Journal of Forestry, 2024, **XX**, 1–14
https://doi.org/10.1093/jofore/fvad058
Advance access publication 11 January 2024
Research Article - measurement

OXFORD

Downloaded from https://academic.oup.com/jof/advance-article/doi/10.1093/jofore/fvad058/7517008 by USDA APHIS HQ Library user on 27 February 2024

The USDA Forest Service's Forest Inventory and Analysis Database and the National Register of Champion Trees — A Potentially Symbiotic Relationship

Francis A. Roesch,[1,*] Todd A. Schroeder,[2] and Charles A. Price[3]

[1]USDA Forest Service, Southern Research Station, Forest Inventory and Analysis, 200 W.T. Weaver Blvd., Asheville, NC 28804, USA (Francis.A.Roesch@usda.gov).
[2]USDA Forest Service, Southern Research Station, Forest Inventory and Analysis, 4700 Old Kingston Pike, Knoxville, TN 37919-5206, USA (Todd.Schroeder@usda.gov).
[3]National Institute for Mathematical and Biological Synthesis (NIMBioS), Department of Ecology and Evolutionary Biology, University of Tennessee–Knoxville, Knoxville, TN 37996-3400, USA (cprice9@utk.edu).

[*]Corresponding author email: Francis.A.Roesch@usda.gov

Abstract

This article shows how probability sampling and citizen science efforts can complement each other, using the USDA Forest Service's Forest Inventory and Analysis (FIA) program and the ongoing search by the National Register of Champion Trees (NRCT) for the largest specimen of each naturally occurring tree species in the United States as an example. We develop a ratio statistic (Z_s) that uses the difference in size of the largest tree of a species from each database to order the tree species according to the assumed ease with which a larger specimen than the current national champion might be found. Our results show ninety-two candidate species that have been recorded by FIA for which there is no national champion and sixty-five species for which a new champion should be easy to find. In a supplemental table, we show ninety-four species listed as observable by FIA in the NRCT but not recorded in the FIA sample.

Study Implications: An interest in forests and forestry is always accompanied by an interest in trees, especially very big trees. Two very different ways of learning about trees are analyzed concurrently in a way that reveals their complementarity. The two efforts are the probability sample, conducted by the USDA Forest Service's Forest Inventory and Analysis (FIA) Program, and the citizen science effort known as the National Register of Champion Trees (NRCT). We develop a statistic that will help tree sleuths find champion trees and provide FIA practitioners with a quality control measure and an indication of which species would benefit from an increase in sample intensity.

Keywords: champion tree, NFI, FIA, probability sample, citizen science

Since at least the inception of recorded history, humans have been attempting to learn more about the world around them. This has produced many formal and informal methods of acquiring knowledge. Scientists often extol the virtues of formal applications of the scientific method, such as hypothesis testing and probability sampling, and favor the knowledge that has been acquired through these applications. The scientific method, as executed within a probability sample, is well suited to answering the questions asked but less well suited to answering the unasked questions. People in general, however, learn through many different paths and under an assumption that learning is a Markov process, an argument could be made that once someone actually knows something for certain, it hardly matters how it was learned (Visser et al. 2006). Although the use of citizen scientists in information gathering has a long history (e.g., Audubon's Christmas Bird Count was first conducted in 1900 and the Big Tree Program was conceived in the 1940s), according to Wikipedia (as of June 13, 2023) the term "citizen science," as it is used today, does not appear until an article by Kerson (1989) in the Massachusetts Institute of Technology's *Technology Review*. Although the conduct of citizen science is often described as the participation of nonscientists in the scientific process, it is not necessarily constrained to the formal requirements of applications of the scientific method. For instance, there are often no experimental controls or identifiable sampling frames but rather a large number of mostly nonexperts focused on an observational task.

Here we explore how two methods, probability sampling and citizen science, can complement and support each other, with a specific example involving the National Forest Inventory (NFI) in the United States (the USDA Forest Service's [Forest Service] Forest Inventory and Analysis [FIA] program [Burrill et al. 2018]), and the National Register of Champion Trees (NRCT), (American Forests 2023). The example involves the ongoing search for the largest specimen of each naturally occurring tree species found in the United States. Credit for the idea that led to this ongoing citizen science effort in the United States (sometimes known as the National Big Tree Program) to identify the largest specimens

Received: September 6, 2023. **Accepted:** December 15, 2023.
Published by Oxford University Press on behalf of the Society of American Foresters 2024. This work is written by (a) US Government employee(s) and is in the public domain in the US.

of many of the tree species that are included in today's NRCT is given by Leverett and Bertolette (2014) to Stearns (1940). Below, we explore how information from this extensive citizen science effort can complement (and be complemented by) information acquired through a probability sample conducted by the FIA program. Although augmented in various ways throughout the country, the areal scale of the base FIA sample is 1:36,000. In Table 1, we list some of the contributory and/or contrasting features of these two knowledge-acquiring efforts with respect to the goal of identifying the largest tree specimen of each species.

Of special note are the reciprocal benefits of the two information-gathering efforts. The citizen science effort that results in the champion tree lists of the various states as well as the NRCT can be, and has been, used to inform the probability sampling efforts of FIA by providing a quality control checkpoint during field data collection. For instance, a data recorder can be programmed to respond with an "Are you sure?" prompt when a height or diameter value is entered that exceeds that of the largest known tree of a species in a state or national champion tree list. Reciprocally, as noted in May (1990), the FIA sample can suggest the degree to which the citizen science effort appears to have been successful in identifying the largest specimen of each species. That is, it can suggest to a citizen scientist tree sleuth the areas within which a larger specimen of any particular species might be found, and it can also suggest which species would require an extreme effort by the citizen scientist to identify a larger specimen. Below, we present an example of a simple data mining task to achieve these reciprocal benefits.

Materials and Methods

We use two major sources of information, FIA's public-facing database (FIADB) as it existed on April 17, 2023, and the NRCT as it existed on April 11, 2023. These two efforts have quite different primary goals, methods, definitions, cost structures, and funding sources. We do not attempt to enumerate all of those differences here, just those important to our study, but do invite the reader to explore the cited documentation for each program.

