CHAPTER 6.

The Invasibility and Invadedness of Eastern U.S. Forest Types

Kurt H. Riitters
Kevin M. Potter

INTRODUCTION

Invasive species can cause a variety of undesirable changes in forest health simply by altering forest species composition (Fei and others 2014, Kettenring and Adams 2011, Mack and others 2000). In the Eastern United States, forest inventory data suggest that a large proportion of the rural forest area already contains harmful invasive species (Oswalt and Oswalt 2015, Oswalt and others 2015). To further inform forest managers about the relative risks of adverse impacts in different situations, the objectives of this study were (1) to compare forest types in the Eastern United States with respect to the likelihood that they contain invasive forest plants, and (2) to evaluate the relative roles of public versus private forest ownership for conserving the uninvaded forest area. Our goal was to identify forest types with relatively high or low probabilities of current invasion, and to highlight the forest types for which either public or private forest management could be focused on the conservation of the uninvaded area. The study area (fig. 6.1) included the 13 ecological provinces (Bailey 1995, Cleland and others 2007) that contain most of the temperate and boreal forest in the Eastern United States. Almost all of the forest in the region has been modified by humans, and approximately 40 percent of the original forest area has been converted to other land uses (Smith and others 2009). Approximately three-fourths of the forest area is privately owned (Oswalt and others 2014). Observations made on Forest Inventory and Analysis (FIA) plots have found 71 harmful invasive plant species (as defined by Ries and others 2004) (Iannone 2018[1]) on approximately one-half of the plots surveyed in the study area (Oswalt and Oswalt 2015, Oswalt and others 2015).

METHODS

The plot data alone do not provide a statistical basis for regional comparisons of invasions among forest types or owners because invasive plant observations have not been made at all FIA plots in the study area. Instead, to accomplish our objectives we integrated a plot-level model of forest plant invasions with a statistically representative sample of FIA plots. Invasibility (the probability that a forest plot has been invaded) was estimated from plot and landscape (neighborhood) attributes. Invadedness (the absolute areas of invaded and uninvaded forest) was estimated by using the statistical design of the forest inventory to scale up the plot-level invasibility estimates to all forest area. Comparisons of forest types and ownerships were then conducted by post-stratifying the estimates of invasibility and invadedness by forest type and land ownership.

[1] Personal communication. 2018. B. Iannone III, Assistant Professor, Residential Landscape Ecology, University of Florida, P.O. Box 110940, Gainesville, FL 32611-0940.

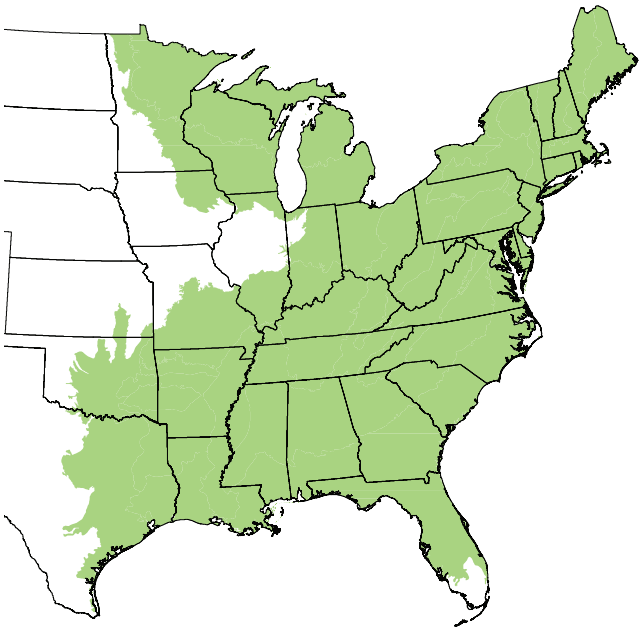

Figure 6.1—The study area encompassed most of the temperate and boreal forest in the Eastern United States. (Data source: Cleland and others 2007)

The plot-level invasibility model (similar to the model described by Riitters and others 2017) was developed using 23,039 FIA plots that had been surveyed for invasive plants between 2001 and 2011. To predict invasibility, the model employed logistic regression with independent variables measuring ecological province, site productivity, distance to a road, land use (590-ha neighborhood), and forest fragmentation (15-ha neighborhood). The model was applied to a representative sample of 82,506 FIA plots from the FIA database (O'Connell and others 2015) that constituted a statistical basis for forest area estimation circa 2006. Each plot record had an expansion factor that indicated the forest area represented by a given condition (defined by, among other attributes, site productivity, forest type, and ownership) (Bechtold and Patterson 2005). The expansion factors accounted for within-plot variability of forest type and ownership.

