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Article

Potentials for Mutually Beneficial Collaboration Between FIA Specialists and IEG-40 Pathologists and Geneticists Working on Fusiform Rust

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Abstract: The purpose of this article is to encourage development of an enduring mutually beneficial collaboration between data and information analysts in the US Forest Service's "Enhanced Forest Inventory and Analysis (FIA) Program" and forest pathologists and geneticists in the information exchange group (IEG) titled "Genetics and Breeding of Southern Forest Trees." The goal of this collaborative partnership is to take full advantage of the Forest Health Monitoring capabilities within the Enhanced FIA Program to provide up-to-date information on the incidence of fusiform rust on loblolly and slash pine stands in the Southern United States and to periodically report the status of the rust epidemic in this region. Our initial analysis of 2000–2011 FIA data demonstrates that careful analysis and interpretation of results from continuing FIA observations can provide valuable guidance for optimizing the performance of forest tree improvement programs in this region.

Keywords: tree diseases; fusiform rust disease; disease losses; disease incidence; disease distribution; forest health monitoring; forest inventory and analysis; *Pinus elliottii*; *Pinus taeda*

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1. Introduction

During the decades between 1930 and 1970, fusiform rust (caused by *Cronartium fusiforme*) became the most widespread and damaging disease of loblolly (*Pinus taeda*) and slash (*P. elliottii*) pine in the United States. In the opening chapter of their 1976 treatise on fusiform rust, Dinus and Schmidt [1] point out that:

> "The disease has increased dramatically in incidence since the 1930s. Prior to that time, the causal fungus *Cronartium fusiforme*, [an endemic rather than introduced pathogen!] was a botanical curiosity rather than an agent of economic destruction."

In 1970, current losses in growth of usable timber caused by fusiform rust were about 280 million board feet each year [2]. At 1970 market prices, this amount of timber was worth about $10 million and about $250 million as finished pulp and wood products. Thus, fusiform rust had become a disease of significant economic importance to the forest economy of the Southern US. As a result, in 1973, the US Department of Agriculture Forest Service, Forest Inventory and Analysis (FIA) Program began tracking this "agent of economic destruction" by collecting data on fusiform rust incidence on its inventory plots across the Southern United States.

The first region-wide analysis of the FIA fusiform rust data was conducted in 1997 by Starkey *et al.* [3]. The objective of this uniquely valuable scientific, as well as forest-management-focused, contribution was a region-wide analysis of the incidence of fusiform rust and changes over time. The team of investigators that completed this study included two forest pathologists (Dale Starkey and Robert Anderson), each with wide experience in fusiform rust research; one specialist in rust-resistance testing (Carol Young); three veteran FIA database analysts (Noel Cost, John Vissage, and Dennis May); and one Geographic Information System (GIS) specialist (Edwin Yockey), with special skills in isopleth mapping. All of these investigators were employees of the US Forest Service.

Together they took full advantage of FIA observations of fusiform rust incidence from 1975 to 1994 in 11 Southern States (Virginia, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, Arkansas, and the eastern parts of Texas and Oklahoma). Their analysis included three specific findings: (1) Slash and loblolly pine plots with ≥10% rust incidence were distributed over nearly the entire natural and contemporary range of each species; (2) There was a slight upward trend in the number of planted and natural acres of slash and loblolly pines in Virginia, North Carolina, South Carolina, and Mississippi from the early to mid-1970s through the early 1990s; (3) Overall there were slight regional trends toward a higher proportion of slash pine acreage with ≥10% rust and a lower proportion of loblolly pine acreage with ≥10% rust.

