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A Summary of 20 Years of Forest Monitoring in Cinnamon Bay Watershed, St. John, U.S. Virgin Islands

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Cover photos
Top right: The island's attractive scenery prompted President Eisenhower to authorize the establishment of the Virgin Islands National Park as a sanctuary of natural beauty in 1956. Left: A hiker looks up at large Ceiba trees (Ceiba pentandra) *at an interpretative stop on one of the many hiking trails scattered throughout Virgin Islands National Park. Bottom right: Picturesque Cruz Bay Harbor with government house situated on a narrow peninsula.*

All photos in report by Peter L. Weaver.

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Abstract

St. John, and probably the Cinnamon Bay watershed, has a history of human use dating to 1700 B.C. The most notable impacts, however, occurred from 1730 to 1780 when sugar cane and cotton production peaked on the island. As agriculture was abandoned, the island regenerated in secondary forest, and in 1956, the Virgin Islands National Park was created. From 1983 to 2003, the staff of the International Institute of Tropical Forestry monitored 16 plots, stratified by elevation and topography, in the Cinnamon Bay watershed. The period included Hurricanes Hugo in 1989 and Marilyn in 1995 and a severe drought in 1994-95. In all years, plot tallies showed that from 55 to 60 percent of the stems were in height classes between 4 and 8 m, and 75 percent of the stems were in diameter at breast height (1.4 m above the ground; d.b.h.) classes between 4 and 10 cm. Stem density was greatest on the summit, followed by ridges, then slopes, and lowest in valleys. After 20 years, 65 percent of the original stems survived, with an average d.b.h. growth rate of 0.07 cm $year^{-1}$. Tree species abundances varied by topography and elevation within the watershed. In 1983, total aboveground biomass on all plots combined averaged 138.7 t ha^{-1}; by 2003, it had declined by nearly 7 percent. In 1983, biomass was greatest on the summit, intermediate on slopes and valleys, and least on ridges; by 2003, the quantities for all sites had converged except on the summit plot. In 1992, total aboveground productivity was estimated at 10.64 t ha^{-1} $year^{-1}$. Standing herbivory for leaves was 4.5 percent, and the herbivory rate was 4.6 percent per year. The standing crop of litter was 9.33 t ha^{-1}. Hurricanes had a major impact on forest structure and species composition. The trees impacted (snapped, uprooted, or standing dead) by Hurricane Hugo totaled 210 ha^{-1} after 10 months and 288 ha^{-1} after 19 months. The proportion of impacted stems differed by elevation, topography, aspect, and slope. Tree species with ≥ 20 individuals showed a difference in the proportion of impacted stems, ranging from as low as 0.6 percent for *Pimenta racemosa* (Mill.) J.W. Moore to as high as 22.8 percent for *Nectandra coriaceae* (Sw.) Griseb. In conclusion, the structure, species composition, and forest dynamics within the Cinnamon Bay watershed vary in time and space, and short-term observations characterize only a fragment of the watershed's continuously changing vegetational history. Monitoring of forest structure and dynamics should continue.

Keywords: Biomass; dry forest; monitoring; St. John, U.S. Virgin Islands; tree species.

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Introduction

The Virgin Islands are comprised of two political units: the American islands of St. Croix, St. Thomas, and St. John; and the British islands of Anegada, Tortola, and Virgin Gorda. From the standpoint of history and archeology, the islands are part of the Lesser Antilles; geographically and geologically, however, they are part of the Greater Antilles (Sleight 1962).

The Virgin Islands, first occupied by Indian groups migrating from South America (Hatch 1972), were inhabited, at one time or another, by explorers, colonists, and opportunists from Britain, Denmark, France, Holland, Spain, and the United States (Varlack and Harrigan 1977). In addition to human activities—mainly colonization, plantation agriculture, and later subsistence activities and grazing—the Island's forests have been periodically disturbed by hurricanes and severe droughts (Colón-Dieppa and others 1991). The landscape today is largely cultural, having been shaped as much by human activity as by natural processes and events (Tyson 1987).

Since the 1950s, scientists at the International Institute of Tropical Forestry (IITF) have been involved with forestry research in the U.S. Virgin Islands. The purpose of this report is to provide an overview of past and current knowledge of St. John's forests, particularly with regard to the Cinnamon Bay watershed, by:

- Reviewing the impact of past human activity
- Briefly summarizing the setting—geology, physiography, soils, climate, and hydrology
- Reviewing past and present vegetation studies and forest monitoring on St. John
- Synthesizing 20 years of research in the Cinnamon Bay watershed, including the most recent measurements in 2003.

Historical Perspective

The presence of Archaic period pre-ceramic sites in the northern Virgin Islands (St. Thomas, St. John, and Tortola) suggests human activity as far back as 1700-225 B.C. (appendix A). About 2000 years ago, Indians of the Saladoid culture from the Orinoco region of Venezuela arrived at Coral Bay and later migrated to other sites on St. John, including Cinnamon Bay (Bullen 1962, Tyson 1987). From then until the Caribs arrived less than a century before Columbus, the Islands probably received sporadic use by the Indians. Destructive storms and droughts made permanent settlements on many Caribbean islands difficult and no doubt contributed to inter-island movements (Haas 1940). The Indians, with small populations confined largely to the coast, had little impact on the vegetation of St. John before European settlement (MacDonald and others 1997). The basic materials used by these groups were stone, shell, bone, and wood (Dookhan 1974). Subsistence activities involved mollusk collecting, fishing, and slash-and-burn agriculture to cultivate manioc, corn, potatoes, yams, beans, and peppers (Dookhan 1974, Hatch 1972, Sleight 1962).

Columbus landed in St. Croix on November 14, 1493, on his second voyage to the New World. On departure, unfavorable winds drove his vessels

Cinnamon Cay, Cinnamon Bay shoreline, and lower watershed from midway along the Cinnamon Bay trail. Virgin Islands National Park, noted for its panoramic views, was set aside in 1956 as a sanctuary of natural beauty (October 1982).

southeast of Virgin Gorda (Dookhan 1974**).** Columbus then sailed west toward Hispaniola through a cluster of islands he named after St. Ursula and the 11,000 virgins (Varlack and Harrigan 1977**),** passing St. John on November 17 (Lawaetz 1991, map on page 32). The island was probably uninhabited at that time. In 1595, Sir Francis Drake visited the Virgin Islands. Later, the channel between St. John and Tortola was named to commemorate his ventures.

In 1671, Denmark and Norway established a trading post on St. Thomas; soon after, the first consignment of African slaves arrived, and permanent settlements and agriculture were developed (Dookhan 1974). In 1675, two men were sent to St. John with munitions and provisions, an action viewed by Denmark as official possession and the basis for subsequent territorial claims (Larsen 1986). In 1684, the Danes took possession of St. John, and between 1718 and 1725 they established a settlement and several sugar cane and cotton plantations (Cosner and Bogart 1972, Larsen 1986). Soon after, the Danes built a small fort in Coral Bay (the Fortsbjerg) to show that the island was occupied (Larsen 1986). In 1727, Peter Durloo acquired a small "cotton piece" with 11 enslaved laborers along the shore of Cinnamon Bay (Knight 1999, page 4). Subsequently, roads and large estate houses were built, and much of St. John was terraced (Cosner and Bogart 1972). In 1727, a Town Bailiff was appointed (Larsen 1986). By 1728, much of the natural vegetation had been disturbed by the island's 800 inhabitants in the development of nearly 90 plantations (Hatch 1972, Tyson 1987), and no large timber remained (Larsen 1986). By 1739, the island had 110 plantations, many operated by absentee owners working through local managers.

In 1733, "a long drought, a hurricane, a plague of insects, and finally an autumn storm, all the same year" (Harman 1961, page 47) accompanied by harsh measures against the slaves led to a revolt that killed one-third of the white inhabitants and destroyed one-half of the island's plantations (Cochran 1937, Harman 1961, Hatch 1972) (appendix A). The dwelling house, storage building, and boiling house at Cinnamon Bay were looted and burned and the cane fields set ablaze (Knight 1999). The uprising was crushed by the French 6 months later (Raphael 1967). By the late 1730s, the areal extent of agricultural activities on the Cinnamon Bay plantation was most likely at its peak.

In 1741, Moravian missionaries arrived from Germany to work with the island's inhabitants (Kemp 1990, Low and Valls 1985). They began using the sturdy hoop vine (*Trichostigma octandrum*) and more delicate wist reed (*Serjania polyphylla*) to make market baskets, placemats, and hats. These items were marketed through the 20th century in the United States and Germany.

During the second half of the 18th century, the demand for sugar continued to rise (Raphael 1967). By 1760, plantations occupied 98 percent of the land surface (Tyson 1987), and by the 1780s, Cinnamon Bay was a well-developed estate (Hatch 1972). A land use map produced at that time showed that about 35 to 40 percent of the island was cleared. Relatively flat areas in the interior and along the coast were favored for cultivation (MacDonald and others 1997).

Denmark was the first state to outlaw the slave trade in 1792 (Hatch 1972), and by 1803 its transatlantic slave trade had ceased. In 1805, tax records for the sugar estates showed that only 15 percent of St. John was in cane and 5 percent in other crops; also, "a great deal of good land [on the Cinnamon Bay plantation is] in woods or uncultivated" (Knight 1999, page 39). From 1807 to 1818, "outbreaks of yellow fever and smallpox, a period of British occupation during the Napoleonic Wars (1807-1815), the failure of the estates to sustain their enslaved populations after the abolition of the transatlantic slave trade, and, in Europe, the perfecting of the process to extract sugar from the sugar beet, all conspired to drive down the Danish West Indian economy" (Knight 1999, page 43). By 1823, nearly three-quarters of the Cinnamon Bay property served little purpose other than to provide fuelwood and the occasional harvest of wild fruits and fowl (Knight 1999). In 1848, after riots on St. Croix, Governor General Peter von Scholten ordered the emancipation of all slaves in the Virgin Islands (Dookhan 1974).

The anchoring of Confederate ships at Charlotte Amalie harbor during the Civil War first prompted an American interest in purchasing the Virgin Islands. At that time, the combined effects of emancipation and increased competition from sugar beets grown in temperate latitudes led to the decline of both sugar estates and population on St. John (Haas 1940). In 1868, the new owner of Cinnamon Bay introduced livestock and dairy cattle, ending the production of

sugar cane. Offshore fishing, cultivation of swidden fields, charcoal production, and grazing became the major occupations (Haas 1940, Near 2003, Olwig 1985). In the 1880s, when Cinnamon Bay was reported all in bush, residents began harvesting the leaves and berries of the bay rum tree (*Pimenta racemosa*) for perfumes and cosmetics. Bay rum production, peaking around 1920, remained the island's most important industry through the 1940s. Bay rum trees regenerated naturally, and owners cleared competing vegetation as desired (Hatch 1972). Subsistence cultivation at the time included tanias, okra, cassavas, yams, pigeon peas, sweet potatoes, and beans, along with bananas, papayas, and other drought-tolerant fruits (Haas 1940).

The recurrent negotiations to purchase the Virgin Islands, rekindled and then suspended during the Spanish-American War, were reinitiated during World War I (Dookhan 1974, Haas 1940). In 1917, two centuries after Danish colonization, one-half century after the Civil War, and one week before entering World War I, the United States bought the Virgin Islands for $25 million (Hatch 1972, Zabriskie 1917). Between 1900 and 1950, the population of scattered settlements on St. John, linked by donkey trails, was around 800 inhabitants. As of 1950, with boats as the primary means of transportation, the island had one truck, two jeeps, and one bulldozer (Low and Valls 1985; MacDonald and others 1997), and St. John was still "the quiet place" (Hatch 1972).

The quiet place began to change in 1952 when the Virgin Islands government created a Tourist Development Board to promote tourism (Dookhan 1974) and Laurence Rockefeller started to purchase 55 percent of St. John. In 1956, President Eisenhower authorized the establishment of the Virgin Islands National Park as a sanctuary of natural beauty (Robinson and Henle 1978, fig. 1). Agriculture, grazing, hunting, and wood cutting within Park boundaries were gradually eliminated (Olwig 1980, O'Neill 1972). In 1962, marine waters and submerged lands totaling nearly 2300 ha were added to the Park. In the same year, a bill "to acquire lands, waters, and interests therein by purchase, exchange, condemnation, or donation or with donated funds" was being considered to lessen impacts caused by in-holdings (O'Neill 1972, page 143). The bill was ultimately modified to prevent unfair land condemnation. Since then, the Park has generated considerable economic activity centered around its spectacular scenery. In 1976, the Virgin Islands National Park became a Biosphere Reserve.