Importantly, there are some minor differences between what species are accepted for the champion tree lists of the various states of the United States and the NRCT as well as the species meeting the definition of a tree between regions in the FIA program. Readers interested in the requirements of a particular state's champion tree list are referred to Table A1 in Appendix 1, which includes the most recent website information that we found for each state. Readers interested in the regional requirements of FIA are referred to Burrill et al. 2018.

The National Champion Tree Program recommends submission of a large tree's measurements to the state tree list first, allowing that it may proceed from there to the National Champion Tree list. Most states require (or are transitioning to a requirement for) a tree species to be native or naturalized and listed in Little (1979). This makes sense, given the intermediate goal of finding the largest specimen of each species within a state, as some would argue, it would be hardly noteworthy to find the largest of a non-native species in a state, if only a few specimens existed which had been transplanted from elsewhere. Others might argue that a big tree is a beautiful sight and should be noted no matter how it happened to get to where it is. As there are tree species that are accepted by some states and not others, our data-mining analysis of the FIADB and the NRCT is segmented into species that occur (or could occur) in only one of the data sets and species that are common to both. We also rectified some minor nomenclature and classification differences between the two data sources. The choices made here in this regard are not indicative of a preference on authors' part or on the part of the authors' employers but rather reflect an arbitrary choice that had to be made to proceed.

Alternative Measures of Large Trees

The NRCT bases selection of the champion tree for each species (S) on the measurements of bole circumference (C) in inches at breast height (4.5 ft), tree height (H) in feet, and average crown spread or width (W) in feet, to obtain the total points for tree (t) determined through the formula:

$$PCT_t = C_t + H_t + (0.25 * W_t) \tag{1}$$

Detailed instructions on measurement methods can be found in Leverett and Bertolette (2014). This formula incorporates the essential elements that lead to a perception of large when it comes to tree size. By this formula, 1 in. of bole circumference (at breast height) is worth the same as 12 in.

Table 1. Attributes of Information available from the USDA Forest Inventory and Analysis (FIA) program relative to the National Champion Tree Program.

Program	FIA	Champion Tree Program
Information category	Probability sample	Citizen science
Main goal	Description of forest populations through the sampling and measurement of those populations.	Identification and measurement of the largest tree(s) in each species.
Information sources	Several well-defined and documented sources of information, such as remote sensing layers, sample observations, etc.	Many unrestricted sources of information, such as local lore, incidental observation, friends and family, etc.
Identification of champion trees as a proportion of programmatic focus	much less than 1% - a collateral benefit	100%
Authentication process	Initial measurement conducted by trained, certified professionals whose results are subject to a well-defined, random quality-control process.	Initial measurement is conducted by citizen scientists from diverse backgrounds and education levels whose results are first authenticated by trained professionals at the state level and subsequently by an elite cadre at the national level.

Downloaded from https://academic.oup.com/jof/advance-article/doi/10.1093/jofore/fvad058/7517008 by USDA APHIS HQ Library user on 27 February 2024

Table 2. The size (in partial points [PPoints]) and Z_s statistic for each species observed by both the USDA Forest Service's Forest Inventory and Analysis program and the National Register of Champion Trees with a Z_s statistic less than 0.15.

Species	FIADB champion tree			National Register of Champion Trees			*Zs* score
	State	County	PPoints	PPoints	County	State	
Acer spicatum	VA	Highland	154	60	Smyth	VA	-1.571
Prosopis pubescens	TX	Llano	56	26	Brewster	TX	-1.161
Pinus strobiformis	AZ	Coconino	217	114	Monroe	NY	-0.902
Clusia rosea	HI	Hawaii	80	49	Broward	FL	-0.638
Quercus buckleyi	TX	Grayson	135	84	Tarrant	TX	-0.611
Prunus pensylvanica	NC	Macon	156	98	Giles	VA	-0.589
Crataegus crus-galli	TN	Lake	83	54	Montgomery	VA	-0.532
Acer pensylvanicum	TN	Carter	143	94	Grayson	VA	-0.524
Quercus ilicifolia	SC	Richland	142	97	Hartford	CT	-0.461
Asimina triloba	TN	Bledsoe	131	96	Montgomery	MD	-0.365
Prosopis glandulosa	TX	Armstrong	326	239	Real	TX	-0.363
Acer leucoderme	TN	Sevier	136	103	Gaston	NC	-0.320
Prunus emarginata	WA	Whatcom	156	118	Marion	OR	-0.318
Juniperus occidentalis	CA	Alpine	388	301	Lake	OR	-0.289
Persea borbonia	GA	Burke	252	198	Montgomery	TX	-0.274
Acer barbatum	AR	Van Buren	310	259	Southampton	VA	-0.198
Fagus grandifolia	NC	Wilkes	373	314	New Kent	VA	-0.188
Sabal palmetto	GA	Camden	153	133	Lafayette	FL	-0.149
Juniperus ashei	TX	Edwards	199	182	Comal	TX	-0.093
Carya texana	TN	Dickson	229	211	Butler	MO	-0.084
Tsuga mertensiana	WA	Grays Harbor	360	335	Mariposa	CA	-0.075
Zanthoxylum clava-herculis	TX	Jasper	72	68	Northampton	VA	-0.052
Pinus resinosa	MN	Clearwater	206	198	Carroll	NH	-0.042
Thrinax morrisii	FL	Monroe	46	44	Miami-Dade	FL	-0.041
Cornus florida	LA	Grant	152	148	Sampson	NC	-0.030
Magnolia macrophylla	TN	Morgan	152	148	Buncombe	NC	-0.030
Sorbus americana	WV	Pocahontas	99	97	Grayson	VA	-0.022
Quercus douglasii	CA	San Joaquin	219	215	Mariposa	CA	-0.017
Pinus elliottii	AL	Monroe	227	224	Portsmouth	VA	-0.012
Pinus monophylla	CA	Alpine	190	189	Washoe	NV	-0.006
Pinus banksiana	MN	St. Louis	158	158	Lake	MN	-0.001
Cercis canadensis	AR	Drew	177	177	Fairfax	VA	0.0016
Populus grandidentata	MA	Hampden	226	227	McKean	PA	0.0054
Tsuga heterophylla	CA	Humboldt	522	533	Jefferson	WA	0.0209
Pinus clausa	FL	Putnam	173	177	Osceola	FL	0.0209
Pinus virginiana	SC	Greenville	194	199	Fairfax	VA	0.0246
Vachellia farnesiana	TX	La Salle	120	123	Maricopa	AZ	0.0249
Pinus serotina	FL	Osceola	208	216	Bladen	NC	0.0352
Quercus rugosa	NM	Sierra	140	146	Santa Cruz	AZ	0.0400
Robinia neomexicana	NM	Otero	103	109	Gila	AZ	0.0550
Pinus glabra	MS	Clarke	238	253	Alachua	FL	0.0607
Ulmus serotina	AR	Crawford	174	187	Hamilton	OH	0.0706
Magnolia virginiana	AL	Tallapoosa	218	236	Jefferson	FL	0.0780
Alnus rubra	WA	Skagit	242	263	Benton	OR	0.0791
Juniperus californica	CA	Fresno	166	182	Yavapai	AZ	0.0852
Diospyros sandwicensis	HI	Hawaii	63	69	Hawai`i	HI	0.0859
Populus tremuloides	MT	Lincoln	214	236	Chippewa	MI	0.0919
Quercus coccinea	TN	Carroll	299	329	Mercer	NJ	0.0921
Castanea pumila	AL	Franklin	64	71	Trinity	TX	0.0927
Halesia carolina	TN	Sevier	177	197	Cheshire	NH	0.0997
Betula populifolia	NY	Saratoga	128	143	Cape May	NJ	0.1024