We applied the approach described by Riitters and others (2011) to extrapolate and stratify the plot-level estimates of invasibility. In the same way that a regional estimate of the area of a given forest type is the sum of the expansion factors for the plot records of that type, a regional estimate of a given level of invasibility was the sum of the expansion factors over all plots with that invasibility. Furthermore, since the product of invasibility and expansion factor estimates the area invaded, a regional estimate of invadedness (total area invaded) was the sum of those estimates over all plots. Finally, stratification was performed by defining subsets of plots according to forest type and/or ownership, and summing the area within each subset. There were 74 forest types (O'Connell and others 2015) after excluding those that were not included in the development

of the plot-level invasibility model.[2] The 17 FIA ownership categories (O'Connell and others 2015) were combined into four classes—Federal (government), State and local (government), private corporate, and private non-corporate.

For simplicity, we report area estimates without confidence intervals. The model correctly classified randomly drawn pairs of invaded and uninvaded plots 76 percent of the time, a reasonably good rate that was significantly ($X^2 = 232$; $p < 0.001$) better than chance. At a broader spatial scale, the regional pattern of predicted, per-plot invasibility was similar to the pattern of observed per-county invasion rates (Oswalt and Oswalt 2015). The FIA sample design has a target precision of ±3 percent for forest area estimates in the Eastern United States (Bechtold and Patterson 2005).

RESULTS AND DISCUSSON

We estimated that invasive forest plants occur on 51 percent of the 152 million ha of forest land considered in this study (table 6.1). Estimated invadedness ranged from 20 to 61 percent of total area of each of the 10 forest type groups recognized by FIA. Over half of the invaded area was contained in two forest type groups (loblolly-shortleaf pine, oak-hickory), in part because those two types were the most common types in the region.[3] The statistics in table 6.1 suggested broad geographical patterns resulting from the overall geographical distinctness of different forest types. For example, the spruce-fir, maple-beech-birch, and aspen-birch type groups tend to occur in the relatively remote portions of the study area, where invasion pressures are probably lower than elsewhere (Iannone and others 2015).

Table 6.1—Total area and invadedness of 10 FIA forest type groups in the Eastern United States, by percent area invaded

Forest type group	Total area[a]	Invadedness (area invaded)[a]	
	thousand ha	*percent*	*thousand ha*
Loblolly-shortleaf pine	23 225	61	14 096
Elm-ash-cottonwood	8442	59	5004
Oak-pine	11 319	58	6564
Oak-hickory	57 732	58	33 480
Oak-gum-cypress	9639	49	4702
Longleaf-slash pine	5256	43	2268
White-red-jack pine	3584	40	1420
Maple-beech-birch	18 936	34	6446
Aspen-birch	6925	32	2186
Spruce-fir	6124	20	1199
All forest type groups	151 180	51	77 365

[a] Sums may have rounding error.

[2] The following forest type groups were excluded because they were not included in the development of the invasibility model: other eastern softwoods; pinyon-juniper; exotic softwoods; other hardwoods; woodland hardwoods; tropical hardwoods; and exotic hardwoods. Also excluded were the Fraser fir forest type (because of small sample size), and data records lacking forest type information (including non-stocked plots).

[3] See O'Connell and others (2015) for scientific names of species, and fuller descriptions of forest types and forest type groups.

At the same time, invadedness varied substantially among forest types within forest type groups (table 6.2). For example, the loblolly-shortleaf pine type group had the highest percent invadedness (61 percent; table 6.1), but included two forest types that exhibited relatively low percent invadedness—pond pine (28 percent) and Table Mountain pine (21 percent). Conversely, within the spruce-fir type group that had the lowest percent invadedness (20 percent; table 6.1), invadedness ranged from 10 percent (red spruce-balsam fir type) to 36 percent (white spruce type). Invadedness also varied substantially among ownerships (table 6.3). Approximately one-third of public forest land was invaded, compared to 46 percent of private corporate forest and 59 percent of private non-corporate forest. The overall percent of forest invaded (51 percent) reflected the higher percentages in private ownerships that together comprised 81 percent of total forest area.

