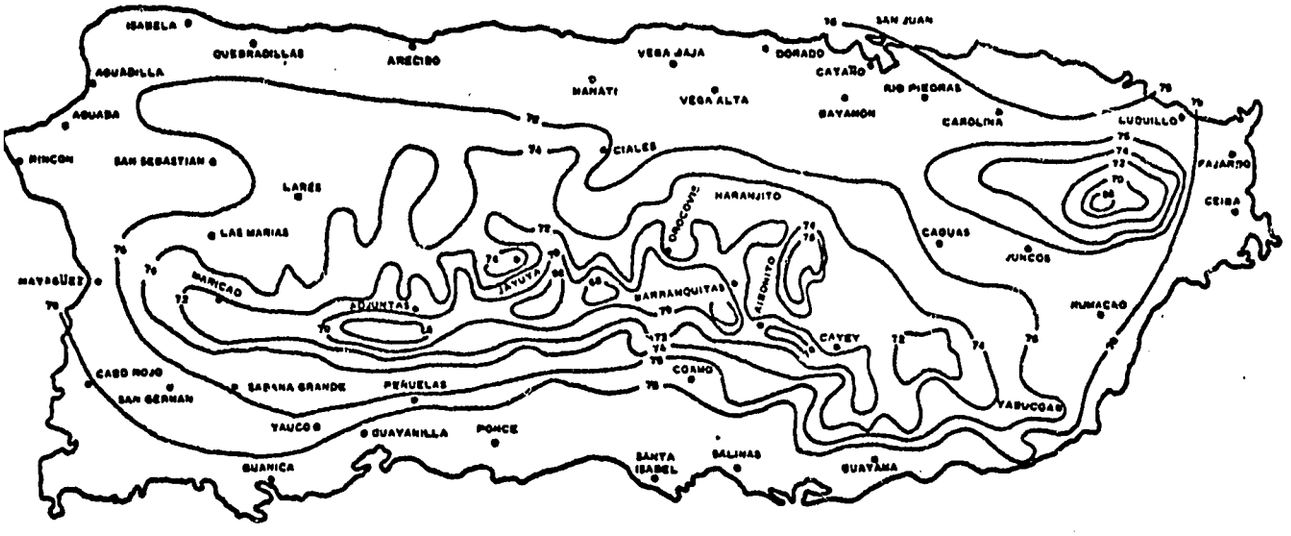


Fig. 6 - Mean Annual Temperatures (°F) in Puerto Rico
Source: U.S. Weather Bureau

Table 1. Climatological data - Puerto Rico.

Location	J	F	M	A	M	J	J	A	S	O	N	D	Annual
						Precipitation (inches)							
Barranquitas	3.67	3.31	2.44	3.45	5.73	5.05	3.97	5.71	6.01	8.95	4.86	6.14	59.32
Corozal	5.17	4.05	4.04	5.87	8.12	5.51	7.51	8.36	7.43	7.26	8.69	6.72	78.76
Isabela	3.80	3.34	3.25	4.84	8.44	7.54	5.00	6.68	6.90	6.52	5.42	4.32	66.05
Lajas	1.38	1.57	2.91	2.19	2.81	2.43	4.93	5.60	6.62	5.69	4.09	2.82	43.85
Mayagüez	1.91	1.44	3.50	4.68	7.45	8.52	9.60	10.08	11.01	8.50	3.87	2.60	76.12
San Juan	4.13	2.70	2.07	3.33	7.16	5.83	6.02	6.34	6.06	5.24	6.05	4.89	60.36
						Temperature (^{o}F)							
Barranquitas	69.7	68.7	70.6	72.6	71.8	73.2	74.7	74.6	76.2	73.2	71.8	67.7	74.0
Corozal	72.9	72.7	73.2	75.0	77.2	78.1	78.3	78.4	78.3	77.7	76.3	73.8	75.9
Isabela	73.5	73.4	74.5	75.5	77.1	78.3	79.1	79.1	78.9	78.3	77.0	75.1	76.7
Lajas	74.3	74.2	75.2	76.6	77.9	79.5	80.7	80.4	79.3	79.0	76.4	74.4	77.3
Mayagüez	74.1	74.8	75.7	76.9	78.3	79.3	79.3	79.6	79.5	78.8	76.4	75.7	77.5
San Juan	75.1	75.1	76.0	77.0	78.8	79.9	80.1	80.8	80.7	80.2	78.6	76.7	78.3
						Evaporation (inches)							
Corozal	3.37	3.33	3.94	4.98	5.07	4.78	5.57	5.25	4.58	4.20	3.10	2.86	51.03
Isabela	3.68	4.97	6.40	6.87	5.81	6.98	6.64	6.55	5.82	4.89	4.59	5.09	68.29
Lajas	4.04	5.34	5.83	6.71	6.83	7.78	8.22	7.38	6.04	5.57	4.58	3.90	72.16
San Juan	6.93	6.25	8.04	7.93	7.34	7.34	7.91	7.69	6.37	5.92	5.42	5.79	82.03

Source: Climatological Data, Puerto Rico and the Virgin Islands - Annual Summary 1967. U.S. Dept. of Commerce, Environmental Science Services Administration.

VEGETATION

By virtue of its climate and location Puerto Rico belongs to the Caribbean province within the paleotropical plant kingdom. This province, set up along the lines of floristic coincidence, comprises virtually all of Central America.