Stand with bay rum trees (Pimenta racemosa*) in dry evergreen woodland at Cinnamon Bay. The harvest of bay rum leaves and berries for the production of cosmetics and perfumes peaked in the 1920s and remained an important island activity through the 1940s (October 1982).*

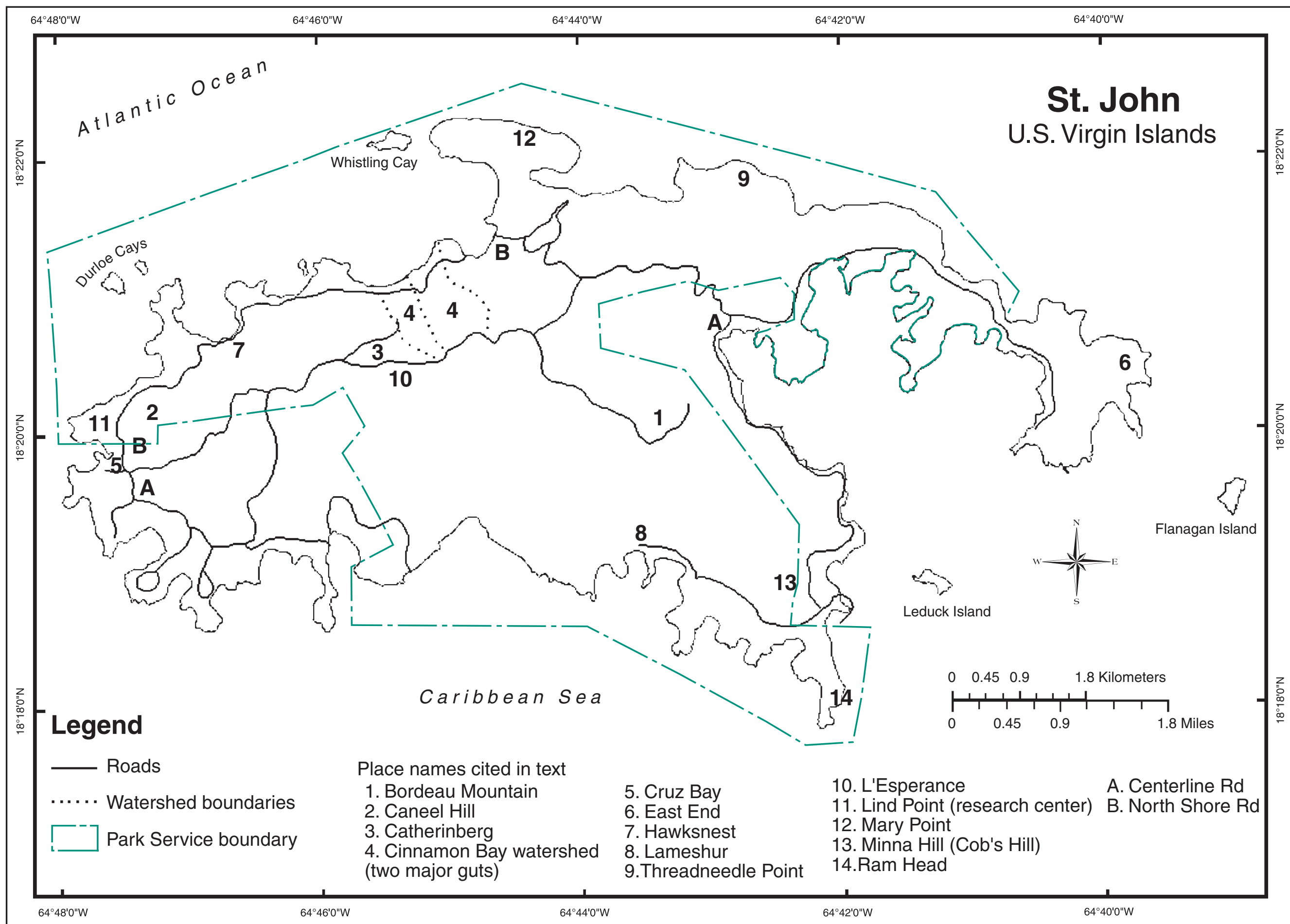


Figure 1—Location of places mentioned in text.

Today, much of St. John is covered by late secondary forest which began to regenerate in the mid- to late 1800s. Although negative comments have been recorded during interviews—such as “the park is just preserving brush, mongooses and jackasses” or “the island was beautiful when it was filled with cows and grass” (Olwig 1980, page 28)—tourism has been responsible for the dynamic growth of the island, leading to the conclusion that “Today St. John’s economy is based squarely on tourism” (Low and Valls 1985, page 91). The trickle of visitors to the Virgin Islands in the 1930s increased to 55,000 in 1962 and to > 2.3 million by 2002 (appendix A). At the same time, the Park protects critical dry forest and provides winter habitat for neotropical migratory birds (Askins and Ewert 1992).

Despite protection from most developmental activities, the Park still experiences impacts caused by tourism, home construction, and introduced animals. The Park already has excellent facilities: a paved road along the north shore, numerous well-maintained trails, and at Cinnamon Bay, a camping complex with dining facilities and a commissary (Olwig 1985). The clearing of unpaved roads, parking areas, and sites for house construction, however, is causing sedimentation rates greater than during the plantation era (Anderson and MacDonald 1998, MacDonald and others 1997, Reid and Dunne 1984). The potential impact of sedimentation on coral reefs and their organisms remains a serious concern (Rogers 1990). Feral pigs, goats, and donkeys frequently roam onto private properties and public recreation areas and continue to pose problems for the survival and growth of certain plant species.

Setting: St. John and Cinnamon Bay

St. John occupies 52 km^2 and is located about 100 km east of Puerto Rico. The island is 15 km long from Cruz Bay to East End and 8 km wide from Threadneedle Point to Ram Head (fig. 1). Cinnamon Bay watershed is 1.32 km^2 or about 2.5 percent of St. John. It is in the north central part of the island, north of Centerline Road. The road which runs along the southern edge of the watershed approximates the island divide.

Geology

St. John is geographically and geologically part of the Greater Antilles, being part of the Puerto Rican platform and Antillean Geanticline (Hatch 1972). Its geologic history appears to date back to the upper Jurassic or Lower Cretaceous when volcanic magmas erupted on the ocean floor (Donnelly 1966). Eruption was mainly by flows because overlying sea water prevented explosive emissions. Toward the end of this period, either volcanic accumulations or structural uplift made the sea shallower, and pyroclastic material increased. Subsequently, major uplift occurred, and deposition altered from marine on gentle slopes to both subaerial and marine on relatively steep slopes adjacent to an emergent island. Volcanism and erosion continued on the exposed island until the Eocene time when quartz-diorite plutons were emplaced.

About 85 percent of the Cinnamon Bay watershed is classified as the Louisenhoj formation. This formation contains augite-andesite volcanic breccia (clastic sedimentary rock made up of angular fragments) and tuff (rock consolidated from volcanic ash) with minor conglomerate, all of Cretaceous (possibly Albian) age (Donnelly 1966). The Water Island Formation, comprised of quartz keratophyre flows (volcanic rock, mainly albite and quartz, with chlorite, micaceous minerals, and iron oxides) and flow breccias of the Lower Cretaceous age, occupies about 7 percent of the watershed at the highest elevations in a narrow strip along Centerline Road. Another 8 percent of the watershed along the shoreline is overlain by Quaternary alluvium.

Physiography and Soils

St. John is comprised of an east-west ridge with steep north-facing slopes; the southern part of the island has several spur ridges extending southward from the island divide. Bordeaux Mountain is the highest point at 390 m. Slopes in excess of 30 degrees occur on > 80 percent of the island (CH2M Hill 1979, see endnotes). The island's coastline is irregular and has numerous bays and small coastal plains associated with major drainages. Cinnamon Bay watershed ranges from sea level to about 300 m in elevation and is drained by two major guts (fig. 1). Steep slopes covered with loose rock and numerous narrow valleys filled with boulders characterize the landscape. Part of the Cinnamon Bay coastal plain has been developed for tourism.

In 1966, soil scientists completed a survey of St. John (Rivera and others 1966) and in 1980 revised the island's soil taxonomy (Lugo-López and Rivera 1980). All of St. John and 41 percent of the entire U.S. Virgin Islands are classified in the Cramer-Isaac soil association (Rivera and others 1970). This association is characteristic of very steep mountainsides, steep lower slopes, and narrow alluvial fans and flood plains. The soils range from shallow to moderately deep, are well-drained, and lie over volcanic rock. Boulders and rock outcrops are common. Most of the Cinnamon Bay watershed is in capability classes above III, indicating that the preferred land use is permanent tree cover (Rivera and others 1966).

Climate

St. John has a tropical maritime climate. The island lies in the path of the northeast trade winds, but east and southeast winds are also common (Cosner and Bogart 1972). Relative humidity averages about 75 percent. In general, the continuous trade winds accompanied by low rainfalls, high evapotranspiration, long hours of sunshine, and high ambient temperatures accentuate drought conditions on the island.

The rainfall-producing mechanisms on St. John are similar to those of nearby Puerto Rico, varying mainly due to the island's smaller size and lower elevation (Calvesbert 1970, Colón-Dieppa and others 1991). Much of St. John's rainfall is orographic and is deposited as the moisture-laden trades pass over the island's interior. Easterly waves also produce rainfall, mainly from May through November. Tropical storms and hurricanes occasionally develop in the easterly waves and may cause high winds and heavy downpours. These phenomena occur mainly from

July through October, with the greatest number of events during August and September. Cold fronts descend from North America from November to April. The degree to which they influence rainfall depends on their intensity and rate of progression into the Caribbean.

Rainfall varies on St. John by location. The mountainous interior stretching from Cinnamon Bay to the lower southeastern slopes of Bordeaux averages > 1200 mm year^{-1}; areas to the east and west receive less, to as little as 900 mm year^{-1} (Bowden and others 1970, Ewel and Whitmore 1973). Extended periods of heavier annual precipitation or prolonged drought occur occasionally (Bowden and others 1970, Colón-Dieppa and others 1991).

The 30-year rainfall normal (1971-2000) for Catherinberg, about 1 km west of the Cinnamon Bay watershed, is 1240 mm year^{-1} (Southeast Regional Climate Center 2003) (fig. 2). The wettest 4-month period, August through November, receives 600 mm, or 46 percent of the total; the driest 4-month period, January through April, receives 285 mm, or 22 percent of the total. The wettest and driest months are November with 160 mm and February with 60 mm. The corresponding annual temperature normal is 24.8 °C. August is the warmest month, averaging 26.3 °C, and January the coolest month, averaging 23.1 °C. Records collected from 1921 to 1967 at Cruz Bay show that the lowest and highest temperatures were 15 and 35 °C (Cosner and Bogart 1972, fig. 1).

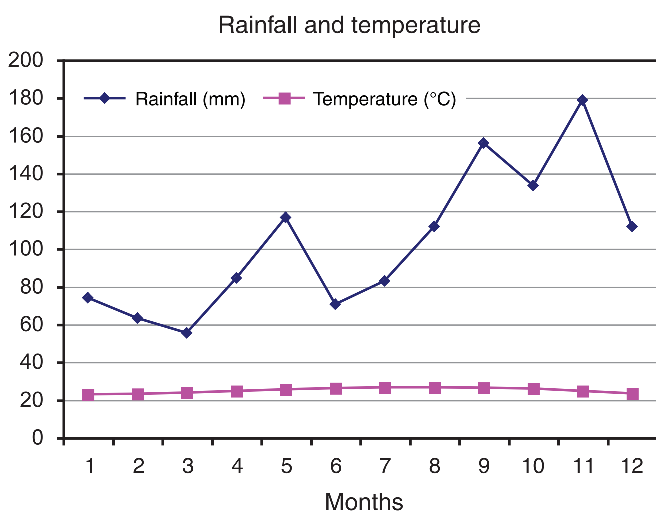


Figure 2—Climatic diagram for the Cinnamon Bay watershed based on 30-year normals for Catherinberg, 1971 to 2000 (N 18°20', W 64°45').

Hurricanes are a regular phenomenon in the Caribbean, as indicated in an old Creole proverb: “June, too soon; July, stand by; August, come it must; September, remember; October, it’s over” (Cochran 1937, page 101). Twenty hurricanes passed over or near St. John before 1900 (in 1695, 1707, 1714, 1729, 1733, 1742, 1748, 1772, 1785, 1793, 1819, 1825, 1830, 1837, 1866, 1867, 1871 (two events), 1876, and 1899), the most destructive of which appear to have occurred in 1695, 1772, 1785, 1819, 1837, 1867, and 1899 (Dookhan 1974, Lawaetz 1991). Ten hurricanes passed over or nearly over St. John during the 20th century, including unnamed hurricanes in 1916, 1924, and 1928 and hurricanes Connie in 1955, David in 1979, Hugo in 1989, Marilyn in 1995, Hortense in 1996, Georges in 1998, and Lenny in 1999 (Colón-Dieppa and others 1991, Forthun 2005). In addition, seven moderate or severe regional droughts were experienced during the 20th century alone: moderate, from 1938 to 1942, 1945-48, and in 1959; and severe, in 1957, 1964, 1967-68, and 1994-95 (Colón-Dieppa and others 1991, Rogers and Reilly 1998).

Hydrology

Water resources are scarce on St. John. During the 18th and 19th centuries, colonists obtained water from a few natural springs, large-diameter wells, and small surface reservoirs (Cosner and Bogart 1972). Archeological, historical, and geological evidence, however, indicates that water resources were greater in the past (Jordan 1972). The most recent decline is attributed to changes in land use from agriculture to secondary forest. Because most rainfall is light, runoff on St. John is limited to 5 or 10 percent of the rainfall, with the remainder being lost through evapotranspiration (Cosner and Bogart 1972). Annual groundwater recharge is low, and groundwater aquifers are confined to narrow alluvial valleys with limited storage capacity, scattered beach sand deposits, and fractured volcanic rock (Cosner and Bogart 1972, MacDonald and others 1997).

