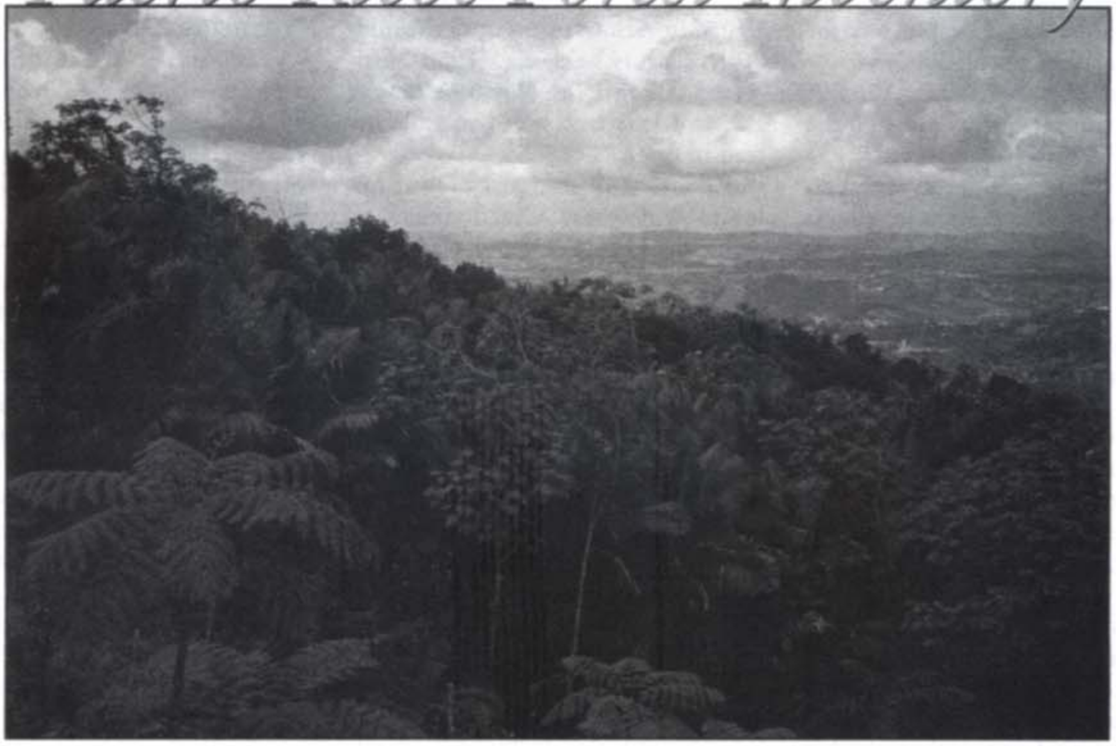
Puerto Rico's Forest Inventory



Adapting the Forest Inventory and Analysis Program to a Caribbean Island

Thomas J. Brandeis

ABSTRACT

Rapid changes in vegetation over short distances, high species diversity, and fragmented landscape challenge the implementation of the Forest Service's Forest Inventory and Analysis (FIA) program on Puerto Rico. Applying the hexagonal FIA grid as used on the continental United States, the Forest Service is installing a new forest sampling and monitoring framework that incorporates previous inventory plots and has an expanded scope. However, an adequate description of Puerto Rico's diverse tropical forests requires additional sampling; the solution is to intensify the base systematic sampling grid. Ultimately, this framework can be used to monitor all vegetation and cover types on the island, plus fauna, soils, and air and water quality—in short, to create a comprehensive, long-term natural resources inventory and monitoring network.

Keywords: FIA; international forestry

The Forestry Research Act (McSweeney-McNary) of 1928 required the USDA Forest Service to "make and keep current a comprehensive inventory and analysis of the present and prospective conditions and requirements for the renewable resources of the forest and rangelands of the United States and cooperate with the appropriate officials of each State, territory, or possession of the United States" (Resources Planning Act of 1974, PL 93-378). The Forest Service is therefore responsible for inventorying not only the forests of the continental United States, Alaska, and Hawaii but also the islands of Guam, the Republic of the Marshall Islands, American Samoa, the Commonwealth of the Northern Marianas, the Federated States of Micronesia, Palau, the US Virgin Islands, and Puerto Rico.