Downloaded from https://academic.oup.com/jof/advance-article/doi/10.1093/jofore/fvad058/7517008 by USDA APHIS HQ Library user on 27 February 2024

Table 2. Continued

Species	FIADB champion tree			National Register of Champion Trees			*Zs* score
	State	County	PPoints	PPoints	County	State	
Quercus marilandica	MS	Amite	188	210	Chatham	NC	0.1033
Larix laricina	NY	Saratoga	177	200	Carroll	NH	0.1158
Magnolia fraseri	NC	Graham	186	212	Carroll	VA	0.1208
Carpinus caroliniana	AR	Cleveland	207	236	Essex	NJ	0.1213
Betula lenta	VA	Wythe	206	235	Windsor	VT	0.1229
Abies concolor	CA	Madera	417	478	Mariposa	CA	0.1276
Populus angustifolia	CO	Mesa	254	292	Hinsdale	CO	0.1289
Pinus jeffreyi	CA	El Dorado	412	475	Fresno	CA	0.1324
Acer glabrum	WA	Chelan	158	183	Island	WA	0.1339
Nyssa biflora	AL	Greene	277	322	Chesapeake	VA	0.1386
Quercus incana	TX	Houston	134	156	Smith	TX	0.1421
Sideroxylon lanuginosum	MS	Tallahatchie	139	162	Freestone	TX	0.1425
Oxydendrum arboreum	NC	Graham	174	204	Amelia	VA	0.1465
Liquidambar styraciflua	MS	Bolivar	307	360	Burlington	NJ	0.1471

in height or 48 in. of crown spread. Unfortunately, as noted in May (1990) and Oswalt et al. (2010), FIA does not collect data on average crown spread, so to facilitate comparison between the two data sources, we calculated a partial points score (identical to the "bigness" score used in the May [1990] and Oswalt et al. [2010]) for the champion tree of each species (T_S) in the NRCT:

$$PPCT_S = C_{T_S} + H_{T_S} \quad (2)$$

Although possible, given the breakdown of the contribution of W_t to (1), and the fact that the additional weight of very large crowns must be supported by an increase in bole circumference, we suspect that it is unlikely that the use of equation (2) as opposed to (1) would significantly change the ranking of the largest trees in a species. This suspicion is partially supported by the observation that the average contribution of crown width to PCT_t in (1) for the 563 trees in the NRCT is .067. Given that W_t tends to increase with both C_t and H_t, the average additional informational value of W_t is something less than .067 in (1). In subsequent analyses, in the case of co-champions existing in the NRCT, we used the tree with the highest partial points score. We also calculated the partial points score for each live tree (t) in the FIA database measured between 1998 and early 2023 to find the tree with the highest score for each species (S):

$$PPFIA_S = \max_S (C_t + H_t) \quad (3)$$

In a probability sample of a large population, such as the population of trees of concern to FIA, the probability of selecting the tree of maximum value is very small. It stands to reason that a targeted search for that same maximally sized tree, such as that conducted by the National Champion Tree Program, should meet with greater success. Therefore, we devised a simple ratio statistic for each species (S):

$$Z_s = (PPCT_s - PPFIA_s)/PPCT_S \quad (4)$$

Owing to the fact that the National Champion Tree Program targets the largest trees of each species, one would expect Z_s to be positive most of the time. One would also assume that when Z_s is large and positive, the citizen science effort has been a remarkable success with respect to that species and that when Z_s is positive but small, larger trees (by the NRCT's total point formula) than the NRCT's champion tree of that species, might be found. Furthermore, when Z_s is negative, a larger tree than the NRCT's champion tree for that species has already been found (by the Z_s statistic criterion).

We note here, as was previously noted in both May (1990) and Oswalt et al. (2010), that the exact location of each FIA sample plot is confidential, so the plot coordinates listed in FIADB have been perturbed and cannot be used to pinpoint the exact location of any particular sample tree. However, the Z_s statistic could be used by citizen scientist tree sleuths to identify county-scale search areas for finding alternative national champion trees of particular species.

If a simple local-area search within each county containing the largest trees in the FIADB proves fruitless, quite a few different approaches to defining expanded search areas for champion trees from the information in the two databases could be used. For instance, one might filter the FIADB to find and map the counties of the x largest trees of a species, add the current national champion listed in the NRCT, and then form a search area around their listed counties (or groups of adjacent counties), possibly within ecotypes, for certain species. That is, the search areas could be suggested by the distribution of counties within which these $x + 1$ largest trees were observed. We give one example of this approach applied to a single species (*Pinus virginiana*) in the Results section.