St. John has several springs, including one at Cinnamon Bay, and spring-fed pools, but no permanent streams (Cosner and Bogart 1972). Storm runoff is considerable, and small pools of water may be observed in guts a few days after heavy downpours. The yield from springs is low, becoming intermittent during droughts. Cinnamon Bay has six

wells. One is used for water supply and another, called the old Danish well, for recording water data (Cosner and Bogart 1972, Torres-Sierra and Rodríguez-Alonso 1987).

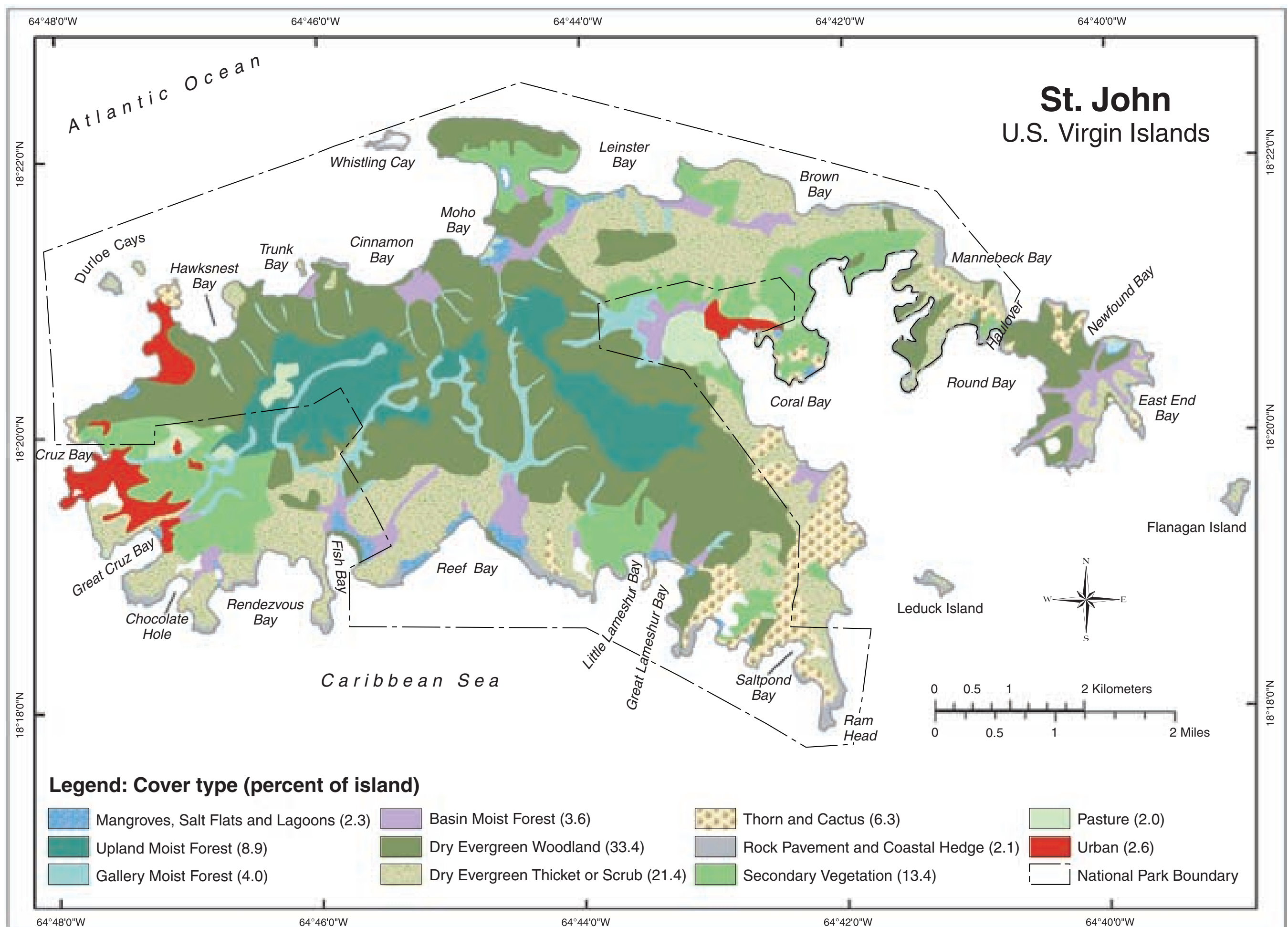
Vegetation

Taxonomists made the earliest studies of the vegetation in the Virgin Islands, mainly on St. Croix and St. Thomas (Eggers 1879, Britton 1918, Britton and Wilson 1923 to 1930). The first surveys on St. John were made when there was less forest cover and much of the island was inaccessible.

During the 1940s, a British researcher assigned to work the West Indies proposed a general classification for Caribbean forests (Beard 1944, 1949, 1955). A few years later, moist and dry forest types were recognized on St. John based on Beard's system; in addition, special, or modified vegetation types were also recognized (Robertson 1957, see endnotes; Robertson 1962). In 1973, the life zone model (Holdridge 1967) was used to classify St. John into subtropical moist and subtropical dry forests (Ewel and Whitmore 1973). Because St. John receives about 900 to 1200 mm year^{-1} of rainfall, the entire island could be considered as transition between these two life zones.

In 1982, St. John's flora was again surveyed using a modification of Beard's system to account for secondary and riparian vegetation (Woodbury and Weaver 1987) (fig. 3). This was the first study to focus on Park Service properties on both St. John and Hassle Islands. Ten vegetation types were recognized and mapped: mangroves, salt flats, and lagoons covered 2.3 percent of St. John; three types of moist forest 16.5 percent; four types of dry forest

Figure 3—Vegetation types on St. John (Woodbury and Weaver 1987).



63.2 percent; secondary vegetation 13.4 percent; pasture 2.0 percent; and urban areas 2.6 percent. A checklist was used to rank nearly 800 plant species by life form and relative abundance in each vegetation type. Reputed medicinal uses were also noted. In 1987, the Park Service established a vascular plant herbarium with at least 600 species in 99 families at Lind Point (Knausenberger and others 1987). Specimens collected during the above survey were included in the collection.

From the mid-1960s through the mid-1970s, researchers at the IITF described tree species in the U.S. Virgin Islands, including rare, endemic, and exotic species (Little and Wadsworth 1964, Little and Woodbury 1980, Little and others 1974). Later, taxonomists revised the flora of the West Indies, including St. John, in comprehensive works (Howard 1979, 1988-89; Liogier 1985 to 1997, Liogier and Martorell 1982). Taxonomic work continued in the 1990s, when a new tree species and two previously described endemics were listed. Today, the island's flora contains 747 species of vascular plants, with 86 percent of the species being native. This includes 117 families (12 introduced) containing 489 genera (55 introduced) (Acevedo-Rodríguez 1993, Acevedo-Rodríguez and Strong 2005, Acevedo-Rodríguez and others 1996). The three most common families are Fabaceae, Poaceae, and Euphorbiaceae, which account for 22 percent of the species. Orchids are represented by 9 genera and 14 species (Ackerman 1992) and pteridophytes (ferns and fern allies) by 5 families and 16 genera (Proctor 1989).

Thorn and cactus vegetation along St. John's south coast (October 1982).

Roy O. Woodbury as his colleagues and students knew him, collecting plant specimens in secondary dry evergreen thicket on the south slopes of St. John above Lameshur (October 1982).

Table 1—Forest monitoring plots on St. John [a]

Forest type	Location	Age	Date[b]	Plot Size	Plot No.	Number of species[b]	Number of stems[b]	Basal area	Source
		(years)		*(ha)*			*(ha^{-1})*	*(m^2 ha^{-1})*	
Dry evergreen to gallery moist	Cinnamon Bay	125	1983	0.05	16	69	3,378	30.4	Weaver and Chinea (1987)
Upland moist	Bordeaux	110	1984	1.00	1	62	2,241	31.2	Earhart and others (1988)
Gallery moist	L'Esperance	90	1985	0.50	1	56	2,521	31.6	Reilly and others (1990)
Dry evergreen woodland	Hawksnest	>70	1986?	0.50	1	52	2,598	26.5	
Secondary	Mary Point	35	1988	0.05	2	8	1,660	4.9	Brown and Ray (1993)
Secondary	Lameshur	50	1988	0.05	2	23	4,900	17.9	Ray and Brown (1995a)
Secondary	Caneel Hill	100	1988	0.05	2	27	4,110	22.9	
Secondary	Caneel Hill	100	1988	0.05	2	29	3,080	25.8	
Dry evergreen woodland	Cinnamon	125	1988	0.05	2	30	4,320	25.3	
Dry evergreen woodland	Caneel Hill	80–100	1991	1.00	1	49	4,288	23.7	Dallmeier and others (1993); Ray and others (1998)
Dry evergreen woodland	Minna Hill[c]	100–120	1994	1.00	1	45	8,574	21.8	

[a] Adapted from Rogers and Reilly (1998). The minimum d.b.h. varied by site: Set 1–Cinnamon Bay, 4.1 cm; Set 2–Bordeaux, L'Esperance and Hawksnest, 5.0 cm; Set 3–Mary Point, Lameshur, Caneel Hill, and Cinnamon, 4.0 cm; Set 4–Caneel Hill, 4 cm and Minna Hill, 2.5 cm.
[b] Initial survey data.
[c] Also called Cob's Hill.

Terrestrial Research Initiative

In 1982, 14 groups formed the Virgin Islands Resource Management Cooperative to initiate baseline research in the National Park; by 1989, the cooperative had completed 29 reports (Anonymous 1988, Rogers and Teytaud 1988). In 1992, the status of the integrated approach to marine and terrestrial research was reviewed and summarized (Rogers 1992).

As part of the research initiative, the IITF began forest monitoring in the Cinnamon Bay watershed in 1983 (table 1, fig. 1). Subsequently, forest structure and composition, diameter growth rates, species-site relationships, forest productivity, and the impacts of Hurricane Hugo were reported (Weaver 1990, 1992, 1994, 1996, 1998; Weaver and Chinea-Rivera 1987). Between 1984 and 1986, collaborators with the New York Botanical Garden set up permanent plots on Bordeaux Mountain, L'Esperance, and Hawknest (Earhart and others 1988, Reilly and others 1990). After Hugo, these plots were assessed for damage (Reilly 1991, 1992, 1994, 1998; Rogers and Reilly 1998). In 1988, the University of Wisconsin began studies on plots at Mary Point, Lameshur, Cinnamon Bay, and Caneel Hill to determine species diversity and forest structure (Brown and Ray 1993, Ray and Brown 1995a). Finally, between 1991 and 1994, collaborators in the Smithsonian Institution's Man and the Biosphere Program set up permanent plots at Caneel Hill and Minna Hill (also called Cob's Hill) to determine species composition, stand structure, and forest dynamics (Dallmeier and Ray 1992, Dallmeier and others 1993, Ray and others 1998).

The monitoring plots on St. John represent differences in vegetation age (i.e., the time elapsed since agriculture was abandoned), plot sizes, sampling design, and measurement procedures (table 1). The Cinnamon Bay plots (table 1, top) totaled 0.8 ha

and were established in forest at least 125 years old. Initially, the plots contained 69 species, averaged 3,378 trees per hectare and had an average basal area of 30.4 m^2 ha^{-1}. The other monitoring sites on St. John were on plots between 0.05 and 1.0 ha and located in forest between 35 and 125 years old. They varied in species numbers from 8 to 62, in stem numbers from 1,660 to 8,574 ha^{-1}, and in basal areas from 4.9 to 31.6 m^2 ha^{-1}.

As part of a systematic approach to dry forest restoration, some researchers tried to determine factors that limit natural regeneration on different sites (Brown and Ray 1993). Seed ecology and the use of propagules (seeds, seedlings, and rooted cuttings) were tested for restoration on degraded lands (Brown and others 1992, Ray 1993, Ray and Brown 1995b). Fruiting and flowering events for 66 woody species were observed in several areas during a 4-year period (Ray and Brown 1994). A survey of fruit dispersal by 148 native woody species showed that 74 percent was by animals, 18 percent by wind, 4 percent by sea currents, and 4 percent by self-dispersion. Nearly 60 percent of the 29 woody species tested in shade house conditions showed > 80 percent germination. The use of seedlings proved to be the most efficient method for establishing propagules on abandoned pasturelands.

Carlos Rodríguez in gallery moist forest near valley plot #1, Cinnamon Bay watershed, beginning the task of geo-referencing all 16 plots (April 1995).

Methods at Cinnamon Bay

Sampling in the Cinnamon Bay watershed used 16 plots, each 50 by 10 m, to determine forest structure and dynamics by elevation and topography (Weaver and Chinea-Rivera 1987). Five groups of three plots (situated on ridge, slope, and valley topography) were established at elevations of 60, 120, 180, 210, and 240 m. Ridge plots were entirely on convex topography and valley plots on concave topography; slope plots were on relatively uniform slopes. The final plot was at 290 m on level terrain near the summit of the watershed. All plots were georeferenced in June 1995.