Since forest types are not distributed uniformly across ownerships (results not shown), the large variation of invadedness among both forest types and ownerships implies that conservation of uninvaded forest (or remediation of invaded forest) could potentially be focused on either public or private forest management depending on the forest type to be conserved (or remediated). To allow detailed examination of those possibilities, the invaded and uninvaded forest type areas by ownership are shown in figure 6.2. In figure 6.2, each row represents a single forest type. Along the

Table 6.2—Invadedness and area by forest type

Forest type group[a]	Forest type	Invadedness	Area
		percent	*thousand ha*
Loblolly-shortleaf pine	Virginia pine	70	836
	Loblolly pine	62	20 207
	Shortleaf pine	53	1329
	Spruce pine	48	18
	Pitch pine	34	305
	Sand pine	32	249
	Pond pine	28	264
	Table Mountain pine	21	18
Elm-ash-cottonwood	Silver maple-American elm	75	328
	Cottonwood	69	252
	Cottonwood-willow	69	145
	River birch-sycamore	68	759
	Sugarberry-hackberry-elm-green ash	63	3217
	Sycamore-pecan-American elm	62	1210
	Willow	53	445
	Red maple (lowland)	51	871
	Black ash-American elm-red maple	42	1217
Oak-pine	Virginia pine-southern red oak	67	867
	Eastern redcedar-hardwood	65	1053
	Loblolly pine-hardwood	63	5075
	Shortleaf pine-oak	59	1192
	Eastern white pine-northern red oak	48	1328
	Longleaf pine-oak	44	395
	Slash pine-hardwood	44	606
	Other pine-hardwood	38	803

continued

Table 6.2 (continued)—Invadedness and area by forest type

Forest type group[a]	Forest type	Invadedness	Area
		percent	*thousand ha*
Oak-hickory	Black walnut	75	259
	Sweetgum-yellow-poplar	71	3080
	Bur oak	69	265
	Cherry-white ash-yellow-poplar	66	2226
	Black locust	65	353
	Elm-ash-black locust	64	2280
	Yellow-poplar	63	1242
	Mixed upland hardwoods	62	8556
	Sassafras-persimmon	61	968
	White oak-red oak-hickory	60	17 967
	White oak	60	2833
	Yellow-poplar-white oak-northern red oak	57	3027
	Red maple-oak	57	1344
	Post oak-blackjack oak	55	4461
	Scarlet oak	52	419
	Chestnut oak-black oak-scarlet oak	44	3754
	Northern red oak	43	1862
	Chestnut oak	37	2122
	Southern scrub oak	37	713
Oak-gum-cypress	Swamp chestnut oak-cherrybark oak	60	559
	Sweetgum-Nuttall oak-willow oak	55	3866
	Overcup oak-water hickory	47	557
	Sweetbay-swamp tupelo-red maple	44	3288
	Baldcypress-water tupelo	41	968
	Baldcypress-pondcypress	34	371
	Atlantic white-cedar	27	32
Longleaf-slash pine	Slash pine	43	3942
	Longleaf pine	42	1313
White-red-jack pine	Eastern white pine	47	1377
	Eastern white pine-eastern hemlock	40	203
	Red pine	38	923
	Eastern hemlock	33	511
	Jack pine	31	570
Maple-beech-birch	Black cherry	57	554
	Hard maple-basswood	47	3760
	Red maple (upland)	32	1843
	Sugar maple-beech-yellow birch	29	12 778
Aspen-birch	Gray birch	42	131
	Aspen	34	4941
	Balsam poplar	34	358
	Pin cherry	26	122
	Paper birch	22	1373
Spruce-fir	White spruce	36	241
	Tamarack	24	733
	Northern white-cedar	23	1417
	Balsam fir	18	1509
	Black spruce	18	1212
	Red spruce	13	503
	Red spruce-balsam fir	10	508

continued

[a] Forest type group is shown for reference.