There is every reason to believe that at the time of Columbus' arrival the island of Puerto Rico was covered by extensive and luxuriant forests. Today the plant cover is almost entirely controlled by man, and native vegetation is only preserved in a few relics. The delineation of ecologic zones can, therefore, only be made by extrapolating from the few remaining virgin forests and from physiographic and climatic features. Ecologists have distinguished several vegetation zones that are conditioned primarily by climate and secondarily by physiography or parent-material. The striking contrasts among these various vegetations types within short distances are mainly the result of differences in the total amount of precipitation and its seasonal distribution, lithologically controlled differences in soils and soil moisture regimes, landforms and relief.

The brief description presented here is based largely upon the work by Little and Wadsworth (9) and deals with the climax vegetation. Although now only preserved in few places, these types of vegetation are nevertheless ecologically characterizing the Island and would be ubiquitous were it not for man's interference. Figure 7 shows the chief climax forest types and their distribution in Puerto Rico.

The Littoral Zone (not shown on figure 7) that extended along the wind-swept seacoast was occupied by littoral woodland and halophytic ecosystems. In the protected bays, lagoons and estuaries were dense stands of red, white and black mangrove (Rhizophora mangle, Laguncularia racemosa, Avicennia nitida). Sea grape (Coccoloba uvifera) was a prominent species of the woodlands near the shore.

Semi-deciduous Tropical Dry Forest (Dry Coastal Forest, Dry Limestone Forest) grew south of the central mountains. There the limited rainfall in the rainshadow of the mountain ranges caused a more xerophytic vegetation characterized by lignumvitae (Guaiacum officinale), silkcotton (Ceiba pentadra), black olive (Bucida buceras), and species of acacia.

In the limestone region of the south coast, the adverse moisture conditions are accentuated by excessive subsurface drainage to a point that many trees cannot subsist. The woodland, therefore, assumed the form of thorn and cactus scrubs with pricklepear (Opuntia dillenii) and turkscap (Cactus inortus). Clearing of the dry forest and the introduction of xerophytic grasses created the now savannah-like aspect of the pastures of the south.

Tropical Moist Forest (Moist Coastal Forest, Moist Limestone Forest) grew on the northern and north-western coastal plains of Puerto Rico. The mostly evergreen trees of this forest were from 12 to 18m. (40 to 60 feet) tall and included Corozo palm (Acrocomia media), west Indian locust (Hymenaea courbarie), black olive (Bucida buceras), and Spanish cedar (Cedrela odorata).

Tropical and Subtropical Moist Forest (Lower Cordillera Forest, Lower Luquillo Forest) occupied most of the lower mountains of the interior that range in altitude from 150 to 750 m. (500 to 2,500 feet). This formation contains about 170 species and was probably the most magnificent forest of Puerto Rico. At their maximum development trees were about 33m. (110 feet) in height and up to 2.5m. (8 feet) in diameter. Typical species of this forest include tree-fern (Cyathea arborea), trumpet tree (Cecropia peltata), angelin tree (Andira inermis), candlewood (Dacryodes excelsa), and yellow sander (Buchenavia caitata).

Subtropical Rain Forest (Upper Cordillera Forest, Upper Luquillo Forest) grew farther up the slopes in the wettest and coolest parts of the central mountains. Lower temperatures and often somewhat swampy soil conditions resulted in a comparatively poor forest about 18m. (60 feet) tall. The most common species are tree-fern (Cyathea arborea) and sierra palm (Euterpe globosa). On the very peaks of the Island's highest mountains this forest is dwarfed to 6m. (20 feet) or less and further contains oreganillo (Weinmannia pinnata) and palo bobo (Brunellia comocladifolia).

At present about 500,000 acres, or somewhat less than one quarter of Puerto Rico's land area, are covered by trees. However, only some 250,000 acres are actually under forest. About 200,000 acres are covered by coffee shade (75,000 acres of which are abandoned), and the remaining 50,000 acres are woodland pasture and, to a minor degree, orchards.

Of the many ornamental plants now found on the Island most are not indigenous. Today, one of Puerto Rico's most characteristic trees is the royal palm (Roystonea borinqueña), a magnificent and stately ornamental that is common throughout the Island. Widely planted for shade and the spectacular flowers along highways and in gardens is the flamboyant-tree (Delonix regia), a native of Madagascar. From May to August, this tree is covered with brilliant masses of orange-red flowers. Another conspicuous ornamental is the African tulip-tree (Spathodea campanulata), a large exotic tree that is also planted for shade and its many large orange-red to scarlet flowers. Very common along highways and in windbreaks is Siamese cassia (Cassia siamea), a legume with bright yellow flowers and numerous dark brown pods. Further introduced was hibiscus (Hibiscus tiliaceus).