All trees ≥ 4 cm in diameter at breast height (d.b.h.), 1.4 m above the ground, were identified to species, measured, and tagged. Crown classes indicating the position of the tree in the canopy were also recorded (Baker 1950). A lower limit of 4 cm was used because it would provide data on the early survival and growth of tallied trees, many of which were small.

A rangefinder was used to estimate tree heights or lengths if leaning (to the nearest 0.5 m), and a diameter tape measured d.b.h. (to the nearest 0.1 cm). Trees were tagged using aluminum nails placed 15 cm below breast height to avert possible swelling at the point of measurement. During the initial survey d.b.h. was marked with paint. Measurements were made during June or July in 1983, 1988, 1993, 1998, and 2003.

Biomass was determined using the relationship:

$$\ln Y = -1.59 + 0.77 \ln X,$$

$$r^2 = 0.94, \; Sy.X = 0.0345, \; n = 20 \text{ (Weaver 1994)}$$

where Y = total aboveground biomass in kg, and X = (D^2 x h) where D = tree d.b.h. (cm) and h = tree height (m). Mean d.b.h. growth rates were determined by species for trees that survived the 20-year measurement period.

Upland moist forest stand marked with paint, second survey on ridge plot #10, Cinnamon Bay watershed (June 1988).

Certain qualifications regarding the methods are appropriate. Monitoring was carried out by a three-person field crew limited to visits of 12 working days once every 5 years. Some tree species, notably in the Lauraceae and Myrtaceae, are difficult to identify from the ground. Moreover, a detailed examination of tree health was not carried out before and after Hurricane Hugo; consequently, pre- and posthurricane species comparisons were kept simple and speculation regarding differences kept to a minimum.

Results at Cinnamon Bay

Forest Structure

Number of stems—In 1983, the stand density for all plots combined was 3,378 trees per hectare (fig. 4, appendix B). Subsequently, it increased to 3,479 stems in 1988, then declined to 3,399 stems in 1993 and to 3,112 stems in 1998, before increasing

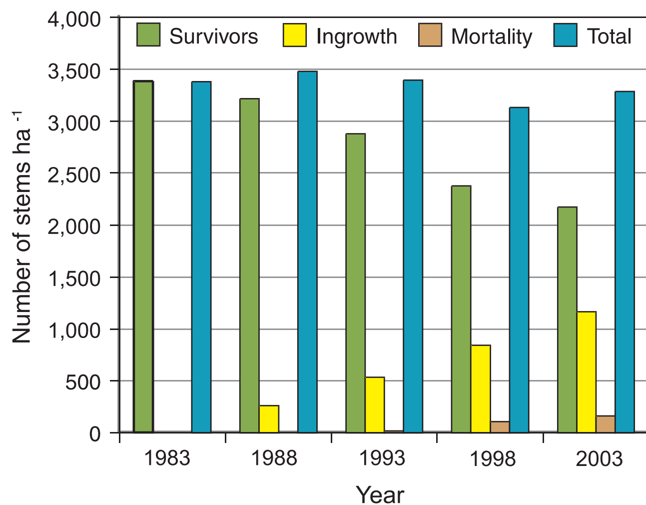


Figure 4—Total number of stems on all plots combined in the Cinnamon Bay watershed: green bars = surviving stems from the initial tally in 1983; yellow bars = cumulative ingrowth; brown bars = cumulative mortality of ingrowth; blue bars = total stems in particular year. Surviving stems are equal to total stems at first measurement in 1983. Ingrowth begins in 1988, and mortality of ingrowth starts in 1993.

to 3,171 stems per hectare in 2003. By 2003, nearly 65 percent of the stems tallied in 1983 still survived. The same pattern is evident for stems on ridge, slope, and valley topography (tables 2 and 3, totals). Stems on the summit plot, however, consistently declined in numbers from 1983 through 2003.

Cumulative ingrowth gradually increased from 262 stems per hectare in 1988 to 1,165 stems per hectare by 2003, when it amounted to 35 percent of the stems on all plots. Cumulative mortality of ingrowth climbed from 22 stems per hectare in 1993 to 166 stems per hectare by 2003 (fig. 4).

Table 2—Summary of stems by height class, topography, and year for the Cinnamon Bay watershed, St. John, U.S. Virgin Islands

Topography and year	Height class <4	4–8	8–12	12–16	>16	Total
			stems ha^{-1}			
Ridge			- - - - - - - - Mean over 5 plots - - - - - - - -			
1983	36	3,056	1,188	68	0	4,348
1988	20	2,572	1,648	204	8	452
1993	56	2,608	1,440	196	8	4,308
1998	124	2,912	860	96	0	3,992
2003	80	2,820	1,068	116	8	4,092
Slope						
1983	20	1,440	848	272	36	2,616
1988	4	1,388	1,016	268	76	2,752
1993	36	1,432	940	256	68	2,732
1998	84	1,500	716	172	24	2,496
2003	64	1,560	756	156	36	2,572
Valley						
1983	80	1,364	740	152	148	2,484
1988	44	1,444	720	188	180	2,576
1993	96	1,420	680	144	156	2,496
1998	172	1,480	484	88	124	2,348
2003	36	1,620	592	100	116	2,464
Summit			- - - - - - - - - Value for 1 plot - - - - - - - - -			
1983	40	4,460	2,100	200	0	6,800
1988	20	3,820	2,660	260	0	6,760
1993	60	3,860	2,560	220	0	6,700
1998	160	3,580	1,500	360	0	5,600
2003	80	3,180	1,500	340	0	5,100
All			- - - - - - - - - - Weighted mean - - - - - - - - -			
1983	45	2,110	999	166	58	3,378
1988	22	1,928	1,224	222	83	3,479
1993	62	1,947	1,116	200	73	3,399
1998	129	2,065	738	134	46	3,112
2003	61	2,074	849	137	50	3,171

Table 3—Summary of stems by d.b.h. class, topography, and year for the Cinnamon Bay watershed, St. John, U.S. Virgin Islands

Topography and year	D.b.h. class (cm) 4–10	10–15	15–20	20–30	>30	Total
	stems ha^{-1}					
Ridge	- - - - - - - - Mean over 5 plots - - - - - - - -					
1983	3,492	592	176	76	12	4,348
1988	3,468	680	196	96	12	4,452
1993	3,344	696	168	88	12	4,308
1998	3,068	672	152	84	16	3,992
2003	3,140	672	184	88	8	4,092
Slope						
1983	1,716	504	196	140	60	2,616
1988	1,804	544	176	168	60	2,752
1993	1,796	540	176	164	56	2,732
1998	1,656	472	164	160	44	2,496
2003	1,732	480	172	148	40	2,572
Valley						
1983	1,928	268	104	100	84	2,484
1988	2,004	276	100	116	80	2,576
1993	1,948	284	88	96	80	2,496
1998	1,912	224	72	76	64	2,348
2003	1,972	280	60	84	68	2,464
Summit	- - - - - - - - - Value for 1 plot - - - - - - - - -					
1983	5,620	780	220	120	60	6,800
1988	5,520	800	240	140	60	6,760
1993	5,300	980	200	160	60	6,700
1998	4,300	920	140	180	60	5,600
2003	3,860	860	160	160	60	5,100
All	- - - - - - - - - - Weighted mean - - - - - - - - -					
1983	2,581	475	163	106	53	3,378
1988	2,619	519	162	128	51	3,479
1993	2,546	536	148	119	50	3,399
1998	2,342	485	130	111	43	3,112
2003	2,380	501	140	110	40	3,171

Height classes—In all years of measurement, from 55 to 66 percent of the stems for all plots combined was between 4 and 8 m in height, and from 90 to 92 percent was between 4 and 12 m in height (table 2). Comparable values by topography were ridge, 58 to 73 percent and 94 to 97 percent; slope, 50 to 61 percent and 87 to 90 percent; valley, 55 to 66 percent and 84 to 90 percent; and summit, 57 to 66 percent and 91 to 96 percent. In all years, only about 2 percent of the total stems tallied on all plots were > 16 m tall. Valleys had the greatest proportion by topography, ranging from 5 to 7 percent.

The height class > 16 m for total stems and for slope trees showed an increase in numbers from 1983 to 1988, a decline through 1998, and then a slight increase in 2003 (table 2). On valley topography, trees > 16 m increased from 1983 to 1988 and then declined through 2003. Stems > 16 m in height were absent from the summit and very uncommon on ridges.

D.b.h. classes—In all years of measurement, 75 percent or more of the total stems was between 4 and 10 cm in d.b.h., and ≥ 90 percent was between 4 and 15 cm in d.b.h. (table 3). Comparable values by topography were ridge 77 and 93 percent, slope 66 and 85 percent, valley 78 and 88 percent, and summit 76 and 92 percent. In all years, < 2 percent of the total stems tallied on all plots were > 30 cm in d.b.h.. The greatest concentration of large trees was in valleys, where about 3 percent of the trees were > 30 cm in d.b.h. in all years.

The d.b.h. class > 30 cm for total stems showed a consistent decline in numbers from 1983 to 2003 (table 3). In general, there was a decline in the d.b.h. class > 30 cm on all topographic positions.

Crown classes—In 1983 and 1988, the percentage of stems by crown class averaged approximately 7.5 for both dominants and co-dominants, 20.0 for intermediates, and 65.0 for suppressed stems (fig. 5). In 1993, the percentage of stems was 8.5 for dominants, 12.0 for codominants, about 36.0 for intermediates, and about 43.5 for suppressed stems. In 1998 and 2003, the percentage of stems by crown class averaged about 3.6 for dominants, 9.3 for codominants, and 42.9 to 44.5 for both intermediate and suppressed stems.

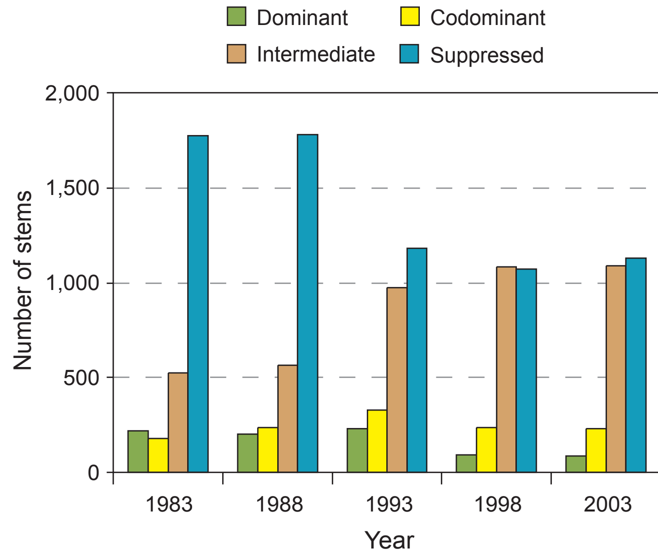


Figure 5—Total number of stems by crown classes on all plots combined from 1983 to 2003.

Forest Dynamics

D.b.h. increment—The d.b.h. growth after 20 years of monitoring for all 1,742 surviving stems of 60 species averaged 0.07 ± 0.00 cm year^{-1} (table 4). *Maytenus elliptica* had the greatest number of survivors with 322 stems. Ten tree species were represented by a single individual. Growth rates for dicots varied from 0.01 ± 0.01 cm year^{-1} for *Guettarda parviflora* with five survivors to 0.22 ± 0.13 cm year^{-1} for *Bucida buceras* L. with three survivors. *Coccothrinax alta*, a palm, showed virtually no change, as expected. D.b.h. growth among crown classes was significantly different: dominant stems 0.10 ± 0.01 cm year^{-1} (n = 149), codominants 0.09 ± 0.01 (n = 119), intermediates 0.07 ± 0.00 (n = 360), and suppressed stems 0.06 ± 0.00 (n = 1,114).

Biomass increment—The standing total biomass of 138.7 t ha^{-1} in 1983 increased to a high by 1988 and then declined to a low by 1998 before making a partial recovery in 2003 (table 5). Biomass accumulation was positive, averaging 2.42 t ha^{-1} year^{-1} from 1983 to 1988, then negative from 1988 through 1998, averaging -2.82 t ha^{-1} year^{-1}, and then positive again from 1998 to 2003, averaging 0.92 t ha^{-1} year^{-1} (tables 5 and 6). The net change over 20 years was -11.5 t ha^{1}, for an average decrease of 0.58 t ha^{-1} year^{-1}.