Table 6.3—Area and invadedness by ownership

Ownership	Total area[a]	Invadedness (area invaded)[a]	
	thousand ha	*percent*	*thousand ha*
Federal	13 641	35	4762
State and local	15 597	33	5173
Private corporate	35 124	46	16 052
Private non-corporate	86 818	59	51 378
All ownerships	151 180	51	77 365

[a] Sums may have rounding error.

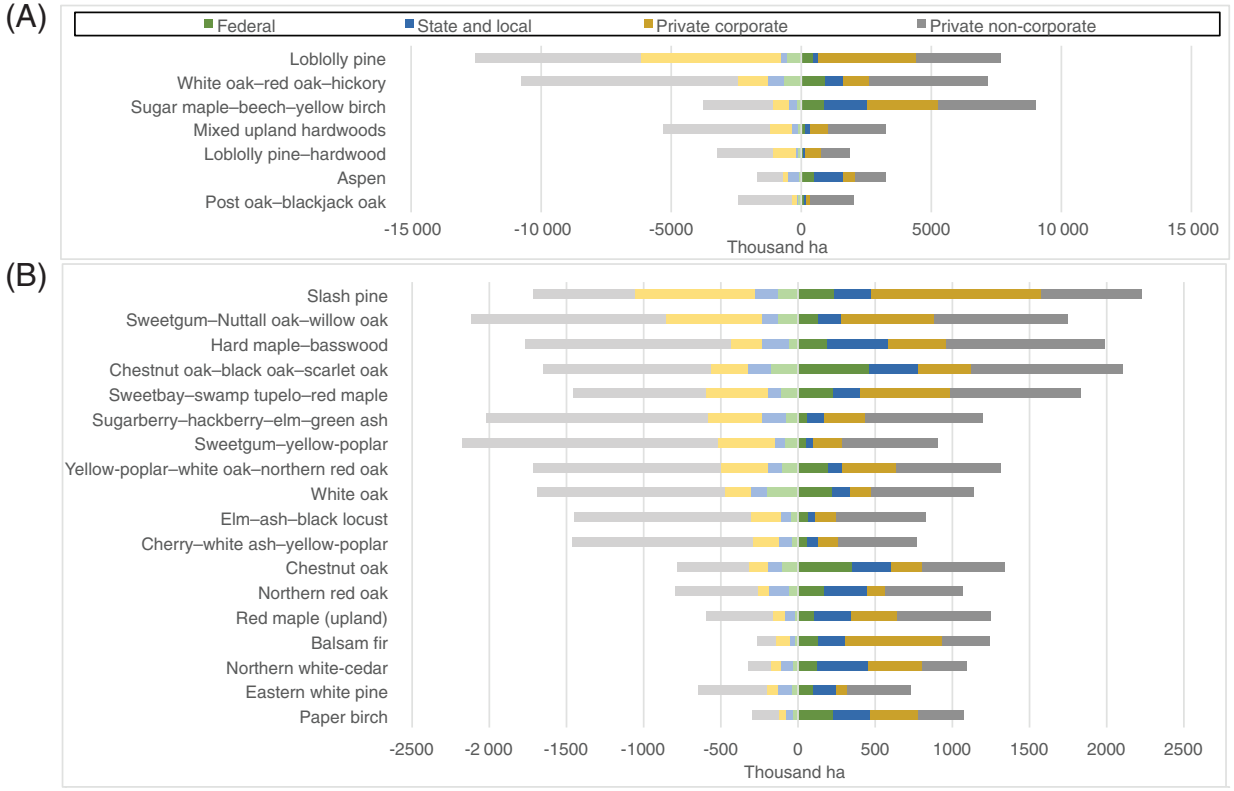

Figure 6.2—Summary of invaded and uninvaded forest area by forest type and ownership. The four panels (A, B, C, D) group forest types with similar total area; note the change in the horizontal axis scale between panels. Within each panel, forest types are sorted by decreasing total area. The invaded area is indicated by negative numbers (left of zero); the uninvaded area is indicated by positive numbers (right of zero). Colors indicate ownership, with lighter shades used for the invaded area. (Data sources: Forest Service Forest Inventory and Analysis; Riitters and others 2017)