Under direction of the Agriculture Research, Extension, and Education Reform Act of 1998, the USDA Forest Service's Forest Inventory and Analysis (FIA) program has developed a nationally standardized sampling scheme and a core set of plot-level inventory and monitoring variables. However, these national protocols do not always lend themselves to work on tropical islands, leading to concerns about the effectiveness and utility of the national

***Above:* The Puerto Rico landscape from the Ruta Panoramica, a highway that runs along the central mountains. The Caribbean Sea is in the distance.**

sample design and variable sets for these areas (Willits et al. 2000).

The challenges to adapting the FIA program's current methodology to the forests of Puerto Rico are three:

1. Maintaining continuity with previous inventories to capture long-term tree growth information and 20 years of land-use change, and incorporating forest health monitoring (FIA Phase 3) pilot study plots.

2. Expanding inventory scope to include and adequately sample all forest types, including rare forests that are of limited extent, while minimizing sampling error.

3. Developing a framework that easily incorporates additional inventories at varying sampling intensities that address specific questions and needs.

For the latest forest inventory of Puerto Rico, the FIA program's standard protocols were adapted to create a comprehensive forest inventory that meets the requirements of statistical rigor, scientific validity, and customer information needs.

Puerto Rico's Forests

Based on the observations of early explorers and historians, the island of Puerto Rico (total area of 890,000 hectares [ha]) was heavily forested prior to European settlement (Wadsworth 1950). The island's diverse forests, comprising more than 500 native species, reflect its physiography (Little and Wadsworth 1995) and location (between 18°31′ and 17°55′ N latitude and 65°37′ and 67°17′ W longitude). Marked moisture and elevation gradients result in changes in forest species composition and structure over relatively short distances.

Pre-Columbian populations cleared land for shifting agriculture and harvested trees, but their impacts on the forests were relatively minor (Domínguez-Cristóbal 1989). European impacts on the forest began in 1505, when Spanish sailors introduced goats and pigs (Domínguez-Cristóbal 1989). Forest clearing for timber, fuelwood, charcoal, and agriculture followed colonization in the early 17th century and continued unabated in various forms until the mid-20th century. Koenig (1953) estimated that in 1951 only 6 percent of Puerto Rico's land area was still covered in forest.

Reversion to secondary forest followed widespread abandonment of agricultural lands during the latter half of the 20th century. By 1990, forest covered 32 percent of the island (Franco et al. 1997). These secondary forests include 117 naturalized exotic species whose ecological impacts are still unclear (Francis and Liogier 1991). The present-day Puerto Rican landscape is a fragmented, dynamic mosaic of shifting land uses—predominantly continued agricultural abandonment, reversion to secondary forest, and urban expansion. Forest Service inventories have now begun to document the land-use changes and forest recovery on Puerto Rico.

Previous Inventories

1980 survey. The first forest inventory in Puerto Rico, completed in 1980, had the primary objective of assessing the timber production potential of the island's forests (Birdsey and Weaver 1982). Across the island, 978 permanent sampling points were established along a square systematic grid at a spacing of 3 square kilometers (900 ha per square) (Birdsey and Weaver 1982). This intensity was derived from sampling errors estimated from earlier fieldwork (Birdsey and Weaver 1982). An island-wide estimate of forest area for commercial and noncommercial areas was made from aerial photographs, although coverage was incomplete.