Table 4—D.b.h. increment from 1983 to 2003 for all surviving stems in the Cinnamon Bay watershed, St. John, U.S. Virgin Islands

Species	D.b.h. growth mean (SE)	D.b.h. range	Number of stems
	(cm/year)	*(cm)*	*(no.)*
Acacia macracantha Humb. and Bonpl. ex Willd.	0.07 (0.02)	6.1–12.3	2
Andira inermis (W. Wright) Kunth ex DC.	0.07 (0.02)	5.5–48.1	9
Ardisia obovata Desv. ex Hamilton	0.05 (0.01)	4.6–11.1	85
Bourreria succulenta Jacq.	0.12 (0.03)	8.3–23.3	7
Bucida buceras L.	0.22 (0.13)	38.5–56.9	3
Bursera simaruba (L.) Sarg.	0.07 (0.01)	9.1–53.5	32
Byrsonima coriacea (Sw.) DC.	0.12 (0.06)	9.9–24.0	5
Capparis frondosa Jacq.	0.11 (0.03)	8.8–37.4	8
Capparis cynophallophora L.	0.03 (0.01)	4.3–14.7	30
Casearia decandra Jacq.	0.05 (0.01)	5.5– 9.2	6
Capparis flexuosa (L.) L.	-0.020	6.5	1
Casearia guianensis (Aubl.) Urban	0.07 (0.02)	4.7–16.3	26
Capparis indica (L.) Druce	0.11	9.3	1
Celtis trinervia Lam.	0.05 (0.03)	6.3–16.5	4
Linociera caribaea (Jacq.) Knobl.	0.07 (0.01)	5.3–13.5	9
Chrysophyllum pauciflorum Lam.	0.07 (0.01)	5.2–19.8	34
Citharexylum fruticosum L.	0.06 (0.01)	5.8–18.4	17
Coccothrinax alta (O. F. Cook) Becc.	0.00 (0.01)	6.7–12.5	10
Cordia alliodora (Rulz and Pavón) Oken	0.10 (0.02)	9.7–26.5	7
Cordia collococca L.	0.11 (0.03)	7.0–32.2	5
Cordia rickseckeri Millsp.	0.06 (0.02)	5.0–27.0	26
Cordia sulcata DC.	0.08 (0.03)	8.1–37.5	11
Coccoloba swartzii Meisn.	0.120	7.0	1
Coccoloba venosa L.	0.12 (0.04)	6.0–13.9	9
Crescentia cujete L.	0.02	10.3	1
Daphnopsis americana (Mill.) J.R. Johnston	0.06 (0.01)	4.9– 9.7	8
Erythroxylum rotundifolium Lunan	0.06 (0.01)	5.2–10.8	15
Eugenia monticola (Sw.) DC.	0.03 (0.01)	9.6–10.4	2
Eugenia procera (Sw.) Poir.	0.07 (0.01)	4.5–16.8	50
Eugenia pseudopsidium Jacq.	0	8.5	1
Faramea occidentalis (L.) A. Rich.	0.07 (0.01)	4.3–13.5	113
Ficus laevigata Vahl	0.15 (0.10)	10.3–12.5	3
Garcinia magostana L.	0.11 (0.03)	6.7– 8.7	2
Guettarda elliptica Sw.	0.04 (0.01)	4.6–14.0	58
Torrubia fragrans (Dum.-Cours.) Standl.	0.09 (0.01)	4.6–79.7	173
Guettarda parviflora Vahl	0.01 (0.01)	6.8– 8.9	5
Guettarda scabra (L.) Vent	0.05 (0.01)	4.5–21.2	50
Guazuma ulmifolia Lam.	0.04 (0.01)	18.4–22.9	2
Inga fagifolia (L.) Wild ex Benth.	0.16 (0.02)	5.1–47.0	30

continued

Table 4—D.b.h. increment from 1983 to 2003 for all surviving stems in the Cinnamon Bay watershed, St. John, U.S. Virgin Islands *continued*

Species	D.b.h. growth mean (SE)	D.b.h. range	Number of stems
	(cm/year)	*(cm)*	
Ixora ferrea (Jacq.) Benth.	0.07 (0.05)	6.9–10.1	2
Krugiodendron ferreum (Vahl) Urban	0.05 (0.01)	6.3–11.8	15
Lonchocarpus pentapyllus (Poir) DC.	0.16	13.2	1
Manilkara bidentata (A. DC.) Chev.	0.18 (0.02)	11.4–37.2	2
Maytenus elliptica (Lam.) Krug and Urban ex Duss.	0.07 (0.00)	4.4–34.5	322
Meliococcus bijugatus Jacq.	0.12 (0.03)	6.2–50.4	13
Morisonia americana L.	0.06 (0.02)	5.7– 9.4	4
Myrcia citrifolia (Aubl.) Urban	0.06 (0.00)	4.3–12.9	98
Myrciaria floribunda (West ex Willd.) Berg	0.07 (0.00)	4.5–26.3	99
Nectandra coriaceae (Sw.) Griseb.	0.10 (0.02)	5.9–14.1	17
Phyllanthus nobilis (L. f.) Muell.-Arg.	-0.01 (0.02)	8.2–18.0	2
Pimenta racemosa (Mill.) J.W. Moore	0.05 (0.01)	4.2–21.4	147
Pisonia subcordata Sw.	0.10 (0.02)	6.7–30.2	17
Quararibea turbinata (Sw.) Poir.	0.06 (0.01)	4.7–12.2	31
Randia aculeata L.	0.02 (0.01)	5.0–17.3	8
Sabinea florida (Vahl) DC.	0.09 (0.01)	5.3–33.7	65
Sapium caribaeum Urban	0.34	21.5	1
Schoepfia schreberi J.F. Gmel.	0.11	6.6	1
Sideroxylon foetidissum Jacq.	0.14 (0.01)	8.7–12.0	2
Spondias mombin L.	0.11 (0.03)	28.8–69.0	4
Tabebuia heterophylla (DC.) Britt.	0.02 (0.01)	4.7–32.2	24
Tetrazygia angustifolia (Sw.) DC.	0.05	6.5	1
Tetrazygia elaeagnoides (Sw.) DC.	0.06	7.8	1
Zanthoxylum martinicense (Lam.) DC.	0.11 ± 0.04	19.3–38.7	4
Mean/Range/Total	0.069 ± 0.002	4.2–79.7	1,742

Cumulative biomass ingrowth increased from 2.0 t ha^{-1} in 1988 to 17.6 t ha^{-1} by 2003. By 2003, the residual stems initially tallied in 1983 still accounted for most of the biomass (table 5).

In 1983, standing biomass varied by topography, ranging from an average of 120.3 t ha^{-1} on the ridges to 197.7 t ha^{-1} at the summit (table 6). Biomass increased on all topographies through 1988 and then decreased on all but the summit by 1993. Losses continued on all plots through 1998, with biomass declining most in valleys and least on ridges. By 2003, only ridge topography showed an average increase in biomass since the initial measurements made 20 years earlier.

Species composition—Eighty species were tallied on the plots throughout the 20 years of measurement: 69 in 1983 and 1988, 68 in 1993, and 74 in 1998 and 2003 (appendix B). Five species were originally recorded and later lost: one in 1988, three in 1993, and one in 1998. Eleven species not previously recorded were first noted as ingrowth: one in 1988, two in 1993, six in 1998, and two in 2003. Eighteen deciduous species with 365 stems and 51 evergreen species with 2,337 stems were present on the plots in 1983 (appendix B). By 2003, deciduous species numbered 21 with 357 stems, and evergreen species numbered 55 with 2,178 stems.

Table 5—Summary of total aboveground biomass by year for the Cinnamon Bay watershed, St. John, U.S. Virgin Islands

	Year				
Factor	1983	1988	1993	1998	2003
			t ha^{-1}		
Survivors [a]	138.7	148.8	137.1	109.8	109.6
Ingrowth by year [b]	0	2.0	4.3	6.5	3.0
Cumulative ingrowth [c]	0	2.0	6.5	12.8	17.6
Total biomass [d]	138.7	150.8	143.6	122.6	127.2
Percent survivors [e]	100.0	98.7	95.5	89.6	86.2
Percent ingrowth [f]	0	1.3	4.5	10.4	13.8

[a] Biomass of the survivors of the original stems (tallied in 1983) to the indicated year.
[b] Biomass of the ingrowth for the particular year.
[c] Sum of all ingrowth to the year indicated.
[d] Total biomass = biomass of survivors + biomass of cumulative ingrowth.
[e] Percent biomass of the 3,378 stems tallied in 1983 to the indicated year.
[f] Percent of the total biomass attributable to ingrowth since 1988.

Table 6—Summary of total aboveground biomass by topography and year for the Cinnamon Bay watershed, St. John, U.S. Virgin Islands

	Year				
Topography [a]	1983	1988	1993	1998	2003
			t ha^{-1}		
Ridge	120.3	135.5	131.2	117.8	124.6
Percent change [b]	—	12.7	9.1	-2.0	3.6
Slope	135.2	146.8	143.9	123.0	123.3
Percent change	—	8.2	6.4	-9.0	-8.8
Valley	148.8	159.2	142.4	113.2	122.5
Percent change	—	7.0	-4.3	-24.0	-17.7
Summit	197.7	206.3	210.3	190.2	182.9
Percent change	—	9.0	6.4	-3.8	-7.5
Total	138.7	150.8	143.6	122.5	127.2
Percent change	—	10.3	5.0	-10.4	-6.9

[a] Means for ridge, slope, and valley are based on 5 plots; data on the summit is based on 1 plot; mean for the total is based on all 16 plots.
[b] Percent change from 1983 to date indicated.

In 1983, the five most common species accounted for 1,126 stems or 41.7 percent of all stems tallied; in 2003, they totaled 1,247 stems or 49.1 percent of all stems (appendix B). In 1983, the 10 most common species accounted for 1,775 stems or 65.7 percent of all stems tallied; in 2003, they totaled 1,711 stems or 67.4 percent. Also in 1983, 23 species were tallied no more than five times and 11 species but once. By 2003, 32 species were tallied no more than five times and 10 species but once. *Maytenus elliptica*, ranging from 343 individuals in 1983 to 443 in 2003, was the most common species throughout the study. Moreover, the latter species along with *Faramea occidentalis* showed considerable flux in ingrowth and mortality, notably after Hurricane Hugo.

The survival of 1983 stems varied by species and ranged from 0 to 100 percent (appendix B). Among species tallied at least 100 times in 1983, those with the best 20-year survival rates were *M. elliptica* (95 percent survival), *P. racemosa* (94 percent), and *Myrciaria floribunda* (89 percent). These species also increased in numbers from 1983 to 2003 by 29, 10, and 22 percent, respectively. The greatest increase in stems during the 20 years, despite a survival rate of only 56 percent, was by *F. occidentalis,* which had 31 percent more stems in 2003. The aforementioned four species increased from 822 stems, or 30 percent of the 1983 total, to 1,014 stems, or 40 percent of the 2003 total (appendix B). The 10 percent survival rate of *Nectandra coriaceae* was the poorest for species with at least 100 stems.

Three species tallied in the watershed are endemic to Puerto Rico and the U.S. Virgin Islands: *Chrysophyllum pauciflorum*, *Coccothrinax alta*, and *Cordia rickseckeri* (appendix B). Two exotics accounted for 15 stems in 1983 and four exotics for 46 stems in 2003. *Garcinia mangostana* and *Melicoccus bijugatus* were present in 1983 and persisted through 2003; *Carica papaya* entered in 1998 and disappeared by 2003. *Ficus elastica* and *Leucaena leucocephala* entered in 1993 and persisted through 2003.

Discussion

Climate

Bordeaux Mountain at 390 m does not reach the 600 to 750 m base of trade wind cumulus clouds in the Caribbean (Baynton 1968). Consequently, it does not present as formidable an obstacle as encountered on the more mountainous Caribbean islands where rainfalls are greater. St. John's climate is dry and is characterized by rain-laden tropical depressions, tropical storms, and hurricanes, as well as prolonged droughts. The 119-year record at Cruz Bay shows that annual precipitation ranged between 600 and 1900 mm and that total monthly rainfall was unpredictable and extremely variable by year (Brown and Ray 1993). Moreover, high monthly rainfalls did not necessarily mean that the entire month was wet; rather, that heavy downpours had occurred at least once or twice.

At the beginning of measurements in 1983, the watershed was recovering from previous events, including a severe drought in 1967-68, a low-pressure system accompanied by strong winds in 1969, and the glancing impact from the massive and powerful Hurricane David in 1979 (Colón-Dieppa and others 1991). Earlier, Hurricane Connie of 1955, a low-pressure system of 1960, and severe droughts in 1957 and 1964 probably caused some tree mortality. Earlier still, human settlement and associated land use dramatically influenced the watershed's forest resources (Knight 1999, Tyson 1987), causing changes in the relative abundances of species that will persist for centuries.

The 20 years of measurement in the Cinnamon Bay watershed span an eventful period from 1989 to 1995, with two hurricanes and a pronounced drought, and two uneventful periods from 1983-88 and from 1996 to 2003 when these climatic phenomena did not occur.

Hurricane Hugo of 1989 passed over the northeastern tip of Puerto Rico, about 100 km west of St. John (Brennan 1991). Meteorologists estimated sustained winds of 160 km $hour^{-1}$ with gusts to 190 km $hour^{-1}$ for nearby St. Thomas, based on radar observations and local damage (Reilly 1991, Weaver 1994). Moreover, in September of 1995, Hurricane Marilyn traversed the northern Virgin Islands with winds estimated at 155 km $hour^{-1}$, destroying about 30 percent of the homes on St. John (Rappaport 1996).