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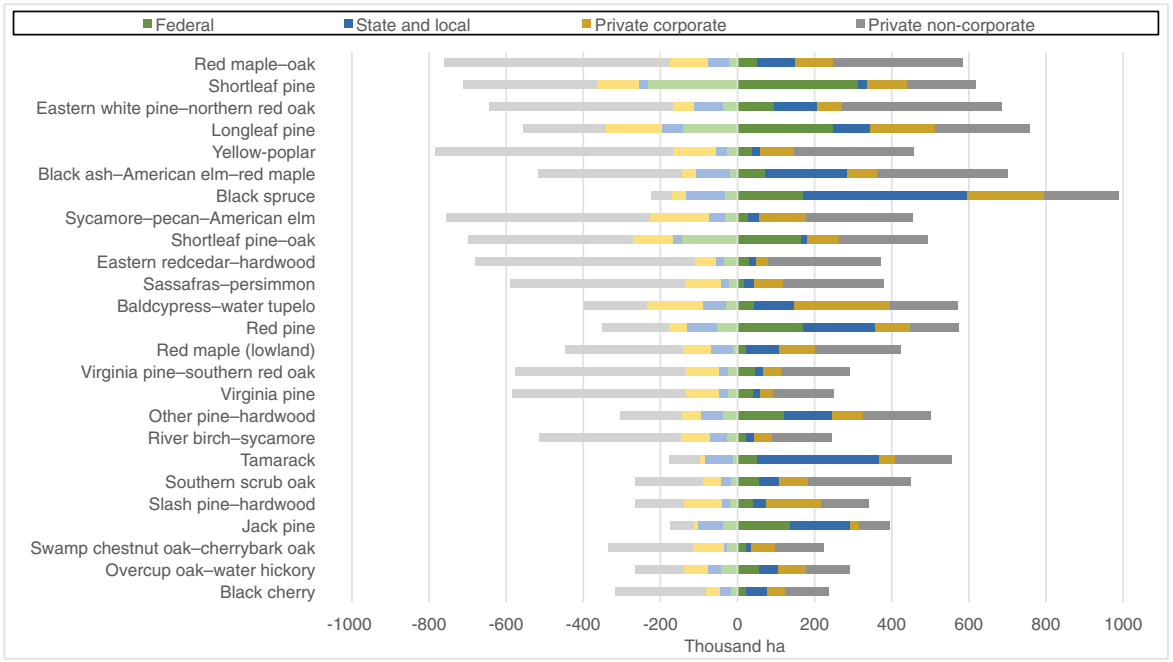

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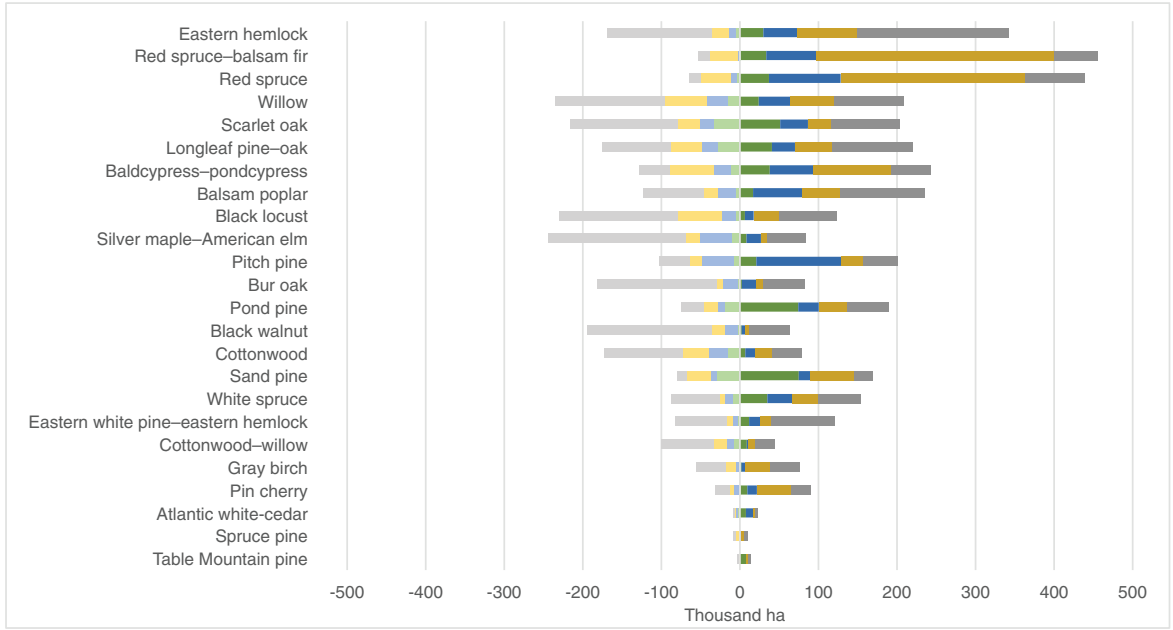