The most valuable parts of this paper were: (1) two maps (one for loblolly pines and the other for slash pines) showing the locations of FIA measurement plots where fusiform rust galls were observed on 10%, or more, of the trees in each plot; (2) a series of graphs showing trend lines for changes in (a) acreage of planted and natural stands of loblolly and slash pines estimated from FIA data for four states and (b) acreage of loblolly and slash pines with 10% of trees with galls induced by fusiform rust; and (3) two isopleth maps showing multi-county areas in all southern states that were determined to be of high, moderate, and low rust disease hazard. These two separate "hazard-zone maps"—one for loblolly pines and the other for slash pines—were widely used by pathologists, tree improvement specialists, and forest managers of both private forest land and industry forest land, in making recommendations and decisions about deployment of planting stock with various degrees of resistance to fusiform rust in the high, moderate, and low rust disease hazard zones across the South. The analysis provided by Starkey *et al.* was a great success as it took full advantage of the combined talents of skilled pathologists, tree improvement researchers, and data analysts.

During June, 2010, thirteen years after the Starkey *et al.* paper was published, and also 20 to 40 years since the FIA field crews had visited the plots where the data had been collected, and on which Starkey's maps were based, leaders of the three university-industry cooperative tree improvement programs in Texas, Florida, and North Carolina, and the manager of the US Forest Service Resistance Screening Center decided that all four programs would benefit by organizing an information exchange working group meeting with the general theme: "Integrating Fusiform Rust Research, Screening, and Breeding." This meeting was held in June, 2012, at the Resistance Screening Center near Asheville, North Carolina [4,5]. Participants in this meeting included rust resistance researchers from various parts of Canada and the US, which, together, make up a very informal information exchange group (IEG) that was established originally as a formally recognized project within the US Department of Agriculture. The original title of this organization (IEG-40) was, and still is, "Genetics and Breeding of Southern Forest Trees" [6]. The term "Information Exchange Group" derives from the original and continuing purpose of this kind of organization: to facilitate communication among scientists and forest owners and managers who share a common interest in the general area of tree improvement. (The origin of the number 40 is unknown).

One of the major agenda items for the 2012 IEG-40 meeting was the topic we have selected as the title of this paper. During the break-out session following the major paper presentations several questions were raised, the answers to which might be obtained by carefully examining monitoring data from FIA field measurements. These questions included:

(1) Where has the incidence of fusiform rust decreased, increased, or remained the same?
(2) Is the incidence of fusiform rust the same in planted and natural stands in the same general locale?
(3) Is the severity of rust symptoms (numbers of galls per tree, or frequency of branch *vs.* stem galls) the same or different in planted and natural stands in the same general locale?
(4) Are areas of low or high frequency of branch and/or stem galls different in loblolly and slash pine plantations?
(5) Have the areas of high rust disease hazard changed over time?
(6) What is the current status of the fusiform rust epidemic in loblolly and slash pines?

Discussion of these questions during the meeting, and also during a follow-up conference call that included the organizers of the IEG-40 meeting, Dale Starkey, and the two of us, led to the general conclusion that IEG-40 participants should look closely at opportunities to increase collaborative working relationships with FIA personnel. Thus, the major purpose of this article is to discuss the potential for mutually beneficial collaboration between specialists in the FIA Program and the forest pathologists and geneticists who share a common interest to understand and wisely manage the current epidemic of fusiform rust.

The approach we have taken involves explicit discussion of the following topics:

(1) Description of both the historical purposes, methods, and procedures used in the FIA Program and how these aspects were changed in 1998–1999 and will be sustained during the early decades of the 21st century;
(2) Preliminary analysis of FIA measurements of fusiform rust incidence during the years after the change in FIA methods and procedures in 1998–1999; and, finally,
(3) Some general conclusions about the potential for mutually beneficial collaboration between FIA analysts and IEG-40 forest pathologists and geneticists with regard to the current epidemic of fusiform rust.

2. Discussion

2.1. FIA Purposes, Methods, and Procedures and Changes Made During the 1990s

Beginning with its founding under the McSweeney-McNary Forest Research Act of 1928 (Public Law 70-466, 45 Stat. 699-702), the mission of the FIA Program was to "make and keep current a comprehensive inventory and analysis of the Nation's forest resources." The Forest and Rangeland Renewable Resources Planning Act of 1978 (Public Law 95-307) amended the 1928 Act and specified that the mission of the FIA Program should henceforth be to "make and keep current a comprehensive inventory and analysis of the present and prospective conditions of, and requirements for, the renewable resources of the forest and range lands of the United States." With these definitions of purpose in mind, the FIA Program was initiated in 1930 and throughout the 20th century maintained a program of commodity-focused periodic surveys in which FIA field crews visited and then "cyclically" revisited many hundreds of permanent FIA observation plots in each state. During each inventory, records were made of each of the following attributes: the living, declining, and dead trees of various tree species on each plot, the diameter and height distributions of these trees, and some other features of the site (including type of ownership, soil type, aspect, *etc.*). Notes also were made about the incidence and severity of damage by some insects, diseases, and other stress factors.