Droughts have also had significant effects on the island's forests. The drought in 1994-95 was the driest 18-month period on St. John during the 20th century (Gibney 2004). Total rainfall at nearby Caneel Bay was only 54 percent of the 40-year average (Rogers and Reilly 1998). Near the end of the drought, the island's forests had very dry soils even within drainages, the landscape had a brownish cast, leaves dried and fell to the ground, and noticeably more light reached the forest understory. The accumulation of dry leaves in a loose arrangement on the soil surface, analogous to unnailed shingles on a roof, made walking up steep slopes difficult. Preliminary data for plots at Caneel Bay showed that mortality after the drought was greater than that reported for some sites after Hurricane Hugo (Rogers and Reilly 1998). It is noteworthy that the century's severest drought was followed by a hurricane, highlighting the extremes that characterize the climate of St. John.

Forest Structure

The 20-year fluctuation in total stem numbers—an increase from 1983 to 1988, a decline from 1988 to 1998, then another increase through 2003 (fig. 4)—reflects distinct periods of forest development, as noted after the 1932 Hurricane San Cipriano in the Luquillo Mountain forests [Luquillo Experimental Forest (LEF)] in northeastern Puerto Rico (Crow 1980, Weaver 1989). The first period appears to be the maturing of the forest after disturbances that occurred before the initiation of measurements. The second period reflects stem losses due to hurricane impacts, and the last period shows the initiation of post-Hurricane Hugo recovery. The notable exception to the general pattern is the extremely high stem density on the summit plot in 1983 (tables 2 and 3). The continual decline of stems on the summit probably reflects a natural thinning, along with losses associated with the 1994-95 drought and Hurricane Marilyn. Biomass fluctuations, both by topographic position and total, parallel the trends in stem numbers (tables 5 and 6).

The impacts of Hurricane Hugo in Cinnamon Bay watershed included defoliation, broken branches, split trunks, uprooted trees, immediate mortality, and delayed mortality up to 19 months after the storm (i.e., aboveground woody biomass decreased by 210 t ha^{-1} after 10 months and by 288 t ha^{-1} after 19 months) (Brown and Ray 1993; Weaver 1994, 1998).

Cruz Bay harbor. (Top) During dry conditions, June 1995; the 1995 drought was the driest on record during the 20th century. (Bottom) During humid conditions, June 1998.

The tallest trees on 44 percent of all plots were lost, including four of the five valley plots, where the greatest proportion of large trees occurred (Weaver 1994, 1998) (tables 2 and 3). Greater hurricane impacts on larger trees and those at low elevations in valleys were noted at other sites (Reilly 1991, 1994). The net impact was the creation of openings within the forest that allowed more light to reach the soil surface. The continual rise in cumulative ingrowth after1993 (fig. 4) indicates that sufficient light was available at the forest floor to stimulate regeneration and early growth of many species.

After Hugo, increases in the density and diversity of seedlings were observed on the Hawksnest and L'Esperance plots, whereas decreases were evident on Bordeaux (Rogers and Reilly 1998). L'Esperance suffered the most damage whereas Bordeaux maintained a fairly dense understory after the storm. Direct and indirect light at all three sites, estimated from canopy photographs, decreased by about 50 percent 2 years later as the canopy recovered (Rogers and Reilly 1998).

Proportions of stems in different crown classes changed considerably during the 20 years of measurement (fig. 5). Before Hurricane Hugo, the mature forest contained a moderate proportion of canopy trees that shaded a large number of suppressed stems. Hurricane damage either reduced or eliminated the influence of many dominant and codominant stems (Weaver 1998), allowing more light to penetrate the forest. Consequently, the proportion of intermediate stems increased, and the proportion of suppressed stems decreased.

Mean heights and mean diameters for all stems in 1983 varied little by topography, whereas the mean heights and mean diameters for dominant and codominant stems alone were greatest in valleys and smallest on ridges (Weaver and Chinea 1987) (table 7). Mean values by plot are heavily influenced by the inclusion of numerous small stems, whereas mean values for canopy trees alone better indicate topographic effects on height growth. Average basal areas were similar on all topographic positions except the summit, where the high stem density inflated the value (table 7).

Structural components of the forest related to net primary production were previously determined for Cinnamon Bay (Weaver 1994, 1996):

- Specific leaf areas—from 58 to 192 cm^2 g^{-1} by species, averaging 99 for the forest
- Average standing crop of loose litter—933 g m^{-2}, partitioned among leaves (36 percent), woody (55 percent), fruits and flowers (4.5 percent), and miscellaneous material (4.5 percent)

Table 7—Summary of structural and species composition data in 1983 for the Cinnamon Bay watershed, St. John, U.S. Virgin Islands [a]

Factor (units)	Topography				Total
	Valley	Slope	Ridge	Summit	
	Mean (SE)				
Structure					
Mean height for all stems (m)	8.4 (0.5)	8.4 (0.4)	7.2 (0.2)	7.5 (0.1)	8.0 (0.2)
Mean height, tallest trees (m)	29.7 (2.1)	19.1 (0.9)	13.5 (0.5)	14.6 (1.1)	NA
Mean d.b.h. for all stems (cm)	9.3 (0.6)	10.2 (0.5)	8.0 (0.1)	7.9 (0.2)	9.1 (0.6)
Mean d.b.h., largest trees (cm)	18.7 (0.8)	12.2 (0.3)	9.7 (0.1)	10.6 (0.2)	NA
Mean basal area (m^2 ha^{-1})	29.6 (6.5)	31.3 (2.1)	27.6 (2.1)	43.6	30.4 (2.3)
Species composition					
Number by topography (total) [b]	37	49	43	16	69
Number per plot (range) [b]	14–20	17–21	19–25	16	14–25

NA = Not applicable.

[a] Source: Weaver and Chinea-Rivera (1987).

[b] Plots: valley, slope, and ridge = 5 each; summit = 1.

- Standing herbivory—between 0.2 and 12.1 percent by species, with a weighted mean for all species of 4.5 percent

The nearest comparable values geographically for island forests come from three different subtropical life zones along an elevational gradient in the LEF of Puerto Rico. Ascending this gradient through subtropical wet forest, lower montane wet forest, and lower montane rain forest in the LEF, the mean specific leaf area declines from 127 to 47 cm^2 g^{-1}, loose litter from 600 to 430 g m^{-2}, and standing herbivory from 7 to 5 percent (Weaver and Murphy 1990). Mean aboveground woody biomass decreases from 190 to 80 t ha^{-1} along the same gradient. The Cinnamon Bay watershed values are within the range of those in the LEF except for loose litter, which decomposes more slowly in the drier environment.

Forest Dynamics

The 20-year mean annual d.b.h. growth for the 1,752 survivors in Cinnamon Bay was the same as the 5-year annual d.b.h. growth for 2,537 survivors between 1983 and 1988 (Weaver 1990). Moreover, the 20-year d.b.h. growth by crown classes was similar to and paralleled the 5-year d.b.h. growth by crown classes. D.b.h. growth generally slows as a forest matures. The Cinnamon Bay watershed, however, is currently recovering from numerous recent disturbances.

A short-term decline in d.b.h. growth was noted for most tree species on plots at Bordeaux, Hawksnest, and L'Esperance after Hurricane Hugo (Reilly 1998). This phenomenon may be attributable to crown damage and to costs associated with crown recovery, including refoliation and the regrowth of branches and twigs. Similar comparisons were not run for the Cinnamon Bay dataset because the posthurricane measurements were confounded by 1.3 years of prehurricane growth (i.e., 5-year measurements were made in June 1988 and June 1993 with the hurricane in September 1989).

In 1992, the total aboveground net primary productivity rate in the Cinnamon Bay watershed was estimated at 10.64 t ha^{-1} $year^{-1}$ (Weaver 1996). The relatively high value had the following components:

- A total litterfall rate of nearly 8.97 t ha^{-1} $year^{-1}$
- A leaf litterfall rate of 5.1 t ha^{-1} $year^{-1}$
- April and September peaks in leaf litterfall
- April and October peaks in flower and fruit fall
- An April peak in the fall of miscellaneous material
- A herbivory rate of 4.6 percent per year (or 0.25 t ha^{-1} $year^{-1}$)
- A 5-year biomass change of 1.42 t ha^{-1} $year^{-1}$
- A litterfall turnover rate of 0.96 times per year

The nearest comparable values geographically for total aboveground net primary productivity rates (in t ha^{-1} $year^{-1}$) again come from the elevational gradient in the LEF of Puerto Rico. Values there were subtropical wet forest 10.5, lower montane wet forest 7.6, and lower montane rain forest 3.7 (Weaver and Murphy 1990). The relatively high Cinnamon Bay watershed productivity was determined during the post-Hurricane Hugo recovery period (tables 2, 3, and 6). In contrast, the LEF values were from closed forests 30 to 50 years after major hurricane impact.

Elsewhere on St. John, flowering peaks were noted in April and June, continuing at a moderate rate until September (Ray 1993, Ray and Brown 1994). Fruiting diminished between October and February, reaching a maximum during the dry season. The frequent hurricanes and pronounced droughts maintain the forests on St. John in a state of flux that influences d.b.h. growth rates, biomass accumulation, litterfall rates, and net primary productivity.

Species Composition

With 75 percent of the species and 86 percent of the stems evergreen, the Cinnamon Bay watershed classifies as dry evergreen woodland (Beard 1955, Woodbury and Weaver 1987). Species numbers varied in space, being greatest on slopes, intermediate on ridges and in valleys, and least on the single summit plot (Weaver and Chinea-Rivera 1987) (table 7). In the lower montane wet forest of the LEF, the cumulative number of species tallied in a similarly designed study was greatest on ridge topography, intermediate on slopes, and least in valleys (Weaver 2000). In the LEF, greater species numbers on ridges than on other topographies was attributed to two factors: the occurrence of rare species and higher stem densities on ridges. The net effect of stem density is to increase the sample size and the likelihood of encountering a new species. The histories of the Luquillo and Cinnamon Bay forests, however, are different. The

Litterfall baskets used during the productivity study in dry evergreen woodland on ridge plot #13, Cinnamon Bay watershed (February 1992).

Extension ladder used during canopy herbivory sampling in dry evergreen woodland on ridge plot #13, Cinnamon Bay watershed (February 1992).

upper areas of the LEF remain largely undisturbed by humans. In contrast, the natural vegetation of the Cinnamon Bay watershed, and virtually all of St. John, was formerly devastated by plantation agriculture.

The 20 species most frequently tallied in the Cinnamon Bay watershed showed site preferences along elevational and topographic gradients (Weaver and Chinea-Rivera 1987):

- *Torrubia fragrans*, *Ardisia obovata*, *Myrcia citrifolia*, and *Eugenia procera* are very common on the summit, followed by ridge topography at high elevation; *Guettarda scabra* and *Cordia rickseckeri* have a similar distribution but are less common.
- *Maytenus elliptica*, *Sabinea florida*, and *P. racemosa* are most common on ridges, the first and second at mid-elevations and the third at high elevation.
- *Daphnopsis americana* is found mainly on ridges at all elevations, particularly at mid-to-high elevations.
- *Myrciaria floribunda* and *N. coriaceae* have relatively even distributions with regard to topography, the first being most common at low elevations and the second with a dip in number of stems at mid-elevations.
- *Bursera simaruba* is most common on slopes and *Capparis cynophylophora* on slopes and ridges, both at low to mid-elevations.
- *Guettarda parviflora* and *Chrysophyllum pauciflorum* are most common in valleys and on slopes at low elevation.

- *Faramea occidentalis* and *Quararibea turbinata* are most common in valleys at mid-elevations, *Inga fagifolia* at mid-to-high elevations, and *Casearia guianensis* in valleys at low to high-elevations.
- *Torrubia fragrans*, tallied on 15 of the 16 plots in the watershed, has the highest plot frequency.

Climatic events affect tree species differently. Hugo damaged a total of 8.4 percent of all stems but damage varied among 24 species with ≥ 20 stems (Weaver 1998). Damage ranged from 0.6 percent of all *P. racemosa* to 22.8 percent of all *N. coriaceae.* Damage also varied along gradients or in accordance with certain factors:

- By elevation: 9.5 percent of the trees above 180 m in elevation were damaged versus 7.0 percent of the trees below 180 m
- By topography: 11.3 percent of the trees in the valleys were damaged, 5.3 percent on slopes, 7.9 percent on ridges, and 10.6 percent on the summit
- By aspect: 12.4 percent of the trees facing a northerly direction (N10°W to N) were damaged as opposed to 6 percent facing west (N30°W to W) and 7.5 percent facing east (N30°E to E)
- By slope: 14 percent of the stems on relatively level terrain (i.e., slopes ≤ 5 percent) were damaged as opposed to 5.6 percent of the stems on intermediate slopes (i.e., slopes between 20 and 25 percent) and 7.5 percent of the stems on steep terrain (i.e., slopes ≥ 40 percent)

The secondary forest in the Cinnamon Bay watershed is among the oldest on the island (table 1). Species distributions and abundances in other watersheds with different rainfall and land use history most likely will show other trends. Moreover, the total sampling area in this study of Cinnamon Bay is relatively small, with each plot representing a single topographic position along an elevational gradient. Earlier research on a 4-ha plot in moist semi-evergreen forest (apparently, basin moist forest) of Reef Bay showed a preponderance of clumped tree distributions with short distances between trees (Forman and Hahn 1980). Microhabitats within the forest were suggested as a possible factor to account for tree distributions on that plot.