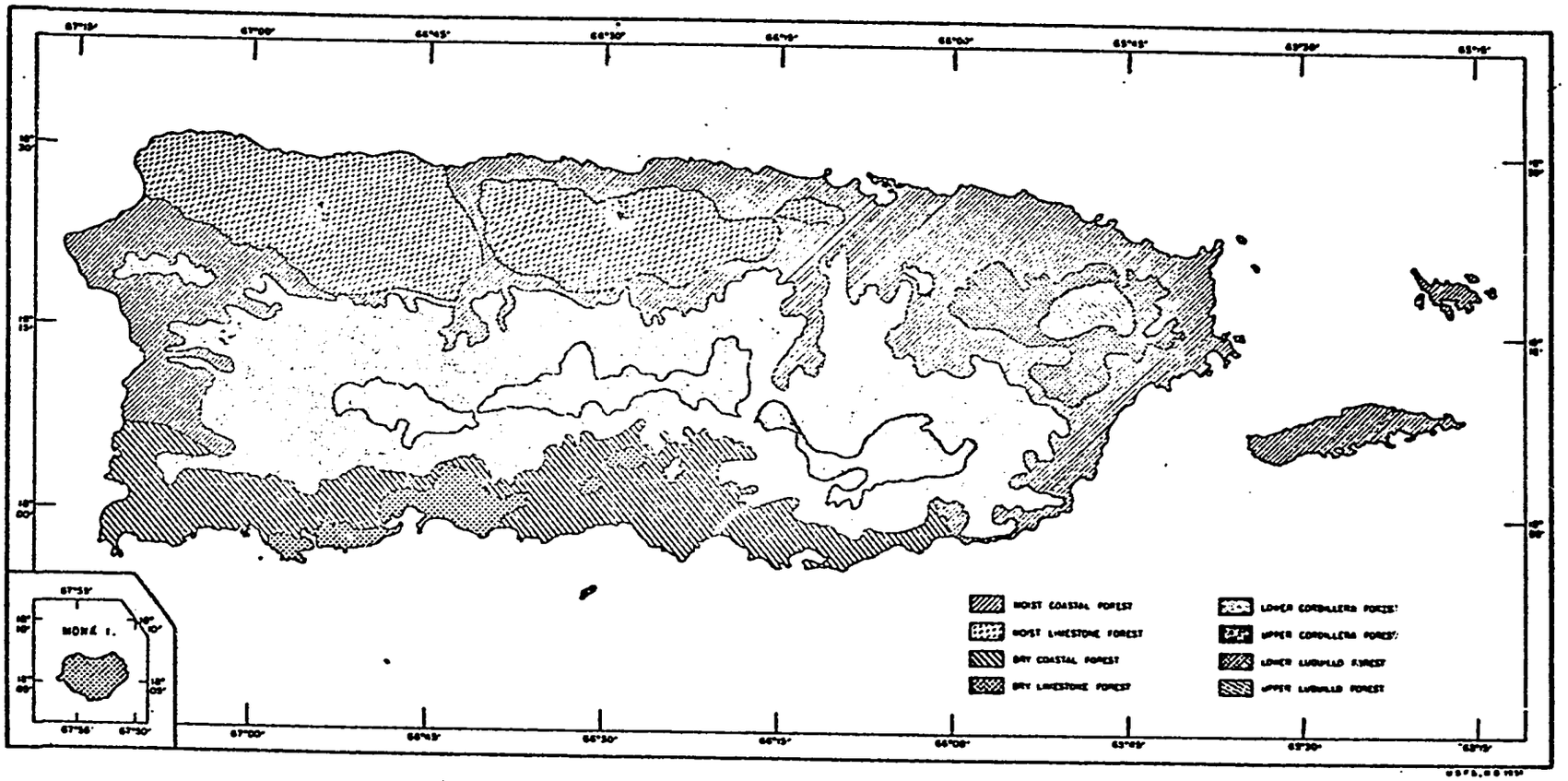


Fig. 7 - Climax Forest Types and Forest Regions of Puerto Rico (LITTLE and WADSWORTH, 1964)

ANIMAL LIFE

Puerto Rico does not have any land mammals that are indigenous to the Island. The most common animal - the mongoose (Herpestes birmanicus) - was imported from Cuba in 1877 for the purpose of destroying rats and snakes. Yet the rats have not been controlled, and there were never many snakes.

Lizards are both prevalent and beneficial as they are insectivorous. Most common is the small "lagartijo" (Anolis poncemesis). Several kinds of frogs have been introduced, but the most typical is a native tree-frog called "coqui" (Eleutherodactylus portoricensis). It is rarely seen, but its distinct mating calls are frequently heard at nighttime.

Birds are not as plentiful as might be expected, owing to the destruction of nests and young birds by hurricanes and man. In less densly populated areas, some of the more conspicuous birds include the Puerto Rican honey creeper, the gray kingbird and the mockingbird. The cattle egret (Bubulcus ibis ibis), that came to the Island in 1953 from Africa, has established itself and has become a common bird. The beautiful Puerto Rican parrot (Amazona vittata vittata) that was once quite common is now almost completely extinct.

Insects are, of course, very abundant and more than 1,400 different species have been identified on the Island. They include many that are destructive to crops and, in the case of termites to wooden structures.

The aquatic life in coastal waters, lagoons, swamps and streams include fish, oysters, lobsters and many kind of mollusks and sponges. The fringe-type coral reefs along some beaches are mainly built up by fan and brain corals.

Parenthetically, it may be noted in this context that malaria- carrying mosquitos have been wiped out completely. However, liver flukes affecting both man and beast are still not uncommon. Bilharzia (Schistosomiasis) is transmitted by an intermediate snail host (Australorbis glabratus) that is found in many streams and ponds of the Island except in those flowing entirely through limestones. The second liver fluke disease, Fascioliasis, appears to be more common in areas of calcareous soils as the intermediate snail host (Lymnaea cubensis) tends to prefer this habitat.

GEOLOGY

The Caribbean Region is geologically young. Thus the datable geologic history of Puerto Rico begins only in the Upper Mesozoic - after more than nine tenths of the earth's known history had already elapsed. During Lower and early Upper Cretaceous times a geosyncline elongated through the Antillean Region. In this trough active volcanism occurred until the end of Middle Eocene and gave rise to a predominantly submarine accumulation of andesitic volcaniclastics (tuffs, lavas, tuffaceous breccias) and other volcanic rocks. Simultaneously, limestones and tuffaceous shales originated.