During the 1980s and 1990s the system of periodic surveys used by the FIA Program in the latter decades of the 20th century came under significant scrutiny. The end result was major changes in the objectives, strategies, and tactics by which the FIA Program sought to maintain its relevancy to contemporary concerns; not only about the adequacy of timber supplies, but also about the health of forest ecosystems, the changing forest land base, rising non-commodity uses of forest resources, *etc.*

In 2005, Bechtold and Patterson [7] described the limitations of the earlier timber-commodity-focused periodic surveys and the transition to the much more broadly focused forest-ecosystem and forest-health-based FIA program for the future. The time between inventories for any given state prior to the transition in 1998-1999 ranged between six and 18 years. With each state inventory taking one to four years to complete, and an additional two to five years for data compilation, data analysis, and report writing, consistent and timely interstate estimation was problematic. Furthermore, the FIA focus on traditional timber measurements made it difficult to address emerging environmental and forest ecosystem health issues. In 1992 and 1998, two Blue Ribbon Panels were convened to evaluate the FIA Program [8]. Recommendations from these panels were included in the 1998 Farm Bill

(Agricultural Research, Extension, and Education Reform Act of 1998 (Public Law 105-185)), which directed the FIA Program to change its inventory system from the established periodic surveys of the 20th century to a new system in which 20% of each state would be measured annually [7]. In order to accomplish this task (and to fulfill a five-year reporting requirement), FIA ground plots now are allocated to one of five spatially well-balanced "panels." All plots within one of the five panels are measured each year and a full cycle of data collection is achieved when all plots in each of the five panels has been measured. A second five-year cycle of data collection begins immediately following the completion of the first five-year cycle. Likewise, a third cycle follows the second cycle and so on into the future. This revised system of FIA measurements was named "The Enhanced Forest Inventory and Analysis Program" [7]. In addition to changes in how and when the FIA inventories were conducted, changes also were made to the kind of data that were collected. Based on the recommendations of the 1998 Blue Ribbon Panel [8], the detection monitoring activities of the FHM Program were incorporated into the Enhanced FIA Program. This added dimension expanded the list of data collected to include assessments of crown conditions, down woody materials, lichen communities, ozone deposition injury, soil condition, and vegetation diversity and structure [9].

This "annualized" system of enhanced ground-plot measurements was introduced in 1999 and gradually implemented across the US over the next two to three years. The first state report based on the new inventory system was published for South Carolina, in 2004 [10]. Although the 1998 Farm Bill prescribed that all states should undergo a full inventory every five years, budgetary constraints and logistical problems have altered this ideal plan. States in the Western US are funded to collect data on a 10-year cycle and some eastern US states have moved to a seven-year cycle. Subpaneling has been used to maintain spatial balance among the plot measurements in states not on a five-year cycle. Ongoing guidance for the FIA Program is provided by a strategic plan [11]. Outcomes and progress of the FIA Program are documented in the five-year state reports as well as annual business reports, all of which are available online through the FIA Program website www.fia.fs.fed.us. As of October 2012, the annual inventory prescribed by the 1998 Farm Bill has been implemented in all states except Hawaii [12].

2.2. Preliminary Analysis of Fusiform Rust Incidence Data Collected by FIA after 1999

Despite the major changes from the periodic surveys of the 20th century to the annualized surveys of the 21st century, actual field measurements used by FIA field crews to identify fusiform rust incidence have not changed since the 1970s. Crews recorded then, and still record after 1999, fusiform rust incidence when there is a fusiform rust gall on the main stem or on branches within 12 inches of the stem. However, FIA field crews no longer assess fusiform rust incidence on trees with diameters less than 5.0 inches. This specification is in distinct contrast to the instructions FIA field crews were given in earlier years when rust incidence was reported on all loblolly and slash pine trees with diameters of at least 1.0 inch.

