ESTIMATING MANGROVE IN FLORIDA: TRIALS MONITORING RARE ECOSYSTEMS

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Abstract—Mangrove species are keystone components in coastal ecosystems and are the interface between forest land and sea. Yet, estimates of their area have varied widely. Forest Inventory and Analysis (FIA) data from ground-based sample plots provide one estimate of the resource. Initial FIA estimates of the mangrove resource in Florida varied dramatically from those compiled by other sources. Estimates of mangrove forest in Florida ranged from FIA's less than 100,000 acres to nearly 600,000 acres elsewhere. FIA discovered inherent measurement difficulties, accessibility constraints, and adverse working conditions affecting accurate sampling and estimation of the resource. Reconciliation of these issues produced improved estimates. However, disparity with other estimates remains. FIA concluded that accurate assessment of peripheral margin-like resources, such as mangrove, must include methods used to sample any spatially limited resource of interest. Current FIA estimates show 238,000 acres of mangrove forest type in Florida with a sampling error of 15.48 percent.

Since Forest Inventory and Analysis (FIA) first inventoried the forests of Florida in 1936, mangroves were treated as noncommercial species and considered unproductive forest land. This designation carried through the 1949, 1959, 1970, 1980, 1987, and 1995 inventories of the State. However, FIA revised the inventory for the new millennium and switched from periodic inventory measurement to collecting field data on an annualized basis. In Florida, this process began in 2001. One important aspect of the new inventory was that mangrove species were now tallied as trees and incorporated into the inventory data. Thus, for the first time, as the inventory progressed, data were available to describe Florida's mangrove resource.

In Florida, four species of mangrove were measured: red mangrove (*Rhizophora mangle)*, black mangrove (*Avicennia germinans)*, white mangrove (*Laguncularia racemosa)*, and buttonwood mangrove (*Conocarpus erectus)*. Many differences between the individual mangrove species exist; for example, the reds are generally most seaward and the buttonwoods most landward. However, for the purposes of this research, they are considered collectively.

Analysis of early mangrove data revealed dramatic disparities with estimates from other sources. The 2004 and 2007 (Fig. 1) FIA estimates of less than 100,000 acres statewide versus other estimates approaching 600,000 acres (Florida Fish and Wildlife Conservation Commission Fish and Wildlife Research Institute 2009, Department of Environmental Protection Florida Marine Research Institute 2002, Johnston and others 1995) prompted questions regarding potential differences in sampling methods as well as forest type definition. The 2004 estimates were based on 60 percent of the sample design plots being captured and, despite algorithmic expansions, produced the lowest mangrove estimates. By 2007, the entire plot sample had been measured, but the improved estimates were still far below those from other sources. Evidently, the high proportion of probable mangrove samples not visited due to access denial and adverse condition field calls were not represented in the data output. FIA methods were largely ground-based samples with expansion factors, whereas other sources were largely aerial photography and satellite imagery based. Furthermore, the FIA forest land definition required a minimum of 1 acre in size with a minimum width of 120 feet to meet the threshold to be classified as forest, precluding small pockets or narrow strips of trees from the estimate.