At the very end of the Cretaceous, and extending through Middle Eocene, mountain-forming processes caused by north-south or northeast-southwest compressive forces resulted in the folding of these rocks into an anticlinorium and intensive faulting into hundreds of fault blocks. This orogeny was accompanied by the emplacement of plutonic rocks, largely granodiorite, quartzdiorite, and some diorite, which are now exposed in the San Lorenzo and Utuado plutons. The serpentinized peridotite of SW Puerto Rico intruded earlier, probably in Lower Cretaceuous.

The diastrophism entailed the appearance of an island which, during mid-Tertiary, was bordered by marine basins to the north and to the south. There the Younger Tertiary limestones were formed from Middle Oligocene to Middle Miocene. This interim of quiescence was succeeded by reviving tectonic movements causing further uplift and slight tilting, thus shaping the island's present form. These periodic movements also controlled cycles of erosion in the interior: at least two peneplaines were denuded and, as a result of subsequent uplift, dissected by rejuvenated rivers. In the Quaternary a variety of sedimentary rocks accumulated ranging from indurated dunes to unconsolidated alluvial and organic deposits.

For simplicity, Puerto Rico can be divided into three geologic provinces:

1. An axial volcanic-plutonic province that traverses the island from the east to west coasts and makes up most of the mountainous interior;

2. A northern limestone province extending from west of Loiza Aldea to Aguada along the north and northwest coasts. Included in this unit are the alluvial, blanket, swamp, and beach deposits that overlay the calcarenitic and chalky limestones; and

3. A southern limestone province along the southwestern coast, similar to the one in the north but dipping southward off the central highland.

In terms of area, the volcanic rocks crop out over some 4,500 sq. km. (1,730 sq. mi) or 51 percent of the total area of Puerto Rico. Intrusive igneous rocks are exposed over about 1,410 sq. km. (545 sq. mi. - 16 percent); serpentinite underlies roughly 100 sq. km. (40 sq. mi. - 1 percent); limestone forms the surface in about 1,510 sq. km. (585 sq. mi. - 17 percent); and surficial deposits cover approximately 1,325 sq. km. (510 sq. mi. - 15 percent).

Structurally, Puerto Rico consists of a central core of strongly faulted and folded Cretaceous and Lower Tertiary rocks unconformably overlain by the Younger Tertiaries on its northern and southern flanks. The general strike is NW-SE or WNW-ESE. Besides folds, transcurrent faults are the dominant structural features. The hiatus between Eocene and Middle Oligicene marks the most profound lithological and structural break in Puerto Rico.

Mineral resources are limited. Of the various metallic ore deposits occurring in Puerto Rico, only a copper deposit valued at some $ 2 billion, warrants commercial exploitation at the present economic conditions. With the exception of a low grade lignite, no fuels have been found as yet. The nonmetallics, particularly limestone, constitute, however, resources of considerable economic importance

Figure 8 depicts a diagrammatic outline of the major geologic events. A generalized geologic map is provided in Figure 9. For a more complete account the reader is referred to "An Outline of the Geology of Puerto Rico" which also contains a bibliography covering the major recent publications of this subject (1).

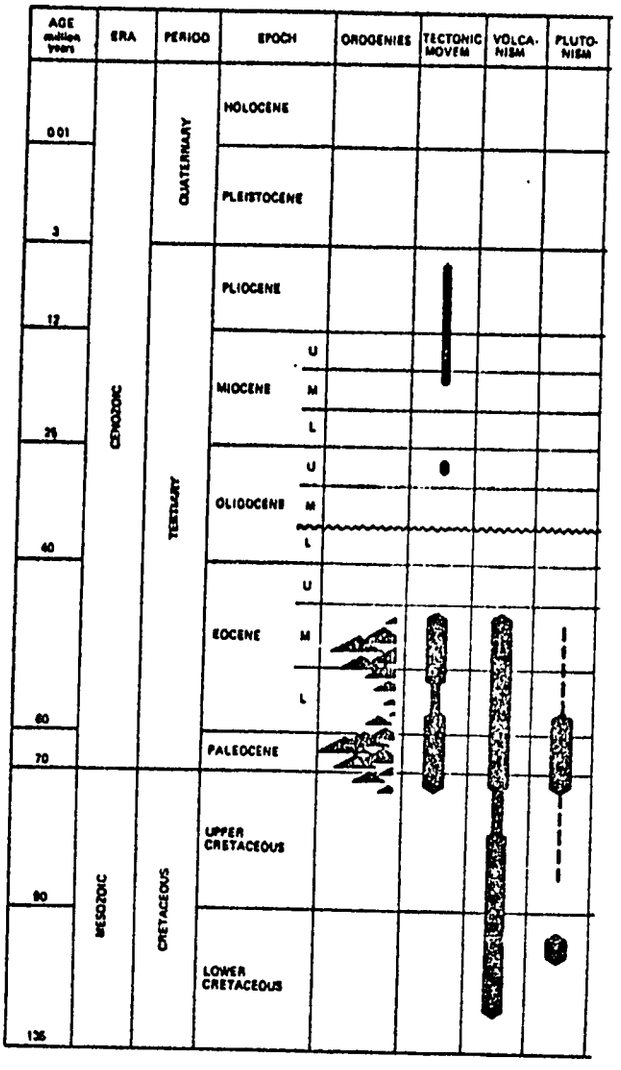


Fig. 8 - Schematic Outline of the Major Geologic Events in Puerto Rico (BEINROTH, 1969)