Figure 6.2 (continued)— Summary of invaded and uninvaded forest area by forest type and ownership. The four panels (A, B, C, D) group forest types with similar total area; note the change in the horizontal axis scale between panels. Within each panel, forest types are sorted by decreasing total area. The invaded area is indicated by negative numbers (left of zero); the uninvaded area is indicated by positive numbers (right of zero). Colors indicate ownership, with lighter shades used for the invaded area. (Data sources: Forest Service Forest Inventory and Analysis; Riitters and others 2017)

horizontal axis, the negative numbers indicate the estimated invaded area, and the positive numbers indicate the estimated uninvaded area. The four primary colors on each bar represent the four types of ownership, with lighter shades of those colors used for the uninvaded area. The scale of the horizontal axis changes between the panels of figure 6.2 to make it easier to see results for the less-common forest types. Using the loblolly pine type as an example (see first row of fig. 6.2A), and reading left to right, the invaded area includes 6.4 million ha of private non-corporate forest (light gray), 5.4 million ha of private corporate forest (light gold), 0.2 million ha of State and local forest (light blue), and 0.6 million ha of Federal forest (light green). The uninvaded loblolly pine type includes 0.5 million ha of Federal forest (green), 0.2 million ha of State and local forest (blue), 3.8 million ha of private corporate forest (gold), and 3.2 million ha of private non-corporate forest (gray).

To simplify the information and to address our immediate objective, that information was condensed to show the percent share of forest type area in public ownership (Federal, State, local) in relation to the percent of forest type area that was invaded (fig. 6.3). From the chart it is apparent that any strategy to mitigate or remediate conditions in highly-invaded (e.g., >2/3 of total area) forest types could be focused on private ownerships, because the public ownership share of the area of those forest types is typically <20 percent. At the other extreme, the conservation of relatively less invaded (e.g., <1/3 of total area) forest types could be focused on either public ownerships or private ownerships depending on the specific forest type. For example, conservation on public lands could focus on Atlantic white-cedar, jack pine, tamarack, and black spruce, while conservation on private lands could focus on red spruce, balsam fir, pin cherry, and red maple (upland).

CONCLUSIONS

We combined the statistical power of the FIA forest inventory system with the predictive power of a plot-level plant invasion model to compare forest types in the Eastern United States with respect to the likelihood that they contain invasive forest plants, and to evaluate the relative roles of public versus private forest ownership for conserving the uninvaded forest area. We estimated that approximately half of the total area of 74 forest types was invaded, and that invasions were almost twice as likely on privately owned land than on publicly owned land. Individual forest types varied widely in terms of historical invasions, but ownership alone was the deciding factor for the most-invaded forest types. There were no forest types for which a remediation focus on public land would be efficient, i.e., consideration of privately owned lands is probably necessary for controlling invasive plants. For the least-invaded forest types, there were several instances for which the efficiency of a conservation focus on either public or private land would depend on the forest type. While a regional analysis can suggest forest management strategies such as these, actual implementation necessarily depends on local conditions.