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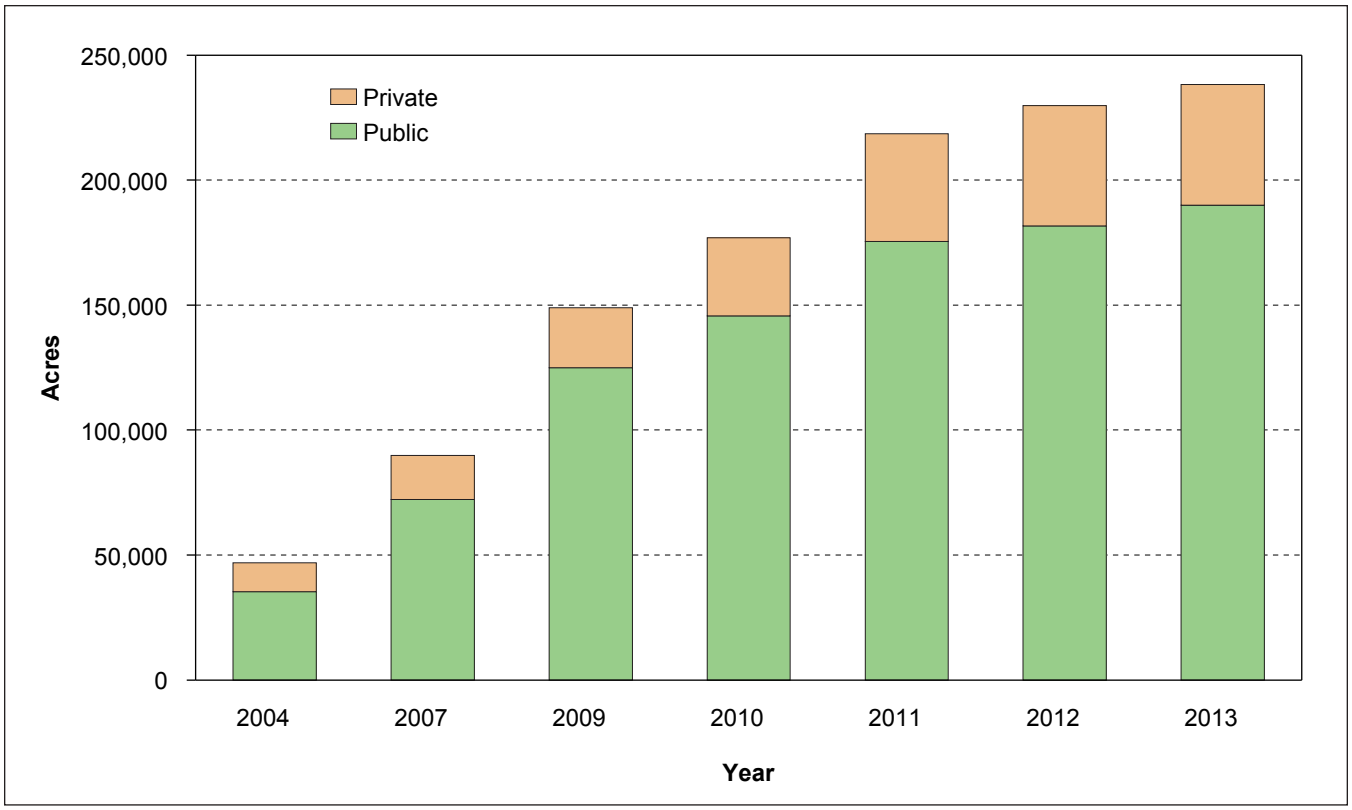

Figure 1—Area of mangrove forest type on forest land in Florida by major ownership group and year.

However, these explanations were insufficient to resolve the entire gap in mangrove area estimates. Subsequent internal investigation discovered shortcomings in the FIA sampling methods. Since the mangrove forest type typically occurs at sea level and within tidal zones, the resulting peripheral distribution along coastlines and tidally influenced drainages presented inherent difficulties to accurate sampling and estimation of the resource. Issues involving accessibility and adverse conditions encountered actually inhibited and prevented measuring many of the sample plots. Many were reported as hazardous or access denied. Having a large percentage of nonsampled plots is known to potentially lead to underestimation of forest attributes (Patterson and others 2012).

FIA evaluated the equipment used by field personnel to access mangrove forests and found the traditional watercraft used to be inadequate to reach these shallow, tidal influenced zones. Acquisition of a kayak for these purposes immediately improved accessibility and permitted the measurement of additional samples previously unmeasured.

Since many of the mangrove forests exist on public lands classified as reserved, reinforced memorandums of understanding (MOUs) were acquired to permit access across sensitive lands administered by other agencies. This added cooperation permitted the measurement of additional samples as well.

Although addressing these issues remains a work in progress, partial reconciliation of the unmeasured samples produced increased estimates of the mangrove resource evident beginning with year 2009 and forward (Fig. 1). Also evident is the increase in the mangrove estimate each year as additional annual inventories remeasured the 2007 plot design and eventually recaptured the full sample by 2013. Since 2007, the FIA estimate of mangrove in Florida has more than doubled. Mangroves can be a fragile resource regarding impacts from hurricanes and coastal urbanization, and they are not known for rapid

growth or colonization; therefore, most of the increase in the FIA estimates can be attributed to the changes in sampling methods and reduction of the nonsampled rate. In 2013, 80 percent of the mangrove area existed on publicly owned lands. Although the mangrove area estimate was enhanced on both public and private lands between 2007 and 2013, it is clear that most of the apparent gain was accomplished on public land, where efforts to improve cooperation through MOUs with other agencies contributed.