This change in protocol significantly weakens the usefulness of the data since mortality from fusiform rust typically occurs before trees reach 10 years of age [13]. When we inquired about why this change in diameter of rust-infected trees had been made, we were informed that this decision was likely the result of the field guide streamlining process that took place during the transition period and was undoubtedly made without an adequate understanding of fusiform rust pathology. For this reason, we intend to work with FIA leaders to consider appropriate avenues by which to encourage reconsideration of this change so that sapling trees with diameters of at least 1.0 inch will again be included in the instructions given to FIA field crews.

In addition to this change and those described in Section 2.1, changes also were made in the allocation of plots on the ground. To accommodate the national sampling frame, some plots from the periodic inventory were dropped from the inventory and some new plots were added [7,14]. Furthermore, the standardization of the plot design to four fixed-radius subplots means that data from plots carried over into the new system may or may not be measurements on the exact same trees.

Bearing these distinctions in mind, one of us (KaDonna Randolph) produced Figures 1 and 2 that were then compared with the two similar figures in the Starkey *et al.* paper [3], reproduced here as Figures 3 and 4. Figures 1 and 2 were created using the same methods outlined by Starkey *et al.* [3], with the exception that the underlying data were based on trees at least 5.0 inches diameter at breast height rather than trees at least 1.0 inch diameter at breast height. Due to the different diameter limits of the underlying data, comparisons between the two sets of maps provide only general, preliminary conclusions about changes in fusiform rust. Please note that the maps in Figures 1 and 3 are for observations in the loblolly pine forest type and maps in Figures 2 and 4 are for observations in the slash pine forest type and that each forest type may include individual trees of the other species. As a result, the loblolly forest type may include fusiform-infected slash pine trees and *vice versa*. Also note that all four maps include stands of both natural and planted origin and that the planted stands of trees may (or may not) have been derived from loblolly or slash pine families that had been tested for genetically-controlled resistance to fusiform rust.

We conclude from our analysis of all four maps that there were only modest differences in the spatial distribution and geographic density of current loblolly pine plots with significant incidence of fusiform rust (Figure 1) observed in the past (Figure 3). The most obvious exception to this generalization is in Virginia where 17 FIA plots showed significant infection by fusiform rust in the late 1990s (Figure 3) and only nine showed significant infection in 2011 (Figure 1). Another possible exception is the somewhat greater geographical density of plots with significant incidence of rust in Louisiana, the upper piedmont and near-coastal areas of Georgia, and the near coastal areas of South Carolina in the 1990s (Figure 3) compared to the density of such plots in 2011 (Figure 1). These observations raise some questions about the changes in the geographic extent of fusiform rust during the many years between the two analyses, e.g., has the epidemic truly subsided in Virginia and parts of Louisiana, Georgia, and South Carolina?

There are some additional features of special interest in the comparison of slash pine plots in recent years (Figure 2) to those of the past (Figure 4). First, the apparent "hot spot" of rust incidence in west-central Louisiana observed in the 1990s (Figure 4) is also evident in recent years (Figure 2). It seems reasonable to assume, at least initially, that whatever factors may account for this apparent "hot spot" in the latter decades of the 20th century may also be operating in this first decade of the 21st century. Second, there are far fewer plots with significant fusiform rust incidence in both North and South Carolina in 2011 (Figure 2) than there were in the 1990s (Figure 4). This suggests that either fusiform rust infection has subsided in these areas or that little or no natural regeneration or planting of slash pine has occurred in these two states in recent years. Indeed, the latter may be the primary cause because total acreage of slash pine in North Carolina decreased by about 95,000 acres from 1990 to 2011 and by about 164,000 acres from 1993 to 2011 in South Carolina [15].