Permanent plots were installed in two of the six Holdridge life zones on the island (as described by Ewel and Whitmore 1973) that were considered

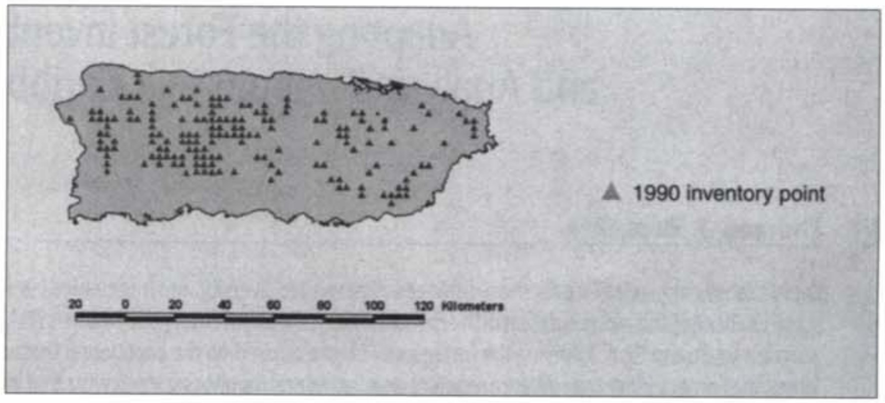


Figure 1. **Preexisting inventory plots in Puerto Rico from 1980 and 1990.**

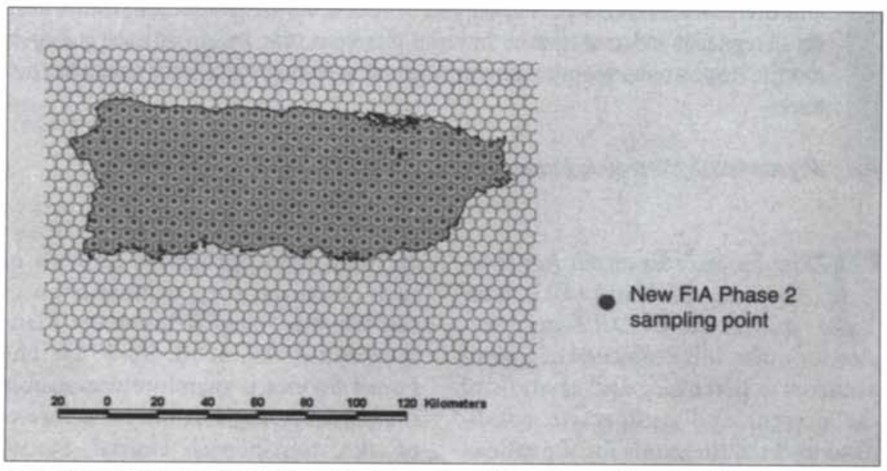


Figure 2. **Base hexagonal sampling grid with new forest inventory and forest health monitoring points.**

FIA inventory crew members measure saplings in a regeneration microplot.

to have the potential for commercial production: the subtropical moist and subtropical wet forests (Birdsey and Weaver 1982). These two life zones included 437 inventory points, 133 of which were forested. The two life zones and four soil categories were used to stratify the plots. Areas excluded from the survey included public forests, floodplains, urban areas, mangrove forests, areas with poor soils, dry subtropical life zones, steep slopes (>60 percent), and critical watersheds with high rainfall.

1985 survey update. Five years after the first inventory, the Forest Service developed a more complete estimate of forest area from newer, more complete aerial photographs of the entire island. Aerial photographic estimation of forest cover was expanded to include all forest types except the montane forests and plantations. A subsample of the 1980 inventory plots installed in forest with commercial potential was revisited to update survey results (Birdsey and Weaver 1987). The data collected during the survey update was expanded to include erosion factors, hydrology, and operating conditions, as well as tree crown and branch measurements.

1990 resurvey. The island's forests were resurveyed in 1990 using the 1985 survey update's methodology. The 437 permanent plots installed in 1980 were revisited to confirm their status, and 167 forested plots were measured (Franco et al. 1997) *(fig. 1).* Field data collection followed the methodology of 1980, with the inclusion of nested 3.6-meter fixed-radius regeneration subplots (Franco et al. 1997).