A Note on Viewing the Current Champion Tree as the Maximum Value Observed in a Trend or as an Outlier

In the case of a 100% census, the observation of the largest value in a population will occur. Otherwise, in the case of a probability sample such as FIA, it is usually unlikely that the sample will include the largest tree of a particular species. The estimation of the maximum value from a sample that would be observed in a population has a broad body of literature in statistics, generally referred to as the statistics of extremes (e.g., de Carvalho 2016). Whether or not it makes sense for the interested reader to try to model the size of the

Downloaded from https://academic.oup.com/jof/advance-article/doi/10.1093/jofore/fvad058/7517008 by USDA APHIS HQ Library user on 27 February 2024

Table 3. The size (in partial points [PPoints]) and Z_s statistic for each species observed by both the USDA Forest Service's Forest Inventory and Analysis program and the National Register of Champion Trees with a Z_s statistic between 0.15 and 0.289.

Species	FIADB champion tree			National Register of Champion Trees			*Zs* score
	State	County	PPoints	PPoints	County	State	
Abies grandis	WA	Chelan	427	502	Humboldt	CA	0.1501
Pinus monticola	OR	Lane	394	464	Douglas	NV	0.1502
Populus heterophylla	AR	Arkansas	228	268	Dunklin	MO	0.1503
Abies procera	WA	Pierce	483	568	Cowlitz	WA	0.1503
Picea pungens	WY	Lincoln	279	329	Wasatch	UT	0.1510
Carya aquatica	LA	St. Landry	256	303	Southampton	VA	0.1553
Juniperus osteosperma	UT	Utah	205	243	Mohave	AZ	0.1557
Pinus echinata	FL	Leon	220	262	Smith	TX	0.1591
Prunus serotina	WV	Webster	244	292	Norfolk	VA	0.1627
Picea engelmannii	OR	Lane	333	400	Flathead	MT	0.1674
Gordonia lasianthus	FL	Nassau	196	236	Duval	FL	0.1708
Fraxinus texensis	TX	Collin	124	149	Monroe	NY	0.1708
Fraxinus pennsylvanica	MS	Bolivar	270	327	Hartford	CT	0.1728
Gleditsia aquatica	TN	Dyer	170	206	Montgomery	PA	0.1734
Pinus lambertiana	CA	Tuolumne	498	603	Tuolumne	CA	0.1740
Pinus palustris	AL	Tallapoosa	202	245	Aiken	SC	0.1744
Carya illinoinensis	MS	Adams	322	390	Isle of Wight	VA	0.1745
Quercus falcata	MS	Wilkinson	342	414	James City	VA	0.1748
Ulmus crassifolia	LA	Franklin	195	236	Butler	MO	0.1751
Quercus nigra	MS	Amite	283	344	Suffolk	VA	0.1763
Picea mariana	MI	Keweenaw	158	195	Aroostook	ME	0.1905
Pinus muricata	CA	Mendocino	261	324	Marin	CA	0.1948
Quercus palustris	IL	Alexander	281	349	Lake	OH	0.1952
Abies fraseri	TN	Sevier	170	212	Harrisonburg	VA	0.1958
Torreya californica	CA	Sonoma	191	238	Santa Cruz	CA	0.1958
Pinus taeda	TX	Polk	279	349	Richland	SC	0.2015
Carya carolinae-septentrionalis	MS	Noxubee	196	246	Etowah	AL	0.2018
Ilex opaca	MS	Amite	196	246	White	AR	0.2036
Picea rubens	NC	Swain	223	280	Giles	VA	0.2044
Pinus strobus	TN	Unicoi	293	370	Waldo	ME	0.2086
Carya glabra	TN	Jefferson	250	317	Allen	KY	0.2100
Hilairanthus germinans	FL	Collier	109	138	Monroe	FL	0.2103
Arbutus menziesii	CA	Humboldt	272	346	Douglas	OR	0.2136
Quercus similis	AR	Drew	179	228	Red River	TX	0.2138
Juniperus coahuilensis	AZ	Yavapai	135	172	Brewster	TX	0.2154
Pinus flexilis	CA	Madera	285	363	Utah	UT	0.2158
Pinus ponderosa	CA	El Dorado	438	559	El Dorado	CA	0.2170
Diospyros virginiana	GA	Macon	191	244	Scioto	OH	0.2174
Magnolia grandiflora	SC	Hampton	256	327	Sussex	VA	0.2181
Acer saccharum	MI	Wayne	267	342	Giles	VA	0.2197
Tsuga canadensis	NC	Jackson	287	369	Macon	NC	0.2222
Carya tomentosa	AL	Macon	243	313	Caroline	VA	0.2225
Acer nigrum	MI	Eaton	198	255	York	ME	0.2227
Quercus montana	VA	Buchanan	293	381	Ward 3	DC	0.2307
Larix occidentalis	WA	Okanogan	321	421	Missoula	MT	0.2379
Carya ovata	TN	Smith	224	295	Anne Arundel	MD	0.2395
Betula neoalaskana	AK	Matanuska	148	196	Matanuska	AK	0.2459
Malus fusca	OR	Lane	104	138	King	WA	0.2488
Acer negundo	VA	Botetourt	222	298	Essex	VA	0.2537
Ostrya virginiana	SC	Florence	136	183	Washtenaw	MI	0.2548
Pseudotsuga menziesii	OR	Lane	651	875	Grays Harbor	WA	0.2565

Downloaded from https://academic.oup.com/jof/advance-article/doi/10.1093/jofore/fvad058/7517008 by USDA APHIS HQ Library user on 27 February 2024