Figure 1. Location of Forest Inventory and Analysis (FIA) plots with the loblolly pine forest type and ≥10% fusiform rust infection on trees at least 5.0 inches diameter at breast height. Estimates of infection are based on FIA inventory year 2010 in Louisiana and 2011 in all other states. (Plot locations are approximate.)

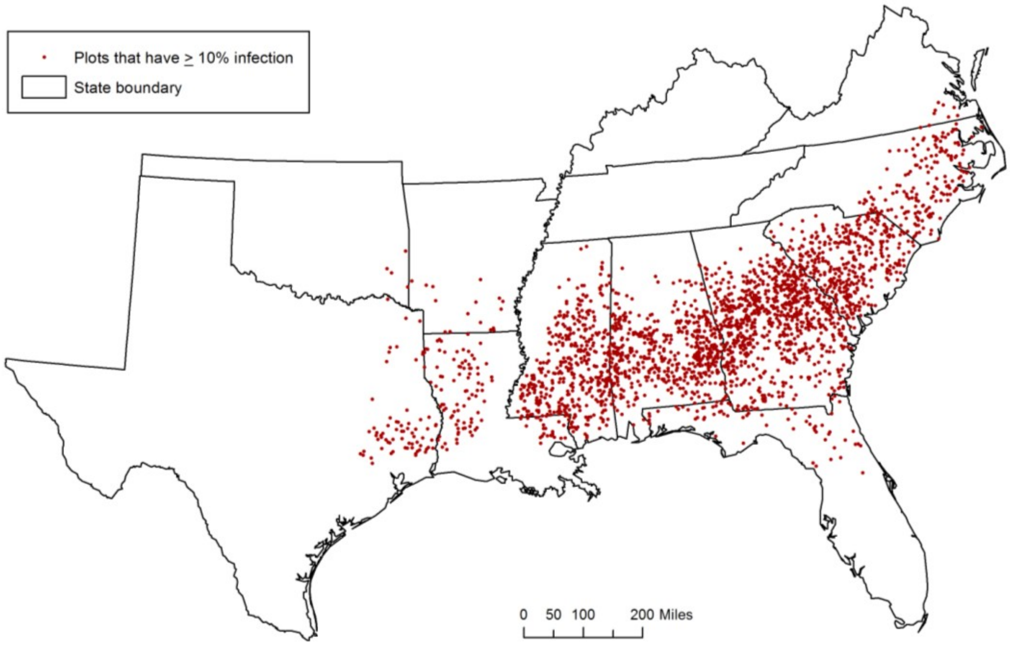


Figure 2. Location of Forest Inventory and Analysis (FIA) plots with the slash pine forest type and ≥10% fusiform rust infection on trees at least 5.0 inches diameter at breast height. Estimates of infection are based on FIA inventory year 2010 in Louisiana and 2011 in all other states. (Plot locations are approximate.)