New Sampling Design

In 2001, a new hexagonal sampling grid was generated over the entire island of Puerto Rico that will serve as the framework around which future forest inventories can be built. The new grid is based on the FIA grid used on the continent, which is approximately one sampling point every 2,400 ha (370 hexagons island-wide) *(fig. 2).* Note that the sampling points are located at the center of each hexagon. However, the actual plot location will be "wobbled" a random azimuth and distance (between 100 and 600 meters) from the hexagon's center to protect landowners' confidentiality.

As a pilot study, forest health monitoring (FIA Phase 3) plots were installed at 55 locations on the new systematic grid (described below) across the entire island in 2001. Based on the sampling intensity of the 1980 and 1990 forest surveys, a sampling point was systematically generated for every 800 ha for 1,110 sampling points island-wide. A Phase 3 plot was installed at every 16th point to produce a forest health monitoring network. Information on crown condition, coarse woody debris, soils, and erosion was collected, along with FIA Phase 2 forest inventory data.

Continuity with previous inventories. If none of the previous inventory plots fall within a hexagon, a new plot is measured at the hexagon's center. If there is an old inventory plot in the hexagon, that plot is remeasured. When two or more older inventory plots fall within the same hexagon, the plot closest to the hexagon's center is retained and the others excluded from the sample. Phase 3 plots have the highest priority for retention when there are multiple old inventory plots in a hexagon, so all Phase 3 plots installed in 2001 will be included in the final, island-wide sample. The 167 forested survey plots installed in 1980 and 1990 contain valuable data that give insight into long-term forest growth and changes in land use and species composition. However, at standard FIA sampling intensity, only 108 plots from the previous surveys will be remeasured, a loss of 35 percent discarded in favor of new Phase 3 plots or other old plots. A sampling grid comprising 800-ha hexagons, triple the standard FIA sample and approximately the previous surveys' intensity, would be required to maintain almost all old plots (2 to 5 percent lost). *Figure 3* presents the framework of Puerto Rico's forest inventory and health monitoring plot network.

Expanding the inventory's scope, sampling intensity, and error. Given the complexity of Puerto Rico's forests, expanding the inventory's scope while maintaining an adequate sample size for all forest types is problematic. Helmer et al. (2002) mapped 21 well-defined woody vegetation formations, several of which cover less than 10,000 ha. As with any inventory project, there will have to be a balance between the number of forest types we hope to accurately describe and the number of plots we can afford to install. To help guide that decision, I used the 1990 survey results to explore how expanding the inventory's scope while decreasing its intensity may affect the sampling errors for two of Puerto Rico's six forested life zones. Each square grid in the 1980 and 1990 surveys had an area of 900 ha, whereas each hexagonal grid in the present FIA inventory has an area of 800 ha.

First, I recalculated mean number of trees per hectare, basal area per hectare, and tree volume per hectare, with associated standard errors, for trees with dbh >12.5 cm *(table 1, p. 13)* from the 167 inventory plots measured in 1990. Note that the sampling errors for the entire 1990 sample are different from those presented in Franco et al. (1997). The secondary forest category presented here includes the 1990 forest types of secondary forest, young secondary forest, and reversion (to forest from agriculture). Inclusion of these younger successional stages and partially forested plots decreased the number of stems, basal area, and volume overall. Data from two plots that were classified as xeric forest were excluded from the analysis because their species composition and structure differ greatly from the rest of the sampled points, giving a total sample size of 165 plots.

If only 37.5 percent of the plots are measured in the newer sampling grid, the new standard errors can be approximated by multiplying the full sample's standard errors by $\{1/\sqrt{(0.375)}\}$, or 1.63 (Steel and Torrie 1980). These values should approximate the sampling errors that can be expected under the standard FIA sampling grid for secondary forest and coffee shade in the tropical moist and wet life zones *(table 1)*.

As would be expected, there was an overall increase in sampling error as the sample size was reduced. Sampling errors for each parameter in all forest types combined, secondary forest, and abandoned coffee shade increased from around 7 to 10 percent of the mean for the full sample to 12 to 15 percent of the mean for the reduced sample, an increase of 39 percent. Sampling errors for the smallest area described here, active coffee shade with only 7,010 ha, began with a sampling error of 16 to 21 percent of the mean and increased to 26 to 34 percent of the mean when the sample size was reduced.