Table 3. Continued

Species	FIADB champion tree			National Register of Champion Trees			Zs score
	State	County	PPoints	PPoints	County	State	
Quercus michauxii	NC	Edgecombe	295	399	Virginia Beach	VA	0.2595
Acer rubrum	MI	Manistee	257	348	New Haven	CT	0.2604
Picea glauca	AK	Prince of Wales	191	259	Koochiching	MN	0.2607
Betula alleghaniensis	NC	Jackson	225	305	Kennebec	ME	0.2610
Ilex cassine	FL	Lafayette	93	126	Palm Beach	FL	0.2643
Carya myristiciformis	TN	Van Buren	142	193	Red River	TX	0.2661
Celtis laevigata	SC	Kershaw	224	305	Caroline	VA	0.2671
Diospyros texana	TX	Kendall	61	83	Refugio	TX	0.2673
Nyssa ogeche	FL	Gulf	195	268	Wakulla	FL	0.2709
Pinus contorta	CA	Madera	281	388	San Bernardino	CA	0.2752
Quercus engelmannii	CA	Fresno	164	228	Los Angeles	CA	0.2807
Magnolia tripetala	TN	DeKalb	144	201	New Haven	CT	0.2824
Ulmus alata	MS	Monroe	197	275	Hopewell	VA	0.2847
Pinus cembroides	NM	Grant	93	130	Brewster	TX	0.2859
Pinus balfouriana	CA	Tulare	281	394	Tulare	CA	0.2870
Quercus texana	MS	Sharkey	266	374	Desha	AR	0.2877
Abies lasiocarpa	MT	Ravalli	268	377	Jefferson	WA	0.2887

largest tree to be observed given the current sample depends on at least two things, (1) the willingness to make a set of very strong (and possibly unrealistic) assumptions, beginning with the assumption that the largest observed tree is the maximum observed value of a predictable trend or known distribution, as opposed to an outlier, and (2) having enough data to model the trend. Although it is beyond the scope of this article, an early approach that assumes a uniform distribution, known as the German tank problem (Ruggles and Brodies 1947), might be applied to the problem at hand. For species with many observations, different models could be built under the assumption that there is one tree larger than the largest tree recorded, or two trees larger, or *n* trees larger, etc. For species with many measured specimens, one could assume a model for the upper tail, possibly as simple as linearity in the upper tail, and then perform a simple linear regression on, say, the ten largest observed trees and assume the next ten larger trees in the population would follow the trend. The Z_s statistic described above could be calculated for the estimated partial points of each projected tree relative to the partial points of the champion tree in the NRCT to obtain a more refined estimate of the likelihood of a larger tree being found.

Results

The largest specimen of each species found in only one of the data sources are given in two supplementary files. Table S1 lists 192 species that occur in the NRCT that have not been observed by FIA on forested sample plots. Of these, ninety-four species are listed as potentially observable by FIA if they would have been found to occur on a sample plot. These ninety-four species, identified in last column of the tables, must be relatively rare to not have been observed at all by FIA, and therefore, finding a larger tree than the one already listed in the NRCT would most likely be difficult. FIA would classify most of the remaining species in this table only to genus, aggregating species within genus.

The FIADB records 217 species, varieties, and subspecies that are not included in the NRCT. The largest specimen of each of these species by partial points is listed in Table S2 online. Ninety-two of the species in this table are listed in Little (1979) and would seem to be valid candidates for the NRCT. These are indicated by a "1" in the last column of the table. A tree sleuth interested in finding a suitable candidate of a particular one of these species for submission to the NRCT could start by looking in and around the county listed in the table for that species.

Tables 2 through 6 list the 299 species common to both the NRCT and the FIADB categorized in order of increasing Z_s. We assume that as the species Z_s statistic increases, the likelihood of finding a larger specimen than the one already listed in the NRCT decreases. Table 2 lists the thirty-one species with negative Z_s statistics and the thirty-four species with very small positive Z_s statistics (less than 0.149), in order of increasing Z_s. A negative Z_s indicates that the tree in the FIADB has more partial points than the tree in the NRCT. Anyone interested in finding candidate trees to propose for inclusion in a state's champion tree list and eventual replacement of the current national champion could start by looking in and around the counties listed in Table 2 for that species.

Table 3 lists the sixty-eight species with Z_s statistics ranging from 0.15 to 0.289 in order of increasing Z_s. As we pointed out above, the FIADB is not likely to contain the largest tree of any species, so there is some likelihood that a search for a larger tree than the one currently in the NRCT from the species listed in this table, in the vicinity of the associated counties, could be successful.

To facilitate our discussion of the potentially symbiotic relationship of these two data sources, we include Tables 4–6. Table 4 lists the sixty-nine species with Z_s statistics between 0.29 and 0.399 in order of increasing Z_s. Table 5 lists the forty-six species with Z_s between 0.40 and 0.499, and Table 6 list the fifty-one species with Z_s statistics greater than 0.50

Downloaded from https://academic.oup.com/jof/advance-article/doi/10.1093/jofore/fvad058/7517008 by USDA APHIS HQ Library user on 27 February 2024

Table 4. The size (in partial points [PPoints]) and Z_s statistic for each species observed by both the USDA Forest Service's Forest Inventory and Analysis program and the National Register of Champion Trees with a Z_s statistic between 0.29 and 0.399.