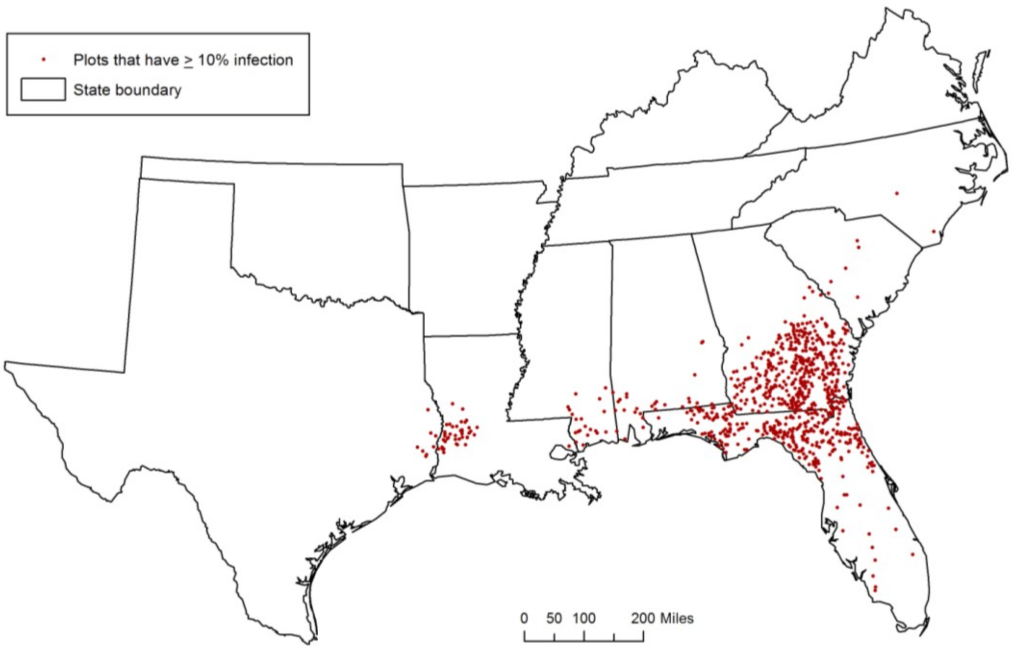


Figure 3. Locations of Forest Inventory and Analysis plots with the loblolly pine forest type and ≥10% fusiform rust infection on trees at least 1.0 inch in diameter at breast height. Estimates of infection are based on FIA inventories between 1987 and 1994. Reproduced from Starkey *et al.* [3].

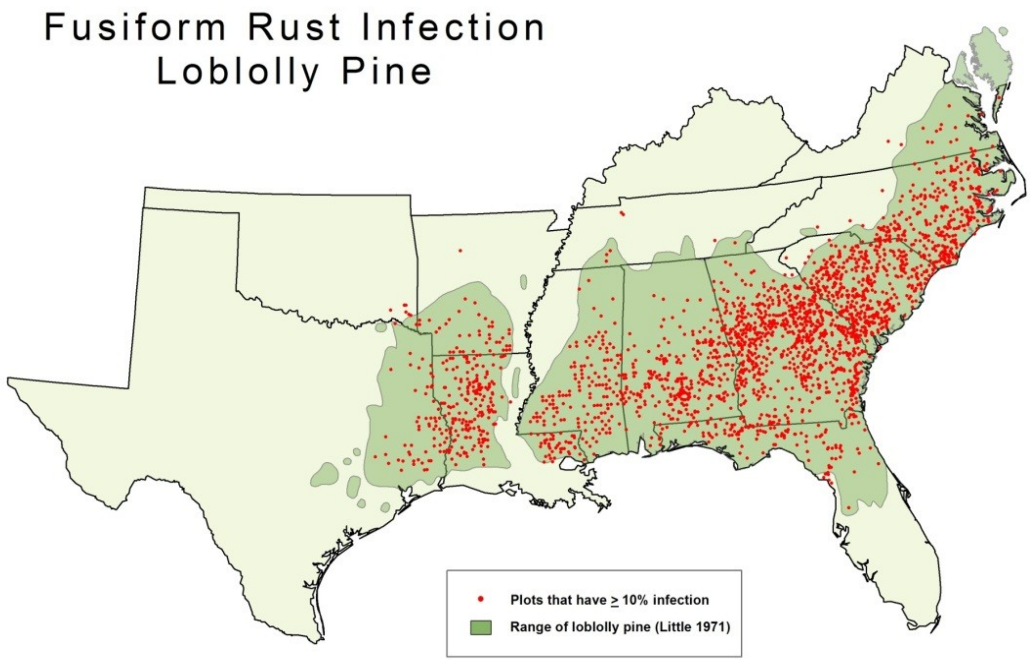
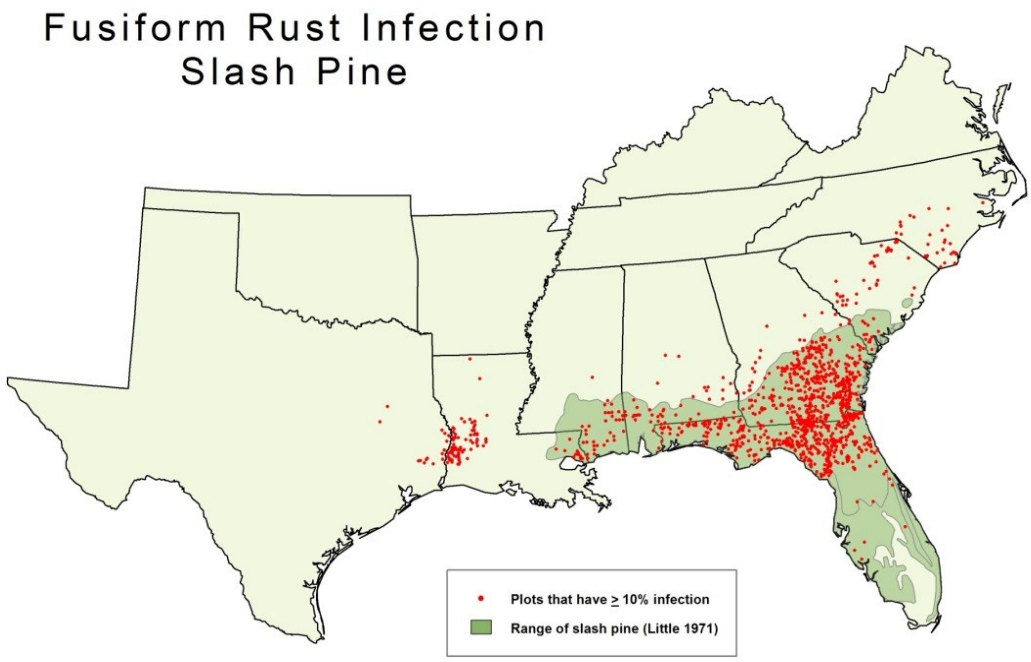