Species numbers also varied in time, being lower in years before and immediately following Hurricane Hugo than in 1998 and 2003 (appendix B). Similar trends were noted about 14 years after Hurricane San Cipriano in both the subtropical wet and lower montane wet forests of Puerto Rico's Luquillo Mountains (Crow 1980, Weaver 1989). A few years after the storms, numerous stems regenerated in openings, including many secondary species (Crow 1980).

Species diversity may be determined several ways, including equitable representation, and requires interpretation (Peet 1974). Although the total number of species in the Cinnamon Bay watershed increased between 1983 and 2003, the total number of stems declined by about 6 percent; moreover, four of the most common species, *Maytenus elliptica*, *Myciaria floribunda*, *P. racemosa*, and *F. occidentalis*, also increased their representation among all species from 30 to 40 percent (fig. 6, appendix B). The first three of these species were observed to be among the most resistant to hurricane impact within the watershed (Weaver 1998). In contrast, *N. coriaceae* was among the species most heavily damaged during Hugo (Weaver 1998). In 1956, after Hurricane Betsy in Puerto Rico, *N. coriaceae* showed a similar loss of stems (Wadsworth and Englerth 1959). Both *F. occidentalis* and *Maytenus elliptica* demonstrated considerable dynamics with regard to ingrowth and mortality, particularly after the hurricanes (appendix B).

Exotics were not common on the plots, accounting for only 0.6 percent of the total stems in 1983 and 1.9 percent in 2003. The openings created by the hurricanes allowed the number of exotic species to double and the number of exotic stems to triple from 1983 to 2003 (appendix B). Most notable were increases of *Meliococcus bijugatus* near mature trees and the arrival of *L. leucocephala*, which was previously absent on the plots.

In southwestern Puerto Rico, only one-third of the 23 exotic species introduced into late secondary subtropical dry forest at Guánica were judged as successful (Chinea 1990). The remaining species were either scarce or had disappeared. Of the exotics currently tallied on the Cinnamon Bay plots, *M. bijugatus*, unsuccessful at Guanica, is likely to persist for a considerable period. The species is capable of regenerating and competing in forest stands and is likely to increase during the next century (Francis

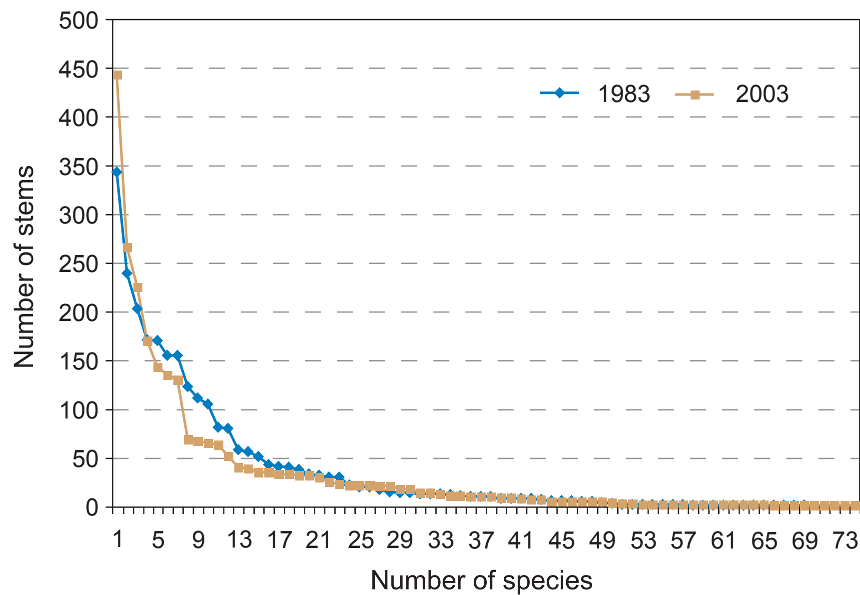


Figure 6—Abundance of stems by number of species for the individual plots in 1983 and 2003.

and Liogier 1991). It is already very abundant at L'Esperance and Hawksnest (Earhart and others 1988). *Leucaena leucocephala* is abundant in young secondary forests elsewhere on St. John but will probably decline at Cinnamon Bay in the absence of major disturbance. *Garcinia mangostana* and *Ficus elastica* are not regenerating in Cinnamon Bay and will likely disappear over time. In general, exotics appear to be less successful within intact late secondary forests than in recently abandoned pastures or storm-created forest gaps.

Conclusions

Caribbean islands like St. John that do not reach the cumulus cloud base at 600 to 750 m are too low to induce much local precipitation. Therefore, their forest ecosystems are exposed not only to an annual procession of rain-bearing tropical depressions along with occasional tropical storms and hurricanes but also to recurrent droughts of varying intensity and length. To date, 20 years' monitoring in the Cinnamon Bay watershed has provided a wealth of information on forest structure, stand dynamics, and species composition during a brief period with two major hurricanes and a severe drought. Indeed, major disturbances are as much a part of the island's climatic regime as are relatively quiet periods.

Monitoring the 16 Cinnamon Bay plots, stratified by environmental gradients in elevation and topography, should continue as long as possible. Dry forests similar to those found on St. John have experienced so much human intervention throughout the world that some consider them to be threatened (Janzen 1988, Ray and others 1998). The only examples of permanent plot monitoring in Caribbean dry forests with > 15 years of data are on St. John (table 1) and in Puerto Rico's Guanica Forest (Murphy and Lugo 1986a, 1986b).

The extent to which the complex patterns observed in the Cinnamon Bay watershed may be extrapolated to other sites or future climatic events on St. John remains as conjecture. First, the study design, although replicated by topography, is confined to the northern slopes of the island. Moreover, since the plots are located along an elevational gradient, each plot provides observations that reflect a single combination of factors. Other watersheds vary in morphology, rainfall, previous agricultural practices, time since agriculture was abandoned, and consequently, in forest structure and species composition. Storms or droughts may vary in intensity, duration, or recurrence. In the case of hurricanes, a difference in prestorm conditions, trajectory, wind velocity, associated tornados, and rainfall could yield varying impacts, even within the same watershed (Weaver 1998). Moreover, as

observed already, Hurricane Hugo showed differential impacts by aspect with greater damage on the south (exposed) side of St. John than the north side (Rogers and Reilly 1998). Continued human intervention (e.g., clearing for road construction or home building) on private properties within the Park (inholdings) or near its border is another factor that varies by site and worsens with time. Localized clearing breaks up the integrity of the forest, probably lessens its resistance to storms, and certainly facilitates the invasion of secondary species and exotics.

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Appendix A

Chronology of major events (exploration, settlement, forest exploitation, forest recovery, terrestrial research, and tourism) in the history of St. John, U.S. Virgin Islands, with emphasis on the Cinnamon Bay watershed

Year	Event
B.C.	
1700-450	Archaic period pre-ceramic sites on northern Virgin Islands suggest possible activity in Cinnamon Bay.
450-225	A pre-ceramic group (Ciboney) migrate through the Lesser Antilles from Venezuela and establish at Krum Bay in nearby St. Thomas.
A.D.	
100-400	Arawaks arrive in the Virgin Islands; occupation of St. John is indicated by materials collected from Cinnamon Bay, Coral Bay, and Cruz Bay.
1400s	Caribs raid the Virgin Islands, attacking the more sedentary Arawaks.
1493	On November 14, Columbus lands at Salt River, St. Croix; on November 17, he sails past St. John and names the Virgin Islands.
1595	Sir Francis Drake anchors in the Virgin Islands, lending his name to the channel between St. John and Tortola.
1671	Denmark and Norway establish a trading post on St. Thomas to exploit the Caribbean by means of the Danish West India and Guinea Company.
1672	First consignment of African slaves arrives in St. Thomas.
1675	Danes take possession of St. John, leaving two men, but make no attempt to colonize the island.
1684	Denmark formally takes possession of St. John.
1717	Governor Erik Bredal begins the first settlement on St. John, followed by other migrations in 1721 and 1724-25; subsequently, the total number of inhabitants varies as follows: 43 in 1717; 800 in 1728; 1,295 in 1733; 1,622 in 1739; 2,434 in 1773; 2,500 in 1841; 925 in 1901; 959 in 1917; 720 in 1930 and 1940; 749 in 1950; 925 in 1960; 3,500 in 1990; and 4,300 in 2001.
1725	St. John is a sugar-producing center; large trees are absent from the landscape.
1727	Peter Durloe from Holland is the first to settle at Cinnamon Bay; Cinnamon Bay estate has 11 documented enslaved laborers; subsequent estimates vary as follows: 54 from 1738 to 1741, 53 in 1767, 69 in 1776, 99 in 1780, 82 in 1783, 75 in 1791-92, 79 in 1799, 113 in 1805, 81 in 1823 and 1835, 93 in 1842, and 91 in 1845.
1729	Plantations in St. John total 87; subsequently they vary as follows: 109 in 1733, 110 in 1739, 83 in 1760, 69 in 1773, and 65 in 1800.

continued

Appendix A (continued)

Chronology of major events (exploration, settlement, forest exploitation, forest recovery, terrestrial research, and tourism) in the history of St. John, U.S. Virgin Islands, with emphasis on the Cinnamon Bay watershed

Year	Event
1733	Drought destroys crops and causes food shortages; harsh treatment of slaves leads to a revolt in November, during which one-third of the white inhabitants are killed and one-half of the plantations are destroyed; slaves hold the island for 6 months.
1734	Slave insurrection is crushed by French soldiers from Martinique.
1730s	The occupation of Cinnamon Bay watershed by the Jansen family peaks.
1741	Moravian missionaries arrive from Germany and introduce basket-making.
1780s	Cinnamon Bay is a well-developed sugar estate; a topographic and land use map shows that 40 percent of St. John is completely cleared.
1792	Denmark is first European nation with colonies in the West Indies to abolish the slave trade.
1796	Area in sugar cane on St. John was 750 ha (15 percent), perhaps near the maximum; in 1805, it was about 15 percent and in 1847 about 6.5 percent.
1803	Danish transatlantic slave trade ceases.
1805	Considerable land in Cinnamon Bay watershed remains wooded or uncultivated.
1820	Epidemics in the Virgin Islands: in 1820 and 1843, small-pox spreads; in 1854, cholera; in 1867, both cholera and small-pox; in 1932, malaria.
1823	Nearly three-quarters of Cinnamon Bay provides fuel and the occasional harvest of fruits and fowl.
1848	Governor General Peter von Scholten orders the emancipation of slaves.
1865	The United States first expresses an interest in purchasing the Virgin Islands from Denmark to develop a naval station.
1868	Last attempt to produce sugar cane in Cinnamon Bay ends; new owner introduces livestock and dairy production.
1870s	Sugar production declines on St. John.
1879	Eggers catalogs the flora of the Virgin Islands with some specimens collected from St. John and notes that the island has considerable forest cover.
1880s	Cinnamon Bay residents harvest bay rum tree (*Pimenta racemosa*) leaves and berries to produce bay rum oil, the island's most important industry through the 1940s.
1884	Cinnamon Bay estate is reported to be all in bush (secondary forest).
1898	During the Spanish-American War, U.S. negotiations with Denmark to purchase the Virgin Islands are suspended.
1900s	Early in century, cattle graze in the Cinnamon Bay watershed.
1917	The United States buys the Virgin Islands from Denmark; livestock, mainly cattle, graze on some estates; only 3 percent of the island is under cultivation.
1920	Bay rum harvest reaches its peak.
1930s	A few tourists arrive in the Virgin Islands; subsequently, they increase as follows: 55,000 in 1962; 281,000 in 1972; 970,000 in 1982; 1.9 million in 1992; and 2.3 million in 2002.
1952	The Virgin Islands Tourist Development Board comes into existence; Laurence Rockefeller buys and donates about 2,850 ha, or 55 percent of St. John, to the U.S. Department of Interior Park Service.
1956	President Eisenhower signs Public Law 85-925 authorizing the establishment of the Virgin Islands National Park.

continued

Appendix A (continued)

Chronology of major events (exploration, settlement, forest exploitation, forest recovery, terrestrial research, and tourism) in the history of St. John, U.S. Virgin Islands, with emphasis on the Cinnamon Bay watershed

Year	Event
1962	Marine waters totaling 2,287 ha are added to the National Park.
1966	A soil survey of the Virgin Islands is completed; in 1980, soil taxonomy for the island is revised.
1976	The Virgin Islands National Park is designated as a Biosphere Reserve.
1982	The Virgin Islands Resource Management Cooperative is formed among 14 entities to initiate baseline research in the Park.
1983	Forest monitoring: the U.S. Department of Agriculture Forest Service initiates permanent forest monitoring in the Cinnamon Bay watershed; subsequently, monitoring begins at Bordeaux, Hawksnest, and L'Esperance in 1984 by the New York Botanical Garden; at Caneel Hill, Cinnamon Bay, Lameshur, and Mary Point in 1988 by the University of Wisconsin; and at Caneel Hill and Minna Hill in 1991 by the Smithsonian Institution.
1995	Flora of St. John is completed.
2006	The U.S. Park Service hosts a 3-day conference entitled "Science in the Park" to celebrate the 50th anniversary of the Virgin Islands (VI) National Park, the 40th anniversary of the VI Environmental Resource Station (VIERS), and the 30th anniversary of the VI International Biosphere Reserve.