With single-intensity sampling, mean estimations for active coffee shade were made with only two samples. Helmer et al. (2002) estimate that there are five natural forest types

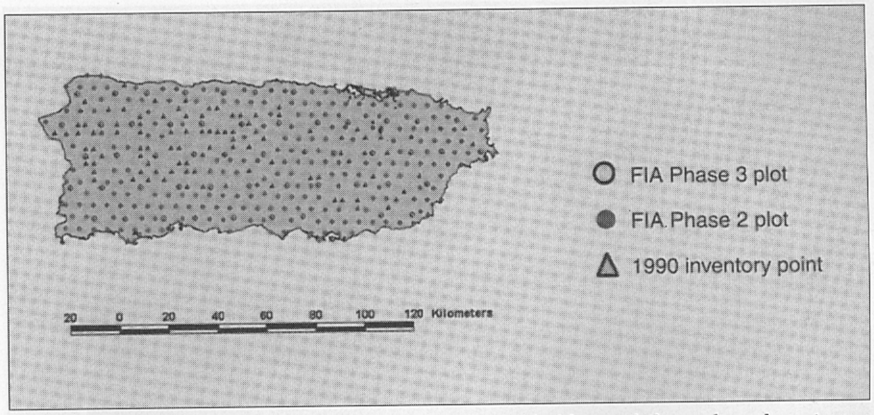


***Figure 3.* Final forest inventory and monitoring sampling grid with preexisting and new inventory plots combined.**

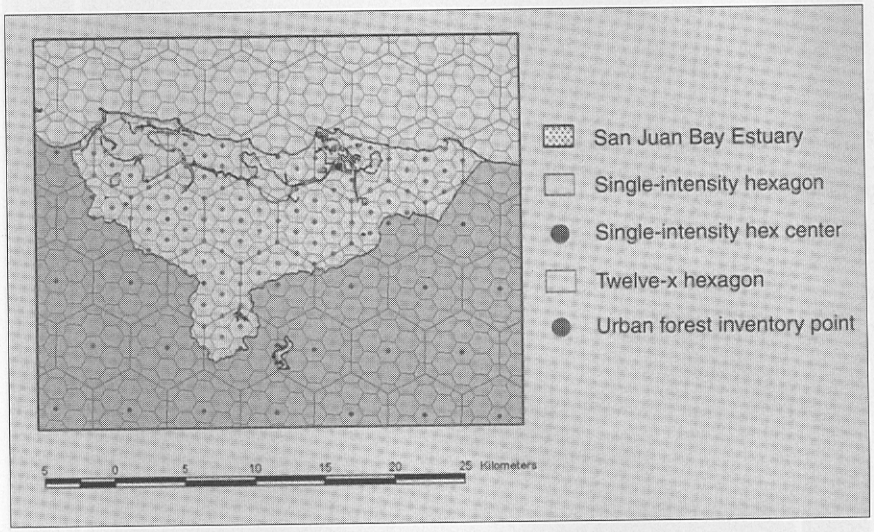


***Figure 4.* San Juan Bay Estuary and 12-fold intensified urban forest inventory plot network.**

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Two inventory crew members measure and mark a plot witness tree.

in Puerto Rico with an extent less than 8,000 ha. Forest types that occupy such a limited area will certainly be undersampled, if sampled at all, with the single-intensity grid. Even at triple intensity, it could be argued that the sample size would be inadequate for forest types represented by less than 10,000 ha.

Incorporating inventory intensifications. To build a flexible sampling framework, we chose to intensify the base FIA sampling grid to accommodate inventory intensifications and future questions. Working from a standard FIA hexagonal grid, three- and 12-fold intensifications were produced to support the first four inventory intensifications currently under way.