Species	FIADB champion tree			National Register of Champion Trees			*Zs* score
	State	County	PPoints	PPoints	County	State	
Fraxinus nigra	MI	Midland	182	258	Gogebic	MI	0.2932
Planera aquatica	MS	Oktibbeha	203	287	Gilchrist	FL	0.2935
Fraxinus profunda	NC	Bladen	212	301	Mississippi	MO	0.2945
Pinus radiata	CA	Santa Cruz	269	381	Humboldt	CA	0.2949
Morella cerifera	SC	Berkeley	51	72	Virginia Beach	VA	0.2957
Chrysolepis chrysophylla	CA	Siskiyou	231	329	Humboldt	CA	0.2970
Betula nigra	GA	Troup	196	279	Hamilton	OH	0.2986
Pinus sabiniana	CA	San Benito	248	354	Nevada	CA	0.2986
Eugenia rhombea	FL	Brevard	32	45	Monroe	FL	0.2991
Ilex anomala	HI	Hawaii	102	146	Hawai`i	HI	0.3003
Quercus imbricaria	IN	Daviess	216	309	Gallia	OH	0.3012
Quercus laevis	FL	Clay	133	190	Moore	NC	0.3016
Aesculus flava	TN	Monroe	263	376	Alleghany	VA	0.3018
Sequoia sempervirens	CA	Del Norte	885	1271	Del Norte	CA	0.3036
Halesia diptera	MS	Wilkinson	96	138	Buncombe	NC	0.3079
Quercus bicolor	KY	Union	258	373	Sussex	NJ	0.3081
Condalia hookeri	TX	Brooks	67	98	Hidalgo	TX	0.3124
Fraxinus americana	TN	Monroe	254	370	Morris	NJ	0.3129
Nyssa sylvatica	NC	Rowan	223	325	Wood	TX	0.3152
Chamaecyparis thyoides	VA	Suffolk city	184	268	Muskingum	OH	0.3152
Quercus pagoda	AL	Lowndes	304	445	Portsmouth	VA	0.3160
Carya pallida	TN	Marion	194	285	Greenville	SC	0.3176
Juglans nigra	MO	Saline	239	350	Westmoreland	VA	0.3180
Quercus muehlenbergii	OH	Mercer	248	364	Fairfield	OH	0.3182
Populus trichocarpa	OR	Clackamas	354	520	Polk	OR	0.3184
Carya ovalis	GA	Floyd	175	258	Caroline	VA	0.3200
Pinus pungens	VA	Montgomery	154	227	Stokes	NC	0.3206
Quercus gambelii	AZ	Navajo	177	261	Coconino	AZ	0.3224
Calocedrus decurrens	CA	Tulare	426	629	Siskiyou	CA	0.3230
Quercus velutina	AR	Phillips	297	440	Hartford	CT	0.3259
Rhizophora mangle	FL	Collier	88	131	Lee	FL	0.3264
Fraxinus caroliniana	GA	Dougherty	169	252	Lake	FL	0.3287
Quercus kelloggii	CA	Placer	283	425	Mariposa	CA	0.3338
Pinus edulis	UT	Grand	145	217	Santa Fe	NM	0.3339
Pinus arizonica	AZ	Cochise	172	258	Pima	AZ	0.3343
Carya cordiformis	TN	Greene	228	343	Russell	VA	0.3353
Quercus alba	NC	Mitchell	280	421	Brunswick	VA	0.3360
Quercus wislizeni	CA	Santa Cruz	228	343	Calaveras	CA	0.3362
Quercus rubra	AL	Montgomery	285	429	Ashtabula	OH	0.3363
Fraxinus quadrangulata	IN	Madison	194	293	Jefferson	KY	0.3385
Quercus macrocarpa	MI	Barry	275	416	Berrien	MI	0.3392
Ulmus americana	MS	Wayne	246	372	Baltimore	MD	0.3394
Aesculus glabra	OH	Hamilton	170	260	Fayette	KY	0.3444
Quercus garryana	CA	Mariposa	252	385	Multnomah	OR	0.3448
Pinus rigida	VA	Alleghany	183	281	Merrimack	NH	0.3473
Syzygium sandwicense	HI	Kauai	71	109	Honolulu	HI	0.3482
Quercus phellos	LA	Madison	281	433	Northampton	VA	0.3511
Quercus laceyi	TX	Bandera	113	175	Comal	TX	0.3525
Quercus laurifolia	LA	St. Landry	260	403	Chesapeake	VA	0.3559
Quercus graciliformis	TX	Brewster	75	116	Brewster	TX	0.3568
Carya laciniosa	MO	Cass	192	299	Culpeper	VA	0.3581

Downloaded from https://academic.oup.com/jof/advance-article/doi/10.1093/jofore/fvad058/7517008 by USDA APHIS HQ Library user on 27 February 2024

Table 4. Continued

Species	FIADB champion tree			National Register of Champion Trees			*Zs* score
	State	County	PPoints	PPoints	County	State	
Pseudotsuga macrocarpa	CA	San Bernardino	276	434	Los Angeles	CA	0.3644
Platanus occidentalis	TN	Lauderdale	353	556	Ashland	OH	0.3648
Salix nigra	MI	St. Clair	257	406	Washington	MN	0.3667
Thuja plicata	WA	Jefferson	576	910	Clallam	WA	0.3668
Quercus agrifolia	CA	Santa Clara	258	408	San Luis Obispo	CA	0.3668
Tilia americana	VA	Augusta	236	378	Fayette	KY	0.3749
Pinus engelmannii	AZ	Cochise	163	262	Cochise	AZ	0.3768
Quercus emoryi	NM	Grant	168	269	Grant	NM	0.3769
Celtis occidentalis	OH	Preble	234	376	Hancock	OH	0.3778
Thuja occidentalis	MI	Marquette	187	302	Nelson	VA	0.3818
Pinus washoensis	CA	Sierra	221	357	Modoc	CA	0.3821
Juniperus deppeana	NM	Catron	232	376	Yavapai	AZ	0.3842
Pinus aristata	NM	Taos	145	237	Huerfano	CO	0.3881
Gleditsia triacanthos	LA	Ascension	214	350	Botetourt	VA	0.3882
Quercus shumardii	AL	Greene	268	441	Powell	KY	0.3918
Styrax grandifolius	LA	Bienville	25	42	Suffolk	VA	0.3953
Abies balsamea	VT	Rutland	160	264	Adams	PA	0.3954
Pinus leiophylla	NM	Grant	128	212	Apache	AZ	0.3982

in order of increasing Z_s. These Z_s statistics indicate, in order of increasing difficulty, the chance of finding a tree larger than the current champion in the NRCT.

For a closer look at one species, Table 7 lists the year and county of observation, height, circumference, and partial points for twelve large specimens of *P. virginiana*, including the current national champion in the NRCT, the largest listed in the FIADB since 1997, and the ten largest listed in the FIADB since 2015. These twelve trees are located in eleven counties in the southeastern United States. The final column in Table 7 groups these eleven counties into four general search areas (I-IV). The locations for the eleven counties in which these twelve trees were observed are depicted in figure 1.

Discussion

In the analysis above, a negative Z_s tells us that the FIA sample has found at least one larger tree than the champion tree of a species, and a small positive Z_s indicates that a larger tree than the current champion could probably be found. The FIA data provide a myriad of ways to narrow the search and increase the probability of success for those searching for champion trees. Our example in figure 1 shows one approach. Other approaches might filter the database by elevation, forest type, owner class, etc. Although some might argue that it would spoil the thrill of the hunt, an obvious initial approach would be to examine aerial photographs or freely available Lidar point clouds (e.g., USGS 3DEP, GEDI) to map canopy heights for potential candidate trees, and then find and measure those candidates in the field.