The subtropical trait of the mangrove forests generally restricts their occurrence to the southern end of the Florida peninsula. Table 1 shows the distribution of the mangrove forest type by survey unit. This table corroborates that 85 percent of Florida's mangrove forest type does exist in the South survey unit of the State. Enhancements in the FIA sampling methods improved estimates to the largest extent in the South survey unit, where large public holdings exist. Noteworthy is the 2010 and onward capture of mangrove forest in the Northeast survey unit. If this measurement were for a more prevalent tree species, this could be construed as evidence of species range extension. However, it is most likely evidence of results from improvements to the FIA sampling methods for mangrove.

Estimating the population of mangrove trees independently of area estimates was done to gain another perspective on the mangrove resource. Population estimates capture mangroves from all forest conditions, including those not classified as mangrove forest type (Fig. 2). The changes in the population of mangrove trees actually emulated those of the area of mangrove forest type. Again, the estimates more than doubled from 2007 to 2013. The tracking similarity of the population estimates with that of the area estimates stems from the tendency of mangroves to occur in homogenous stands due to the wet and brackish to saline conditions not tolerated by many other tree species.

Table 1—Area of mangrove forest-type on forest land in Florida by survey unit, major ownership group, and year

Survey unit and major ownership group	2004	2007	2009	2010	2011	2012	2013
				acres			
Northwest							
Public	0	0	0	0	0	0	0
Private	0	0	0	0	0	0	0
All	0	0	0	0			
Northeast							
Public	0	0	0	9,118	9,118	9,406	9,453
Private	0	0	0	0	0	0	0
All	0	0	0	9,118	9,118	9,406	9,453
Central							
Public	19,018	13,109	20,146	20,088	19,922	19,572	19,656
Private	0	0	0	0	6,169	5,989	6,019
All	19,018	13,109	20,146	20,088	26,091	25,561	25,675
South							
Public	16,270	59,050	104,756	116,430	146,398	152,725	160,893
Private	11,568	17,700	24,109	31,246	36,911	42,095	42,161
All	27,838	76,750	128,865	147,676	183,309	194,820	203,054
State							
Public	35,288	72,159	124,902	145,636	175,438	181,703	190,002
Private	11,568	17700	24,109	31,246	43,080	48,084	48,180
All	46,856	89,859	149,011	176,882	218,518	229,787	238,182