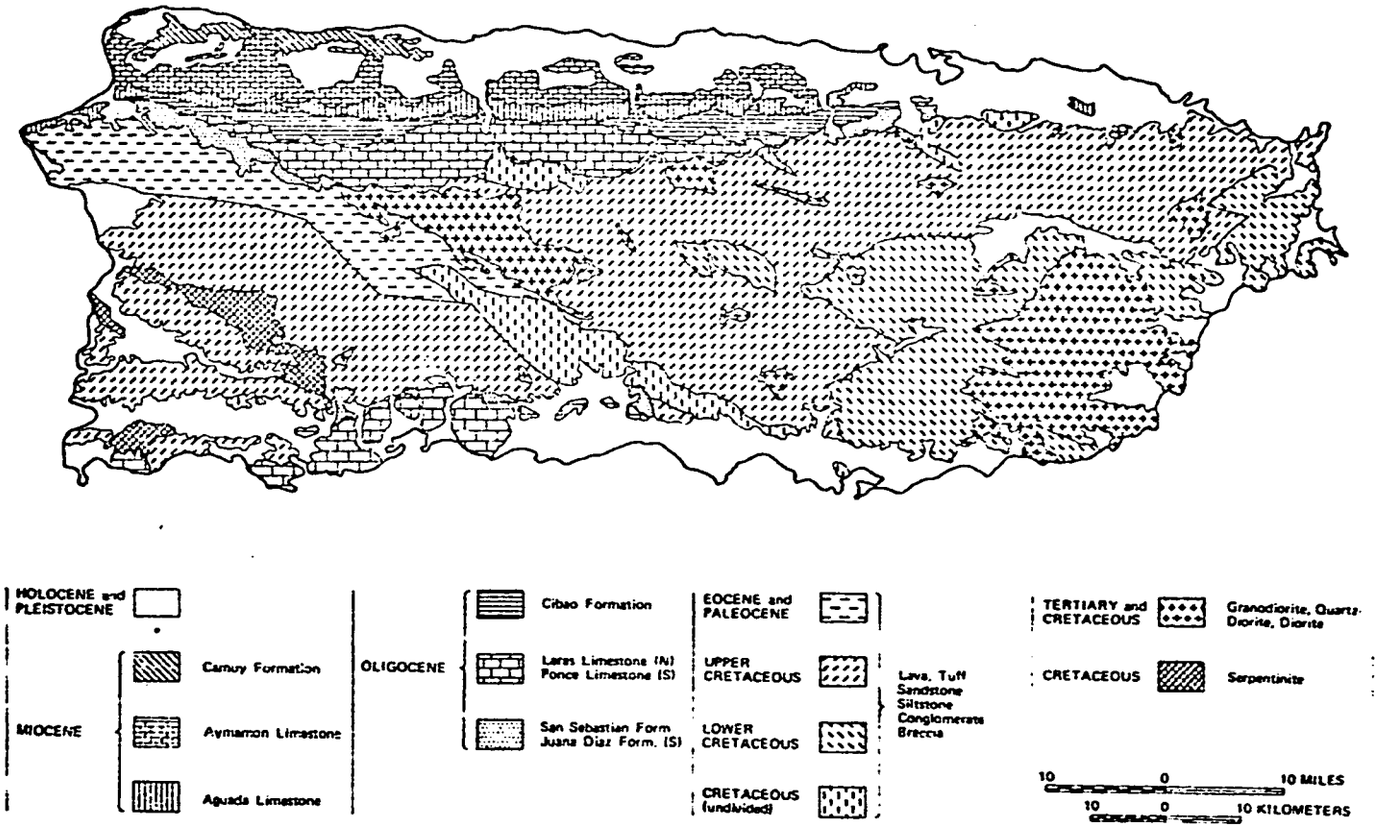


Fig. 9 - Simplified Geologic Map of Puerto Rico (BEINROTH, 1969)

SOILS

Soils form in response to the combined effect of several environmental factors, namely climate, flora and fauna, parent rock, relief and time. Because Puerto Rico exhibits a wide range in these conditions, a great variety of contrasting soils is encountered on the Island.

The chief environmental factors controlling pedogenesis in Puerto Rico are the amount and distribution of rainfall, the lithologic nature of the parent rocks, the degree of slopes and the age of the geomorphic surfaces. The latter is of particular importance in the tropics in general: soil formation in the intertropical areas was not interrupted by Pleistocene ice-ages and thus may comprise geologic times. Recent studies in Puerto Rico (7) indicate that some Oxisols began to form more than 20 million years ago. For the most part, however, the Island is characterized by youthful geomorphic surfaces.

Figure 10 shows a generalized soil map of Puerto Rico. The units depicted correspond to the highest category, or broadest grouping, of the new soil classification system (Soil Taxonomy) and contain much generalizations. Equally general is the brief account that follows.

Entisols are mineral soils with low degrees of horizonation, mainly those soils that have been identified as Lithosols, Regosols and Allivial Soils in recent years. In Puerto Rico the Entisols are of small extent. They occur on narrow strips at elevations close to sea level on the Recent alluvial deposits along all coasts and on some alluvial fans and floodplains. They are rather poor agricultural soils and used for coconut groves and pasture.

Histosols are organic soils and were formerly classified as peat, muck, or bog soils. On the Island they are closely associated with mangrove swamps and lagoons that are found mainly on the north coast. In the Caño Tiburones east of Arecibo a large tract of swamp has been reclaimed and was planted to sugarcane.