There are a few possible reasons that a species would have a low Z_s statistic: the species could be rare or not well known or possibly so common that tree sleuths just are not very interested in it. A tree sleuth interested in finding a suitable candidate of a particular one of these species for submission to the NRCT could start by looking in and around the county listed in the table for any of the ninety-two species listed in Little (1979) and indicated in Table S2 online.

As we noted above, Tables 2 through 6 list the species common to the two databases in order of increasing Z_s and we assume that as the species Z_s increases, the likelihood of finding a larger specimen than the one already listed in the NRCT decreases. Table 2 lists the species that already are included in both the FIADB and the NRCT of greatest promise to tree sleuths. Anyone interested in finding candidate trees to propose for inclusion in a state's champion tree list and eventual submission to the NRCT could start by looking in and around the counties listed in Table 2 for that species. Table 3 is the next most helpful table to tree sleuths, listing the species with small positive Z_s statistics. As we pointed out above, no database resulting from a probability sample is likely to contain the largest tree of any species, so there is some likelihood that a search for a larger tree than the one currently in the NRCT from the species listed in this table, in the vicinity of the associated counties, could be successful.

Tables 4–6 and S1 mostly show which species should be investigated last in the search for champion trees, as they list, in increasing order of difficulty, species for which a larger specimen than the current champion would most likely be difficult to find. However, as indicated in our title, these two data sources offer a potentially symbiotic relationship, and, as a more complete knowledge of all of the tree species in the United States, in addition to other rare events, becomes more desirable, an adaptation to the FIA sample design such as that suggested in Roesch (1993) and Roesch and McWilliams (2007), guided by Tables 4, 5, and especially 6, could be made. The reader should note that the subject species of Roesch and McWilliams (2007), *Castanea dentata*, is found in Table 6.

Table 7 illustrates how one could narrow the search for a champion tree of a particular species armed with only the two databases by first finding the counties within which a small set of the largest members of that species have been observed.

Downloaded from https://academic.oup.com/jof/advance-article/doi/10.1093/jofore/fvad058/7517008 by USDA APHIS HQ Library user on 27 February 2024

Table 5. The size (in partial points [PPoints]) and Z_s statistic for each species observed by both the USDA Forest Service's Forest Inventory and Analysis program and the National Register of Champion Trees with a Z_s statistic between 0.40 and 0.499.

Species	FIADB champion tree			National Register of Champion Trees			*Zs* score
	State	County	PPoints	PPoints	County	State	
Quercus stellata	MS	DeSoto	226	377	Cherokee	AL	0.4009
Liriodendron tulipifera	VA	Russell	300	501	Bedford	VA	0.4014
Populus deltoides	KS	Washington	322	538	Gage	NE	0.4021
Sassafras albidum	MS	Warren	206	345	Daviess	KY	0.4032
Prunus caroliniana	SC	Aiken	69	115	Williamsburg	VA	0.4038
Juniperus virginiana	TN	Rutherford	183	307	Coffee	GA	0.4049
Gymnocladus dioicus	IL	Warren	180	304	Montgomery	MD	0.4076
Quercus lyrata	MS	Lowndes	263	444	Isle of Wight	VA	0.4079
Quercus virginiana	FL	Levy	305	518	Ware	GA	0.4117
Cornus drummondii	LA	Concordia	40	69	Tunica	MS	0.4150
Ulmus rubra	SC	Marion	215	372	Jefferson	KY	0.4209
Morus rubra	SC	Lee	220	380	Ashley	AR	0.4214
Ulmus thomasii	MN	Fillmore	158	275	St. Louis	MO	0.4272
Taxus brevifolia	CA	Humboldt	139	243	Lewis	WA	0.4292
Picea sitchensis	OR	Tillamook	530	931	Grays Harbor	WA	0.4303
Juglans cinerea	MN	Hennepin	187	329	Thurston	WA	0.4308
Prunus virginiana	ME	Oxford	135	237	Baltimore	MD	0.4318
Baccharis halimifolia	GA	Long	32	56	Chesapeake	VA	0.4332
Quercus myrtifolia	FL	Putnam	63	111	Collier	FL	0.4333
Larix lyallii	WA	Okanogan	211	372	Chelan	WA	0.4333
Bursera simaruba	FL	Collier	80	142	Miami-Dade	FL	0.4341
Acer saccharinum	IN	De Kalb	269	478	Houston	MN	0.4382
Quercus arizonica	AZ	Gila	162	290	Santa Cruz	AZ	0.4404
Salix amygdaloides	MN	Benton	161	287	Aitkin	MN	0.4405
Quercus oblongifolia	AZ	Pima	116	209	Lincoln	NM	0.4446
Juniperus scopulorum	NM	Colfax	180	324	Cache	UT	0.4454
Quercus grisea	NM	Sierra	145	263	Hidalgo	NM	0.4482
Acacia koa	HI	Hawaii	252	458	Hawai`i	HI	0.4489
Magnolia acuminata	VA	Tazewell	220	400	Stark	OH	0.4508
Cupressus nootkatensis	WA	Snohomish	316	578	Jefferson	WA	0.4525
Crataegus mollis	NC	Northampton	87	161	Madison	OH	0.4580
Prosopis velutina	AZ	Santa Cruz	131	242	Santa Cruz	AZ	0.4592
Olneya tesota	CA	Riverside	130	241	Maricopa	AZ	0.4611
Ficus aurea	FL	Collier	102	189	Miami-Dade	FL	0.4612
Salix caroliniana	FL	Hillsborough	81	152	Alachua	FL	0.4651
Vaccinium arboreum	GA	Cherokee	48	90	Houston	TX	0.4699
Malus coronaria	PA	Westmoreland	76	144	Orange	VT	0.4699
Catalpa bignonioides	TX	Bowie	172	326	Baltimore	MD	0.4734
Arbutus arizonica	AZ	Cochise	87	166	Santa Cruz	AZ	0.4766
Acer macrophyllum	WA	King	305	582	Lane	OR	0.4766
Maclura pomifera	IN	Montgomery	205	393	Charlotte	VA	0.4781
Carya floridana	FL	Polk	69	133	Lake	FL	0.4785
Quercus lobata	CA	Mendocino	257	501	Mendocino	CA	0.4878
Robinia pseudoacacia	NC	Jackson	217	425	Columbia	NY	0.4892
Persea palustris	NC	Dare	96	190	Virginia Beach	VA	0.4933
Sapindus oahuensis	HI	Honolulu	59	116	O'ahu	HI	0.4947