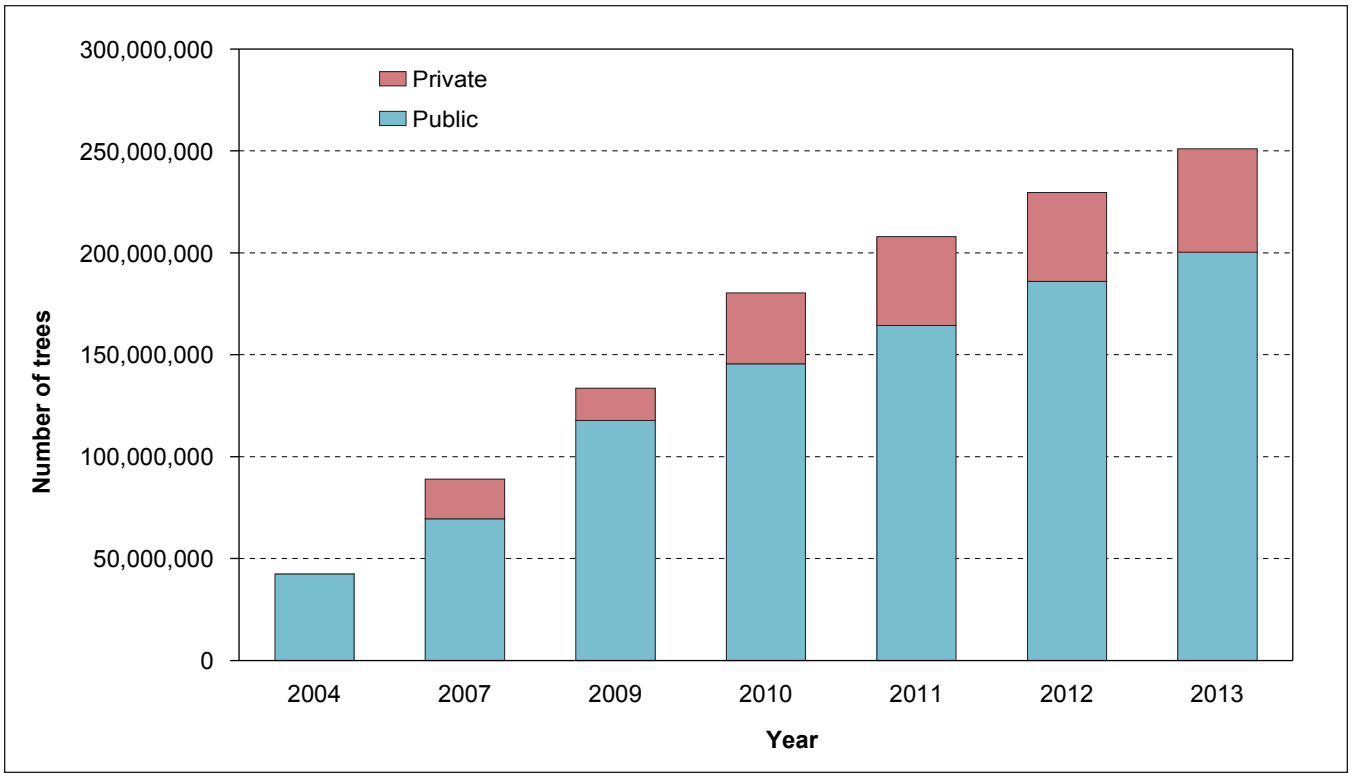

Figure 2—Number of live mangrove trees at least 1 inch d.b.h. on forest land in Florida by major ownership group and year.

The population of mangrove trees by survey unit closely tracks that of the forest type distribution (Table 2). In 2013, the South survey unit accounted for 83 percent of the State's mangrove trees. Similar to forest type, mangrove trees were measured in the Northeast survey unit beginning in 2010 and onward.

Figure 3 reveals the weaknesses and the progress FIA has made in improving estimates of the occurrence and distribution of mangrove trees in Florida. The map shows the location of samples that recorded one or more mangrove trees present. From the 2001 inception of mangroves recorded as trees, the 2004 map (Fig. 3A) shows the weakness of a partial sample and the flaws in accessibility issues affecting the data. The 2007 map (Fig. 3B) shows the full sample measured, but accessibility issues left the estimate inadequate. By 2010 (Fig. 3C), the map shows the impact of improved access methods and a better picture of the mangrove resource. By the full remeasurement of the 2007 sample in 2013 (Fig. 3D), the map shows an improved distribution. However, some gaps still appear in known areas of mangrove, such as those around Cape Canaveral and within Everglades National Park. The fact that these areas appear to remain undersampled indicates that mangroves are still being underestimated.

The gains in achieving a more accurate estimation of the mangrove resource in Florida have primarily resulted from improved access methods. The percentage increases between survey years shown in both figures and both tables appear to be diminishing. Considering the remaining disparity with other estimates leads to the premise that either other sources have overestimated the mangrove resource or FIA has to further refine the sampling method for this rare ecosystem. Ultimately, FIA has learned that other issues regarding spatially restricted resources need to be addressed to further improve its estimation. Solutions identified involve sample intensification and strata development for mangrove. FIA has concluded that more accurate assessment of the mangrove resource must include sampling methods like those employed for estimates of individual islands, singular ownerships like national forest, inclusions, and any spatially limited resource of interest.

Table 2—Number of live mangrove trees at least 1 inch d.b.h. on forest land in Florida by survey unit, major ownership group, and year.

Survey unit and major ownership group	2004	2007	2009	2010	2011	2012	2013
				number			
Northwest							
Public	0	0	0	0	0	0	0
Private	0	0	0	0	0	0	0
All	0	0	0	0	0	0	0
Northeast							
Public	0	0	0	11,391,626	11,391,626	11,751,546	11,810,674
Private	0	0	0	0	0	0	0
All	0	0	0	11,391,626	11,391,626	11,751,546	11,810,674
Central							
Public	17,995,717	13,425,064	24,967,830	23,083,166	22,825,838	22,301,343	22,046,632
Private	0	0	0	0	10,284,787	9,984,987	10,036,005
All	17,995,717	13,425,064	24,967,830	23,083,166	33,110,625	32,286,330	32,082,637
South							
Public	24,369,169	56,099,499	92,832,692	111,036,320	130,110,212	151,918,301	166,330,362
Private	69,617	19,457,355	15,796,261	34,752,196	33,343,348	33,655,103	40,784,461
All	24,438,786	75,556,854	108,628,953	145,788,516	163,453,560	185,573,404	207,114,823
State							
Public	42,364,886	69,524,563	117,800,522	145,511,112	164,327,676	185,971,190	200,187,668
Private	69,617	19,457,355	15,796,261	34,752,196	43,628,135	43,640,090	50,820,466
All	42,434,503	88,981,918	133,596,783	180,263,308	207,955,811	229,611,280	251,008,134