Vertisols are dark-colored clay soils with high contents of expanding lattice-clay. These soils have gone by a variety of names such as Grumusols, Regurs, Black Cotton Soils, and Tropical Black Clays, and are, in Puerto Rico, typically developed in the Lajas Valley and in other low depressions along the semi-arid south coast. Small acreages further occur in a tectonically and lithologically controlled interior lowland near Caguas. Most of these Vertisols are planted to cane but require irrigation.

Inceptisols are soils exhibiting initial stages of soil formation that have also been called Brown Forest Soils. They are the most extensive soils of Puerto Rico. Aquepts are common in low-lying alluvial positions, while Tropepts are characteristic for the highly dissected mountainous areas, especially in central and eastern Puerto Rico. Most of the Tropepts of the uplands are considered rather productive soils and were until recently extensively cultivated to sugarcane, coffee, tobacco and subsistence crops, but now pasture is the dominant land use. It would seem that high natural fertility is largely a function of a moderate rate of erosion which tends to expose fresh minerals in the solum.

Mollisols are soils characterized by a dark-colored surface horizon of high base saturation, formerly classified as Chernozems, Chestnut Soils and Rendzinas. In Puerto Rico they occur in the outcrop area of the Tertiary limestones along the northwestern and southwestern coasts, in the southern foothill zone of Cordillera Central, and on alluvial fans and older floodplains. Those of the karsted limestone areas cannot be used for crop production, but the alluvial Mollisols are extensively planted to sugarcane and considered as some of the best agricultural soils of the Island.

Alfisols are moderately weathered soils also known as Non-calcic Brown Soils. They are of moderate extent in Puerto Rico and occur mainly on the footslopes of the northern limestone hills. Most of these soils are now used as pasture.

Ultisols are highly leached soils with low base saturation and include most of the soils that have been called Red-Yellow Podzolics, Reddish-Brown Lateric Soils and some of the Ground-Water Laterites.

Ultisols constitute the second most important order in Puerto Rico. They occur in a variety of physiographic positions ranging from subtropical rain forest, old terraces and blanket deposits to moderately sloping areas of the central mountains, particularly in the western part of the island. Ultisols are still widely used for growing coffee, some cane and truck crops, however, lately considerable areas were shifted to pasture. One of the peculiar properties of the Puerto Rican Ultisols is their high level of exchangeable aluminum (5-10 meq/100 g) which approaches the toxicity level for many crops.

Oxisols are highly leached, strongly weathered, and normally red soils that are restricted to tropical regions. Previously, they were described as Laterites, Rubrozoms, Ferralites, Fersiallitic Soils or Terra Roxa.

Oxisols are of relatively limited extent in Puerto Rico. They occur in the vicinity of Mayaguez where they are developed in serpentinite, on the pre-weathered blanket deposits along the northern coastal plain, and on some remnants of old peneplains in the interior uplands. In the latter position they are intricately associated with Inceptisols and Ultisols in areas too small to delineate on Figure 10. The agricultural use of the Oxisols of the interior is similar to that of the Ultisols,

whereas those of the northern coastal plain are widely used for the production of pineapples.

The relatively small area occupied by what is customarily thought of as the tropical soils, Oxisols, emphasizes the fact that a tropical climate per se is not necessarily conducive to their formation if other environmental factors are dominant.

Table 2 lists the approximate extent of the soils mentioned above in Puerto Rico. For more detailed information the reader is referred to the literature cited, in particular to the Soil Survey of Puerto Rico by Roberts et. al. (12).

Table 2. Estimated Acreage of Soil Taxonomy Orders and Great Groups in Puerto Rico.

Order	Great Group	Acres (10^3)	Percentage of total land area
Inceptisols	Eutropepts	591.5	27.0
	Humitropepts	7.9	.4
	Tropaquepts	130.9	6.0
	Ustropepts	201.7	9.2
		932.0	42.6
Ultisols	Haplustults	7.2	.3
	Paleudults	53.2	2.4
	Tropaquults	2.7	.1
	Tropohumults	427.9	19.6
	Tropudults	52.5	2.4
		543.5	24.8
Mollisols	Hapludolls	32.7	1.5
	Haplustolls	62.7	2.9
	Rendolls	146.9	6.7
		242.3	11.1

Order	Great Group	Acres (10^3)	Percentage of total land area
Oxisols	Acrorthox	1.3	.1
	Eutrorthox	51.8	2.4
	Haplorthox	72.7	3.3
		125.8	5.8
Vertisols	Chromuderts	6.4	.3
	Chromusterts	34.4	1.6
	Pellusterts	30.8	1.4
		71.6	3.3
Alfisols	Haplustalfs	8.8	.4
	Tropudalfs	42.1	1.9
	Tropaqualfs	13.9	.6
		64.8	2.9
Histosols	Tropohemists	37.0	1.7
Entisols	Quartzipsamments	2.9	.1
	Tropopsamments	12.3	.5
	Ustipsamments	.7	.1
	Ustorthents	15.0	.7
		30.9	1.4
Limestone Rockland		119.8	5.4
Volcanic Rockland		2.6	.1
Serpentinite Rockland		18.7	.9
Total land area of P.R.		2,189.0	100.0