Figure 4. Locations of Forest Inventory and Analysis plots with the slash pine forest type and ≥10% fusiform rust infection on trees at least 1.0 inch in diameter at breast height. Estimates of infection are based on FIA inventories between 1987 and 1994. Reproduced from Starkey *et al.* [3].



2.3. General Conclusions about Potentials for Mutually Beneficial Collaboration between FIA Analysts and Forest Pathologists and Geneticists Regarding the Current Epidemic of Fusiform Rust

During the IEG-40 meeting many references were made to the value that forest pathologists, geneticists, and tree-improvement researchers had derived from the paper Starkey *et al.* published in 1997 [3]—not only the value of the data on rust incidence across the South and the trends over time, but especially the hazard zone maps. These isopleth displays of hazard zone areas have been used time and time again in making recommendations to forest industry cooperators about where to deploy a few among the many thousands of select trees that had been evaluated for many different desirable traits, including, resistance to fusiform rust, both in field-based progeny tests and also in the artificial inoculation tests performed at the US Forest Service's Resistance Screening Center [5].

As also discussed during the IEG-40 meeting in Asheville, many participants knew that major changes had been made in the FIA Program after the Starkey *et al.* report [3] was published. They had heard about "annualized panels," "statistical design bands," "ecological indicators," and "use of remote sensing methods" that seemed far removed from the traditional survey methods with which they were familiar. The general impression was that it would now be much more difficult to do an up-to-date analysis like the one Starkey *et al.* had done before. Many had the impression that the new "Enhanced FIA Program" [7] would require a small army of "mathematical wizards" to do what was necessary to develop "simple declarative statements that tell the truth, are consistent with all relevant evidence, and are not contradicted by any important evidence" [16] about fusiform rust and how it could be managed [17]. In fact, the "Current Status of the Epidemic of Fusiform Rust" was listed as one of the major goals of the 2012 IEG-40 meeting [4].

Having once before succeeded in helping to build a collaborative partnership with leaders in the FIA Program in the South [18–20], one of us (Ellis Cowling) decided to try again by asking for advice from two current leaders in the Southern FIA Program, John Coulston and Bill Burkman, with the hope of learning who among their FIA data analysts might be willing, interested, and able to work with a group of pathologists and geneticists regarding fusiform rust problems in our region. Their advice came in the form of a mathematical statistician (KaDonna Randolph) who provided detailed knowledge about the FIA Program and the analysis presented in Section 2.1.