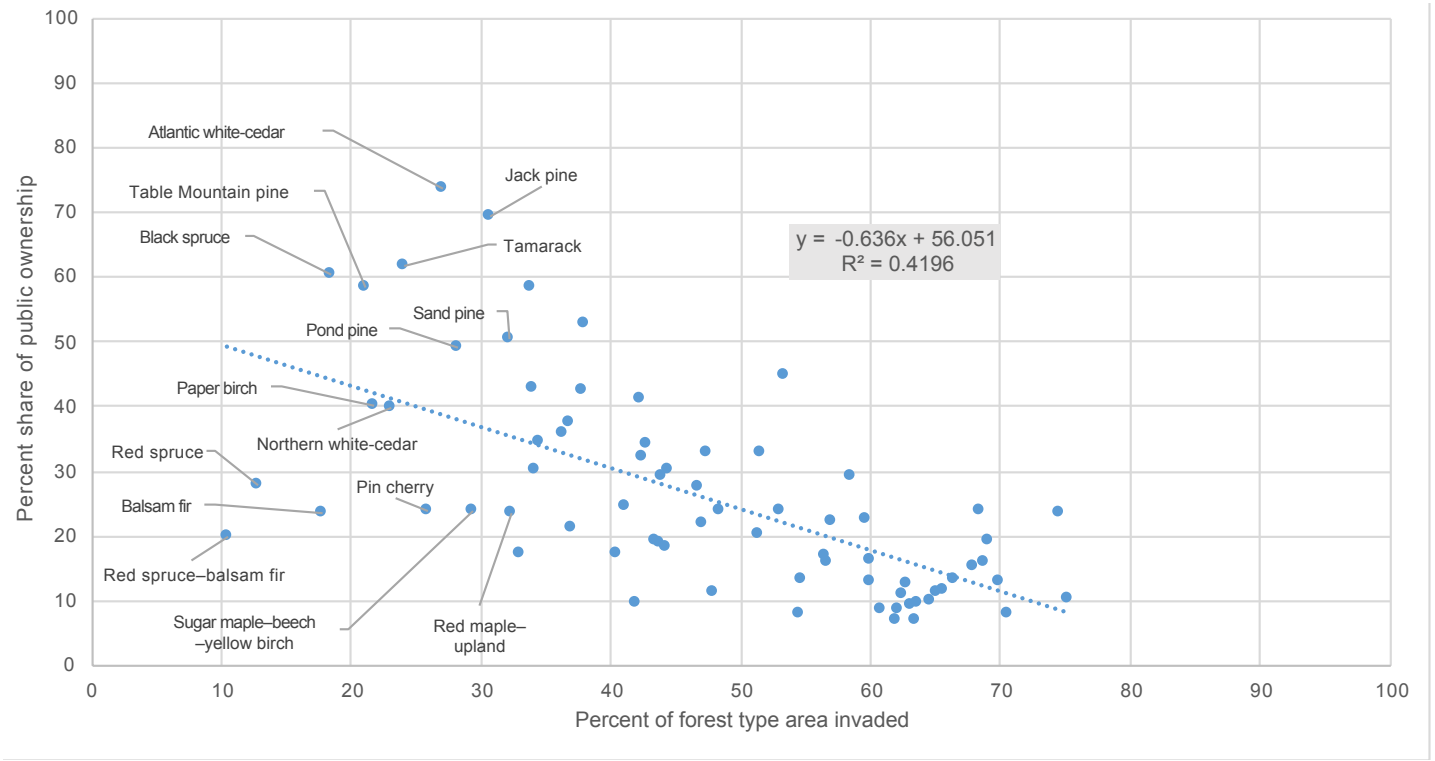

Figure 6.3—Share of public ownership in relation to percent of area invaded for 74 forest types. The forest types with less than one-third of total area invaded are labeled. Public ownership includes Federal, State, and local government ownership. The estimated linear regression line is shown for information only.

ACKNOWLEDGMENTS

Thanks are due the many U.S. Department of Agriculture Forest Service FIA staff who collected all of the data used in this study. Basil Iannone III (University of Florida) and Christopher Oswalt (U.S. Department of Agriculture Forest Service) provided FIA plot summaries of invasive forest plant data. John Coulston (U.S. Department of Agriculture Forest Service) identified the representative set of FIA plots and provided plot summaries of statistical weights, forest types, and ownerships. This research was supported in part by U.S. Department of Agriculture Forest Service Agreement 13-JV-113301-046 with North Carolina State University.

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