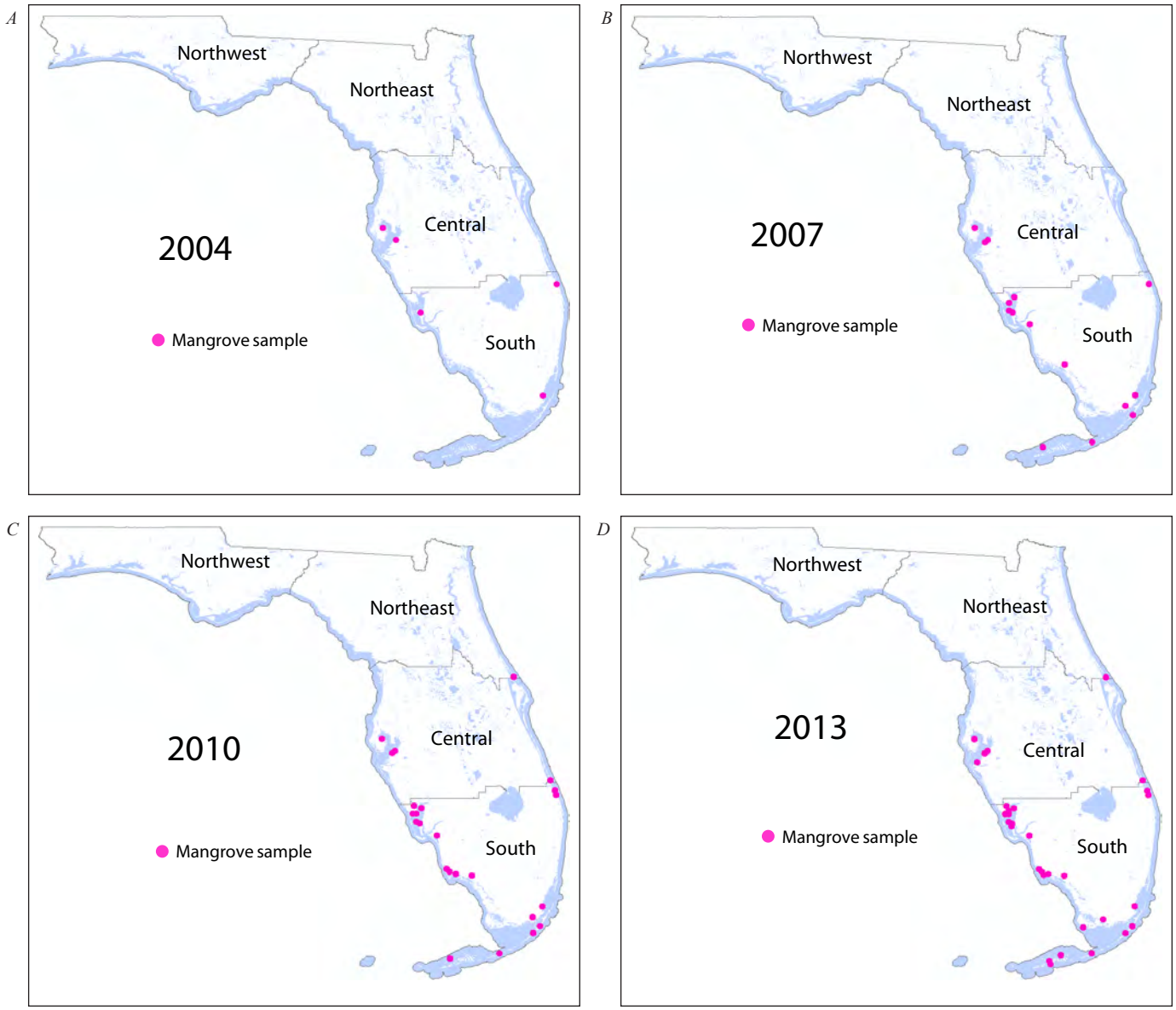

Figure 3—Mangrove sample locations and year (A) 2004, (B) 2007, (C) 2010, (D) 2013, Florida.

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