From these preliminary results we conclude that much more can be learned by further detailed analysis of the currently available FIA fusiform rust data, including:

(1) Extent of rust incidence between 1970 and 1994 if rust incidence had been reported only for trees with diameters 5.0 inches or larger as was true in the FIA surveys conducted in 2000–2011.
(2) Identification and comparison of areas where fusiform rust infections are evident on more than 10%, more than 20%, and more than 30% of the total number of trees in FIA plots.
(3) More detailed analysis of rust incidence data for planted stands compared to naturally regenerated stands, including differences in the age-class distribution of trees in these two types of stands.
(4) Further analysis of trends over time in the incidence of fusiform rust in each of the Southern States.
(5) Construction of updated hazard zone maps for both loblolly and slash pines.
(6) Identification of areas in which the hazard of fusiform rust has increased or decreased over time.

We also believe, on the basis of our own experience in working together, that clearly defining research questions and continuous learning while working toward common and useful goals is much more important than being employed by the same organization!

3. Conclusions

Growing global and international concerns, especially during the 1980s and 1990s, about the cumulative impacts of human activities on the health, welfare, and sustainability of both terrestrial and aquatic ecosystems prompted the need for more realistic perspectives about the relationship between humans and nature, and for a new and more integrative field of science called Ecosystem Health. E.O. Wilson of Harvard University, John Cairns of the University of Virginia and David Rapport of the University of Guelph in Ontario, Canada, were (and still are) among the most discerning and forward-looking advocates for this new field of science.

John Cairns offered the following analysis in 1991 [21]:

> "The world's ecosystems respond to the aggregate of both anthropogenic and natural stresses on their well-being, but our attempts to protect them are fragmented and unduly reductionist. While not intending to denigrate the reductionist approach" … "ecosystem quality control requires integrative science that employs a holistic view of multiple stresses, subsidies, and interactions in complex aquatic and terrestrial ecosystems. Integrative Science requires that complex multivariate systems be considered in their entirety, not fragment by fragment."

Similarly, David Rapport offered this perspective in 1997 [22]:

> "The incessant quest for economic growth has dominated human energies for centuries. …This thinking entrains the notions of unlimited substitutions for scarce resources, growth without limits, and the myth that nature's services are in never-ending supply. …This thinking must give way to the realization that the economic process has steadily undermined one of the most critical social goals, namely, that of preserving the integrity of the earth's ecosystems. If we are to find our way, economic development must be tempered by ecological and social realities."

This growing national and global realization that commodity-focused periodic survey methods were not providing the quality and completeness of data and information necessary for wise choices in the management of forest lands, soils, water, and atmospheric resources of either our nation or the world as a whole was one of the most compelling philosophical motivations for adoption of the Enhanced FIA Program in the United States. Another, much more pragmatic motivation for the Enhanced FIA Program was the desirability of merging the ongoing FIA Program activities with the detection monitoring activities of the Forest Health Monitoring Program. Such a merger offered improved coordination between the two programs and a significant decrease in total costs.

As shown in Figures 1 and 2, fusiform rust is still very widely distributed within the natural ranges of its two principal host tree species. Furthermore, the FIA data sets are the only reliable means by which to gain a long-term (multi-decade long) perspective on the impact of fusiform rust across the entire Southern US.

Finally, we have found it both intellectually satisfying and challenging to venture into each other's disciplines [16] and, thus, to discover that there are many things FIA specialists like one of us (KaDonna Randolph) and pathologists like Dale Starkey and the other one of us (Ellis Cowling) can do together that we could not do alone.

Acknowledgments

We both are grateful for the invitation from the leaders of the IEG-40 meeting in June 2012 to make a presentation on some aspects of the history of the Resistance Screening Center and the current status of the epidemic of fusiform rust for which one of us (KaDonna Randolph) provided an even earlier version of Figures 1 and 2. We also appreciate the encouragement these leaders provided in a conference call in November, 2012, to develop this article for publication in this Special Issue of *Forests*.

Conflicts of Interest

The authors declare no conflict of interest.

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