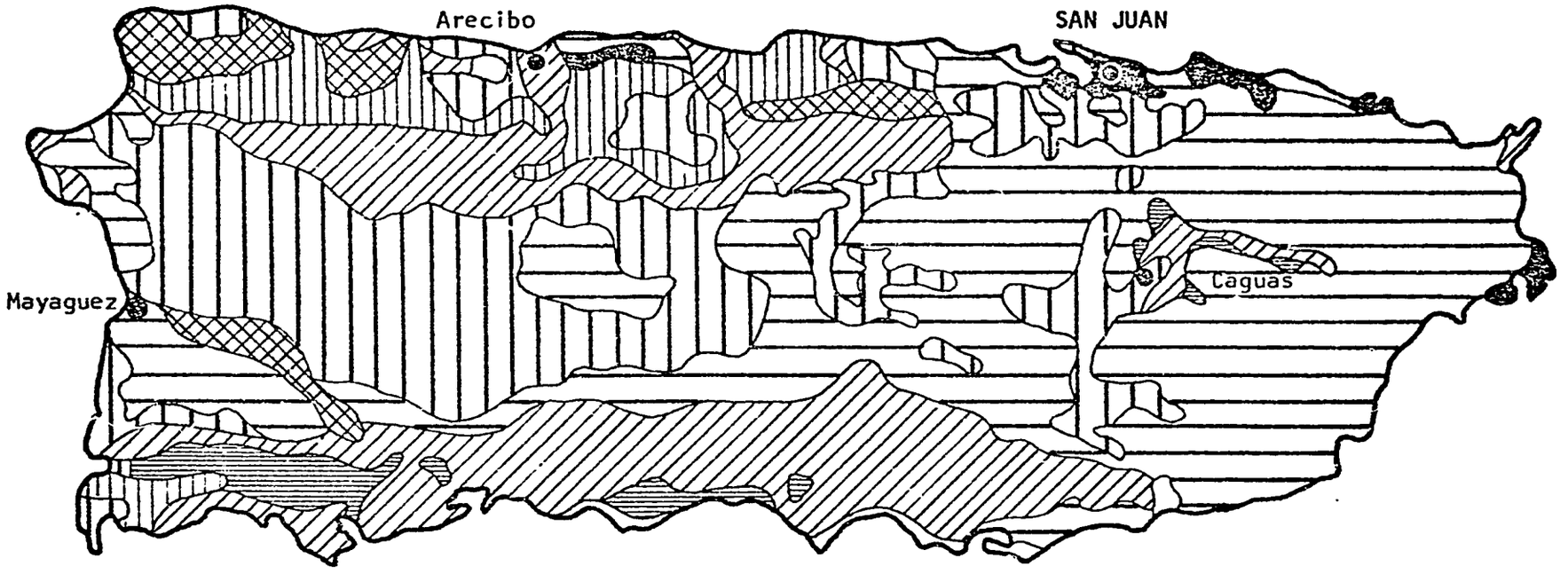


Fig. 10 - Generalized Soil Map of Puerto Rico (BEINROTH, 1971)

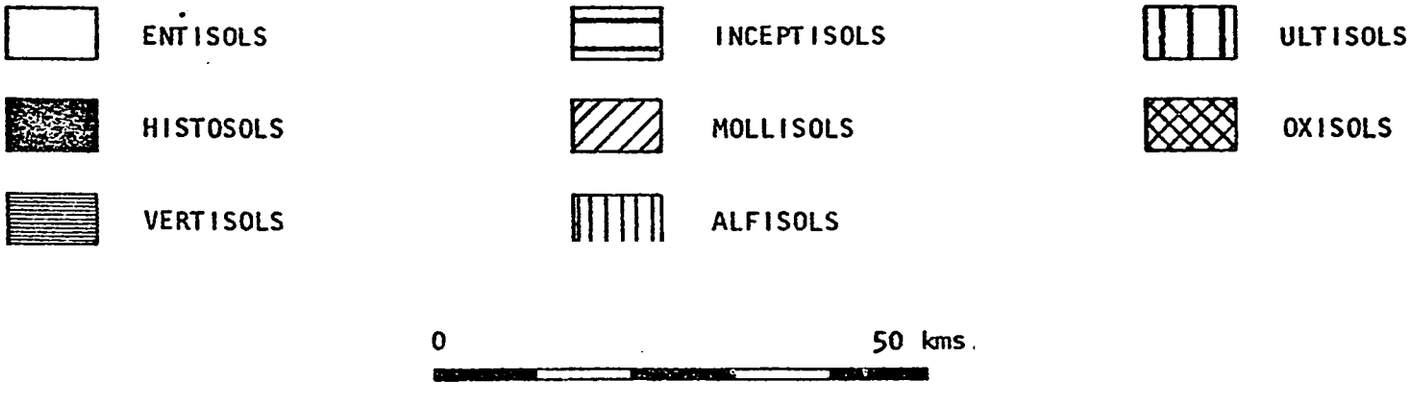


FIGURE 1–Generalized Soil Map of Puerto Rico

AGRICULTURE

Sugarcane, coffee, and tobacco traditionally have formed the mainstay of the Island's agriculture. (Cane was introduced in Puerto Rico in the beginning of the 16th century from Santo Domingo; coffee was imported via Haiti in 1736; tobacco is a native crop of Puerto Rico). Recent years, however, have witnessed a pronounced trend for diversification and in particular a significant growth of the livestock industry (Table 3).