Sources: Acevedo-Rodríguez and others 1996; Britton 1918; Colón-Dieppa and others 1991; Dookhan 1974; Earhart and others 1988; Eggers 1879; Haas 1940; Hatch 1972; Harman 1961; Knight 1999; Larsen 1986; Low and Valls 1985; Lugo-López and Rivera 1980; MacDonald and others 1997; Near 2003. Raphael 1967; Ray and Brown 1995a; Ray and others 1998; Reilly 1991; Rivera and others 1966; Rivera and others 1970; Robertson 1957 (see endnotes); Tyson 1987; Varlack and Harrigan 1977; Weaver 1994, 1998; Zabriskie 1918.

Appendix B

Stem density by species and year on 16 plots totaling 0.8 ha in the Cinnamon Bay watershed, St. John, U.S. Virgin Islands

Species	1983	1988			1993			1998			2003			Survival
	Total	Ingrowth	Mortality	Total	Ingrowth	Mortality	Total	Ingrowth	Mortality	Total	Ingrowth	Mortality	Total	1983–2003
														percent
Acacia macracantha Humb. & Bonpl. ex Willd.[a]	5			5		2	3		1	2			2	40
Amyris elemifera L.	1			1		1							0	0
Andira inermis (W. Wright) Kunth ex DC.[a]	13		1	12			12		3	9			9	69
Ardisia obovata Desv. ex Hamilton	171	14	13	172	29	22	179	8	36	151	9	30	130	50
Bourreria succulenta Jacq.	7			7			7	1		8			8	100
Byrsonima coriacea (Sw.) DC.	6			6			6			6		1	5	83
Bucida buceras L.	3			3			3			3			3	100
Bursera simaruba (L.) Sarg.[a]	38			38			38	2	1	39	1	5	35	84
Capparis cynophallophora L.	41			41	2	3	40		7	33		1	32	73
Capparis flexuosa (L.) L.	1	1		2			2			2			2	100
Capparis frondosa Jacq.	10			10	5		15		3	12		1	11	80
Capparis indica (L.) Druce	1	6		7	1		8	4	2	10	3		13	100
Casearia decandra Jacq.[a]	22	3	3	22		2	20	7	11	16	1	3	14	27
Casearia guianensis (Aubl.) Urban	51		3	48	2	9	41		13	28	2		30	51
Celtis trinervia Lam.[a]	8			8			8	1	4	5			5	50
Chrysophyllum pauciflorum Lam.[b]	40		2	38	2	2	38	3	1	40	2	2	40	85
Citharexylum fruticosum L.	30	1	1	30		1	29		8	21	4	3	22	57
Clusia rosea Jacq.	11		1	10		7	3	1	2	2	1	1	2	0
Coccoloba swartzii Meisn.	1			1			1			1			1	100
Coccoloba venosa L.[a]	15	1		16	3	1	18	9	2	25	13	5	33	60
Coccothrinax alta (O.F. Cook) Becc.[b]	13	3		16	6	1	21		2	19	4		23	77
Cordia alliodora (Ruiz & Pavón) Oken	10	1		11		1	10		3	7			7	70
Cordia rickseckeri Millsp.[a, b]	33		1	32	1	1	32	4	3	33	2	2	33	79

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Appendix B (continued)

Stem density by species and year on 16 plots totaling 0.8 ha in the Cinnamon Bay watershed, St. John, U.S. Virgin Islands

Species	1983	1988			1993			1998			2003			Survival
	Total	Ingrowth	Mortality	Total	Ingrowth	Mortality	Total	Ingrowth	Mortality	Total	Ingrowth	Mortality	Total	1983–2003
														percent
Cordia sulcata DC.[a]	14			14		2	12		1	11			11	78
Cordia collococca L.[a]	6			6			6			6		1	5	83
Crescentia cujete L.[a]	1			1			1			1			1	100
Daphnopsis americana (Mill.) J.R. Johnston	43	2	8	37		10	27	1	15	13		3	10	19
Erythroxylum rotundifolium Lunan[a]	32		5	27	1	7	21	3	5	19	3	1	21	48
Eugenia monticola (Sw.) DC.	20	1	8	13	3	6	10	1	2	9	7	2	14	10
Eugenia procera (Sw.) Poir.	123	12	17	118	4	12	110	8	40	78		13	65	41
Eugenia pseudopsidium Jacq.	2			2		1	1			1			1	50
Faramea occidentalis (L.) A. Rich.	203	42	2	243	53	26	270	52	52	270	37	41	266	56
Ficus laevigata Vahl	8		1	7	2	1	8	1	3	6		1	5	38
Garcinia magostana L.[c]	2			2			2			2			2	100
Guazuma ulmifolia Lam.	5			5		2	3		1	2			2	100
Guettarda elliptica Sw.	80			80	5	6	79	1	8	72	3	8	67	72
Guettarda parviflora Vahl	6	8	1	13			13		1	12		2	10	83
Guettarda scabra (L.) Vent	81	5	8	78	5	13	70	3	9	64	1	2	63	62
Inga fagifolia (L.) Willd ex Benth.	56	2	7	51	3	5	49	3	14	38	2	1	39	54
Ixora ferrea (Jacq.) Benth.	2			2			2			2			2	100
Krugiodendron ferreum (Vahl) Urban	17	1		18	1	1	18		1	17	1		18	88
Linociera caribaea (Jacq.) Knobl.	14	2	1	15	2	2	15	12	3	24	11		35	64
Lonchocarpus pentaphyllus (Poir) DC.	1			1			1			1			1	100
Mammea americana L.	1			1			1		1				0	0
Manilkara bidentata (A. DC.) Chev.	2			2			2			2			2	100
Maytenus elliptica (Lam.) Krug & Urban ex Duss.	343	23	1	365	26	2	389	33	13	409	40	6	443	94

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Appendix B (continued)

Stem density by species and year on 16 plots totaling 0.8 ha in the Cinnamon Bay watershed, St. John, U.S. Virgin Islands

Species	1983	1988			1993			1998			2003			Survival
	Total	Ingrowth	Mortality	Total	Ingrowth	Mortality	Total	Ingrowth	Mortality	Total	Ingrowth	Mortality	Total	1983–2003
														percent
Melicoccus bijugatus Jacq.[c]	13			13	1		14	3		17	5		22	100
Morisonia americana L.	4			4	1		5			5			5	100
Myrcia citrifolia (Aubl.) Urban	155	27	3	179	9	11	177	7	36	148	10	15	143	63
Myrciaria floribunda (West ex Willd.) Berg	111	9	1	119	7	3	123	12	8	127	11	3	135	89
Nectandra coriacea (Sw.) Griseb.	170	15	21	164	8	77	95	8	60	43		21	22	10
Phyllanthus nobilis (L.f.) Muell.-Arg[a]	2			2			2			2			2	100
Pimenta racemosa (Mill.) J.W. Moore	155	5		160	6	2	164	4	6	162	9	1	170	95
Pisonia subcordata Sw.[a]	20			20	1		21		2	19		1	18	85
Quararibea turbinata (Sw.) Poir.	58	7		65	5		70	4	25	49	8	5	52	93
Randia aculeata L.[a]	12			12		1	11	1	2	10		1	9	67
Rauvolfia nitida Jacq.	1		1										0	0
Rauvolfia viridis Roemer & J.A. Schultes	2			2		2							0	0
Sabinea florida (Vahl) DC.[a]	105	3	6	102		11	91	3	18	76	2	9	69	62
Sapium caribaeum Urban	1			1			1			1			1	100
Schoepfia schreberi J.F. Gmel.	1			1			1	1		2			2	100
Sideroxylon foetidissum Jacq.	2			2			2			2			2	100
Spondias mombin L.[a]	8			8	1	2	7		2	5			5	50
Tabebuia heterophylla (DC.) Britt.[a]	30			30		2	28	1	4	25			25	80
Tetrazygia angustifolia (Sw.) DC.	1			1			1			1			1	100
Tetrazygia eleaegnoides (Sw.) DC.	10	2	3	9		2	7	1	4	4		2	2	10
Torrubia fragrans (Dum.-Cours.) Standl.	239	12	9	242	15	20	237	17	30	224	14	13	225	72

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Appendix B (continued)

Stem density by species and year on 16 plots totaling 0.8 ha in the Cinnamon Bay watershed, St. John, U.S. Virgin Islands

Species	1983	1988			1993			1998			2003			Survival
	Total	Ingrowth	Mortality	Total	Ingrowth	Mortality	Total	Ingrowth	Mortality	Total	Ingrowth	Mortality	Total	1983–2003
														percent
Zanthoxylum martinicense (Lam.) DC.	8	208		8		2	6		2	4			4	50
Zanthoxylum monophyllum (Lam.) P. Wilson[a]	1			1		1								0
Subtotal	2,702	208	128	2,782	210	285	2,707	220	470	2, 457	206	206	2,457	64
Cinnamomum elongatum (Vahl ex Nees) Kosterm		1		1			1			1	31		32	
Eugenia fragrans (Sw.) McVaugh					10		10	1		11		1	10	
Ficus elastica Roxb. ex Hornem.[c]					1		1			1			1	
Capparis portoricensis Urban								1		1			1	
Carica papaya L.[c]								2		2		2	0	
Cinnamomum cassia Nees[c]								2		2			2	
Eugenia biflora (L.) DC.								7		7			7	
Eugenia sintenisii Kiaersk.								2		2			2	
Leucaena leucocephala (Lam.) de Wit1,[a c]								3		3	18		21	
Securinega acidoton (L.) Fawcett & Rendle[a]								3		3			3	
Ceiba pentandra (L.) Gaertn.[a]											1		1	
Total stems	2,702	209	128	2,783	221	285	2,719	241	470	2,490	256	209	2,537	

[a] Deciduous species.
[b] Species endemic to Puerto Rico and the Virgin Islands.
[c] Exotic species.

Weaver, Peter L. 2006. A summary of 20 years of forest monitoring in Cinnamon Bay watershed, St. John, U.S. Virgin Islands. Gen. Tech. Rep. IITF-34. San Juan, PR: U.S. Department of Agriculture Forest Service, International Institute of Tropical Forestry. 35 p.

St. John, and probably the Cinnamon Bay watershed, has a history of human use dating to 1700 B.C. The most notable impacts, however, occurred from 1730 to 1780 when sugar cane and cotton production peaked on the island. As agriculture was abandoned, the island regenerated in secondary forest, and in 1956, the Virgin Islands National Park was created. From 1983 to 2003, the staff of the International Institute of Tropical Forestry monitored 16 plots, stratified by elevation and topography, in the Cinnamon Bay watershed. The period included Hurricanes Hugo in 1989 and Marilyn in 1995 and a severe drought in 1994-95. In all years, plot tallies showed that from 55 to 60 percent of the stems were in height classes between 4 and 8 m, and 75 percent of the stems were in diameter at breast height (1.4 m above the ground; d.b.h.) classes between 4 and 10 cm. Stem density was greatest on the summit, followed by ridges, then slopes, and lowest in valleys. After 20 years, 65 percent of the original stems survived, with an average d.b.h. growth rate of 0.07 cm $year^{-1}$. Tree species abundances varied by topography and elevation within the watershed. In 1983, total aboveground biomass on all plots combined averaged 138.7 t ha^{-1}; by 2003, it had declined by nearly 7 percent. In 1983, biomass was greatest on the summit, intermediate on slopes and valleys, and least on ridges; by 2003, the quantities for all sites had converged except on the summit plot. In 1992, total aboveground productivity was estimated at 10.64 t ha^{-1} $year^{-1}$. Standing herbivory for leaves was 4.5 percent, and the herbivory rate was 4.6 percent per year. The standing crop of litter was 9.33 t ha^{-1}. Hurricanes had a major impact on forest structure and species composition. The trees impacted (snapped, uprooted, or standing dead) by Hurricane Hugo totaled 210 ha^{-1} after 10 months and 288 ha^{-1} after 19 months. The proportion of impacted stems differed by elevation, topography, aspect, and slope. Tree species with ≥ 20 individuals showed a difference in the proportion of impacted stems, ranging from as low as 0.6 percent for *Pimenta racemosa* (Mill.) J.W. Moore to as high as 22.8 percent for *Nectandra coriaceae* (Sw.) Griseb. In conclusion, the structure, species composition, and forest dynamics within the Cinnamon Bay watershed vary in time and space, and short-term observations characterize only a fragment of the watershed's continuously changing vegetational history. Monitoring of forest structure and dynamics should continue.

Keywords: Biomass; dry forest; monitoring; St. John, U.S. Virgin Islands; tree species.

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A Summary of 20 Years of Forest Monitoring in Cinnamon Bay Watershed, St. John, U.S. Virgin Islands

Spine