Additional inventory points are being added in forest types that were not adequately sampled by the standard FIA grid because they occupy small areas on the island or have a very fragmented distribution. Unique forests grow on 11,518 ha of serpentine parent material found in the southwest of the island, and lower montane wet evergreen forest (cloud forest) occupies a discontinuous area of 25,454 ha at upper elevations. Additional points have been randomly selected from the 12 places where the intensified grid intersects these areas to give at least 10 to 15 plots in each of these forest types.

A similar intensification is being used to quantify the urban forest extent, structure, health, and services within the critical 25,000-ha San Juan Bay estuary watershed. The watershed, part of the EPA's National Estuary Program, encompasses San Juan Bay, several large lagoons and channels, extensive wetlands, and mangrove forest; it is home to 622,000 people (Webb 1998, cited in Villanueva et al. 1999). The 12-fold intensification grid gave 109 points within the watershed, which fit well within the minimum recommended sample size of 100 plots based on urban forest inventory experiences in continental cities (Nowak et al. 2001) *(fig. 4)*.

On a larger scale, another priority for inventory intensification is the northern karst belt, a 142,544-ha area in the northwestern part of the island (Lugo et al. 2001). Karst landforms are the product of chemical dissolution of limestone bedrock that often forms spectacular, rugged topography. The northern karst belt is biologically and geologically unique, and efforts are under way to transfer significant portions to the public domain; a comprehensive inventory of the forest resources is therefore especially timely and relevant (Lugo et al. 2001). A triple intensification of the base FIA hexagonal grid was used to generate an additional 104 sampling points in the northern karst belt.

Outlook

An island-wide inventory was required because of the need for information on more questions than those addressed in the past. However, adequately sampling Puerto Rico's diverse forests would not be possible without substantial intensifications implemented outside the FIA program. The FIA base grid provides a solid foundation on which to build. Intensifying the hexagonal grid to zoom in and zoom out according to the demands of

Table 1. Tree density, basal area, and volume of forest types surveyed in 1980–1990 inventories, by sampling intensity.

			Original sampling intensity		New base sampling intensity	
Forest type	Parameter	Mean	*n*	% SE[1]	*n*	% SE[1]
All forest (143,933 ha)	Trees/ha	189.10	165	7.91	63	12.9
	BA/ha	8.48	165	7.55	63	12.3
	Volume[2]	62.21	165	8.02	63	13.1
Secondary (113,558 ha)	Trees/ha	238.79	94	9.12	35	14.87
	BA/ha	9.64	94	8.92	35	14.52
	Volume[2]	69.08	94	9.96	35	16.13
Abandoned coffee shade (23,365 ha)	Trees/ha	238.75	33	8.10	12	13.20
	BA/ha	13.41	33	8.05	12	13.12
	Volume[2]	101.87	33	7.84	12	12.78
Active coffee shade (7,010 ha)	Trees/ha	175.22	5	16.0	2	26.1
	BA/ha	10.17	5	18.8	2	30.6
	Volume[2]	81.92	5	21.1	2	34.4

[1]*Percent SE (sampling error) is computed by dividing the expected sampling error by the mean.*
[2]*Total volume is expressed in cubic meters per hectare and includes all sound and cull stem volume, branches, forks, and above-bole sections for all tree classes.*
Source: Area estimates from Franco et al. (1997).

the data being collected is, and will continue to be, a vital part of the sampling framework's design. Although the new sampling design attempts to maintain continuity with the previous surveys to allow examination of long-term trends in tropical forest growth and dynamics, the elimination of more than a third of the previous inventory plots represents a significant loss of data on change.

Puerto Rico now has an island-wide forest inventory and monitoring framework with flexibility, longevity, and a rigorous statistical design. The future holds further challenges for the island's inventory and monitoring program. Puerto Rico's increasing rate of urbanization means more emphasis will be placed on describing urban expansion into forested land and the growing urban forest. It is envisioned that the inventory and monitoring program can be expanded into all vegetation and cover types on the island, with the logical next step being the sampling of forest types of small extent, and then all understory vegetation at existing FIA plots. Further expansion on this framework to include invertebrate and vertebrate surveys, soils maps, and air and water quality data could form the basis for a comprehensive, long-term natural resources inventory and monitoring network.

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