Starting as a low-income sugar economy, Puerto Rico has undergone rapid industrialization in the last two decades. In the process, agriculture lost its predominance in 1955 when the income from the manufacturing industry surpassed the income from agriculture. Presently the gross farm income amounts to some 278 million dollars annually or about 6 percent of the total gross income of Puerto Rico. 129,000 people, equivalent to 16 percent of a total labor force of 807,000 workers, are employed in agriculture.

About 80 percent of the total land area of Puerto Rico is -somewhat irrelevantly- regarded agricultural land (Table 4). According to estimates by the Soil Conservation Service, only one-tenth of this area is classified into land-capability classes I and II. Approximately one-third is considered class III and IV, and almost two-thirds fall into classes V and VI, i.e., nine-tenths of the agricultural land of Puerto Rico has severe limitations for cultivated crops.

Sugarcane. Although in recent years the sugar industry has been suffering a marked decline, sugarcane continues to be the most important single crop. About 13 percent of the agricultural land, mainly the alluvial soils of the coastal plains, is devoted to the cultivation of cane. In 1971 some 4,000 farms produced 320,500 tons of sugar, whereas in 1960 nearly 15,000 farms produced about 1 million tons of sugar. Thus the farm value of this crop decreased from about $90 million in 1960 to approximately $34 million in 1971, and now accounts for only 12.2 percent of the Island's gross farm income. Moreover, Puerto Rican sugar is produced at prices substantially above the world level and requires heavy government subsidies.

Coffee. Roughly 8 percent of the island's agricultural land - mainly Ultisols in the central and west-central uplands - are planted to coffee. This crop is second in importance and yields a farm income of $22 million in 1971. Since Puerto Rico's coffee industry must compete with low wage producing countries, it obtains significant subsidies, averaging about $27 per hundredweight.

Tobacco. About 7,000 acres in the east-central part of the Island are cultivated to tobacco. Puerto Rico produces a top quality cigar leaf, although the gross production is for cigar filler, 80% of which is exported to the U.S. mainland. The farm value of this crop amounts to some 2 million.

Starchy vegetables. The most important crops included in this group are plantains, bananas, taniers, yams, sweet potatoes, and cassava. They are grown throughout the island and most are intercropped with each other, but bananas are mostly intercropped with coffee. The farm value of the starchy vegetables approximates 29 million dollars.

Other vegetables and legumes. Tomatoes, pumpkins, peppers, pigeon peas, and similar crops are grown mainly in the hilly interior of Puerto Rico. At present the return from these crops amounts to about $9 million, but there are favorable prospects to expand this agricultural enterprise.

Fruits. The variety of tropical fruits grown in Puerto Rico includes pineapples, oranges, coconuts, avocados, grapefruits, citrons, mangoes, and less known fruits such as "papaya" (papaw fruit), "acerola" (West Indian cherry), guava, and tamarind. Of these, pineapples are the most important fruits. They are grown at a constantly increasing scale in commercial plantations in the well-drained Oxisols of the central northern plain around Arecibo and Manatí. Coconuts are mainly obtained from the sandy Entisols adjacent to the shore lines. Oranges are mostly intercropped with coffee in the mountainous areas. The other fruits are produced in different parts of the Island where they are obtained from scattered trees rather than commercial plantations. The gross farm income from this source amounts at present only to about $10 million, but fruit production has a large potential for future development.

Livestock. The rapidly growing livestock industry has become an important branch of the Island's agriculture as evidenced by the figures in Table 3. More than 500,000 heads of cattle are kept in Puerto Rico, approximately half of it in commercial dairy and beef farms. Pork production has also shown a remarkable increase, but only 15,000 out of a total of some 176,000 heads are kept in commercial herds. The modernized poultry enterprises account for a substantial part of the livestock industry, producing some 22 million dozen eggs and 29 million pounds of meat annually. The total income from livestock production amounts to 136 million dollars equivalent of almost 49 percent of the total gross income from agriculture.

Table 3. Gross Income from Agriculture in Puerto Rico, 1971.

Item	Farm value Thousands of $	%of total gross income
Crops		
Sugarcane	34,071	12.2
Coffee	22,776	8.2
Tobacco	1,980	.7
Starchy vegetables	28,725	10.4
Other vegetables and legumes	9,107	3.3
Fruits	9,712	3.5
Total Crops	106,371	38.3
Livestock products		
Milk	70,691	25.4
Eggs	12,820	4.6
Beef	24,553	8.8
Pork	14,456	5.2
Poultry	13,003	4.6
Other livestock products	693	.2
Total Livestock Products	136,216	48.8
Other Items (mainly incentives)	36,181	12.9
TOTAL GROSS INCOME	278,768	100.0

Source: Adapted from Fact Sheet on Puerto Rico's Agriculture. Agr. Exp. Sta., Univ. PR., 1971

Table 4. Land Utilization in Puerto Rico.

Land use	Area in acres	% of total agricultural land	% of total area of Puerto Rico
Cropland			
Sugarcane	237,700	13.4	10.9
Coffee	174,600	9.8	8.0
Tobacco	6,800	.4	.3
All other crops	163,000	9.1	7.4
Total Cropland	582,100	32.7	26.6
Pasture and Range			
Improved pasture	475,000	26.7	21.6
Unimproved pasture	330,000	18.5	15.1
Total Pasture and Range	805,000	45.2	36.7
Forest and Brush	315,300	17.7	14.4
Other land	77,600	4.4	3.5
Total agricultural land	1,780,000	100.0	81.3
Total land area of Puerto Rico	2,188,711		

Source: Adapted from Fact Sheet on Puerto Rico's Agriculture. Agr. Exp. Sta., Univ. P.R., 1971

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