Although somewhat older, the detailed tables in May (1990) and Oswalt et al. (2010) would also be excellent starting points in the southern United States. The reader should note that, while our focus is at the national level, these analytical suggestions can be applied at other scales. In addition to the FIADB, there are also many other data sources resulting

Downloaded from https://academic.oup.com/jof/advance-article/doi/10.1093/jofore/fvad058/7517008 by USDA APHIS HQ Library user on 27 February 2024

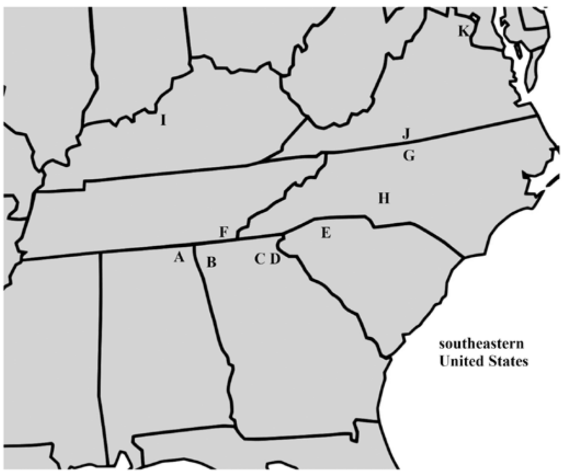
Table 6. The size (in partial points [PPoints]) and Z_s statistic for each species observed by both the USDA Forest Service's Forest Inventory and Analysis program and the National Register of Champion Trees with a very large Z_s statistic (≥ 0.50).

Species	FIADB champion tree			National Register of Champion Trees			*Zs* score
	State	County	PPoints	PPoints	County	State	
Pisonia brunoniana	HI	Hawaii	91	183	Hawai`i	HI	0.5032
Alnus oblongifolia	AZ	Apache	161	327	Socorro	NM	0.5085
Quercus chrysolepis	CA	Shasta	288	597	San Bernardino	CA	0.5168
Taxodium distichum	AR	Arkansas	340	717	West Feliciana	LA	0.5263
Leucaena pulverulenta	TX	Cameron	71	151	Nueces	TX	0.5295
Prunus angustifolia	GA	Telfair	30	63	Alachua	FL	0.5302
Cladrastis kentukea	TN	Cocke	138	301	Morris	NJ	0.5405
Amelanchier arborea	MI	Otsego	70	154	Upshur	WV	0.5424
Sapindus saponaria	OK	Canadian	105	232	Hawai`i	HI	0.5454
Catalpa speciosa	IN	Allen	154	345	Lawerence	OH	0.5528
Chamaecyparis lawsoniana	OR	Curry	341	764	Coos	OR	0.5532
Nyssa aquatica	NC	Hertford	257	576	White	AR	0.5539
Ehretia anacua	TX	Goliad	86	196	Kenedy	TX	0.5632
Acer grandidentatum	AZ	Graham	117	269	Coconino	AZ	0.5639
Quercus hemisphaerica	GA	Clay	153	351	Richmond	VA	0.5652
Quercus gravesii	TX	Jeff Davis	70	160	Brewster	TX	0.5656
Malus angustifolia	GA	Laurens	67	157	Montgomery	MD	0.5753
Coccoloba diversifolia	FL	Dade	50	118	Miami-Dade	FL	0.5800
Pinus longaeva	CA	Mono	209	507	Clark	NV	0.5869
Aesculus californica	CA	Amador	91	222	Santa Cruz	CA	0.5879
Umbellularia californica	CA	Sonoma	287	702	Curry	OR	0.5914
Quercus georgiana	GA	Newton	61	149	Clarke	GA	0.5926
Cotinus obovatus	AL	Madison	72	183	Windham	CT	0.6083
Erythrina sandwicensis	HI	Kauai	88	227	Hawai`i	HI	0.6127
Quercus prinoides	SC	Aiken	31	81	Monroe	NY	0.6205
Populus fremontii	CA	Glenn	250	662	Yavapai	AZ	0.6229
Juniperus flaccida	TX	Brewster	56	152	Brewster	TX	0.6337
Hesperocyparis arizonica	AZ	Pima	119	350	Pima	AZ	0.661
Halesia tetraptera	TN	Carter	73	217	Sevier	TN	0.6640
Castanea dentata	ME	Somerset	110	331	Thurston	WA	0.6675
Aesculus sylvatica	GA	Rabun	37	111	Sussex	VA	0.6685
Swietenia mahagoni	FL	Monroe	84	255	Broward	FL	0.6708
Sequoiadendron giganteum	CA	Tulare	479	1506	Tulare	CA	0.6816
Arbutus xalapensis	TX	Brewster	66	208	Brewster	TX	0.6844
Juglans major	TX	Coryell	108	354	Pima	AZ	0.6958
Fraxinus berlandieriana	TX	Starr	83	276	Cameron	TX	0.6981
Piscidia piscipula	FL	Monroe	54	185	Monroe	FL	0.7095
Ilex vomitoria	TX	Montgomery	37	127	Wayne	NC	0.7103
Conocarpus erectus	FL	Collier	72	264	Monroe	FL	0.7279
Prunus mexicana	TX	Polk	31	113	Harris	TX	0.7292
Sophora chrysophylla	HI	Hawaii	81	319	Hawai'i	HI	0.7453
Cupressus macrocarpa	CA	Humboldt	154	690	San Mateo	CA	0.7767
Cordia boissieri	TX	Hidalgo	34	157	Cameron	TX	0.7820
Ebenopsis ebano	TX	Starr	51	236	Hidalgo	TX	0.7855
Morus microphylla	TX	Bosque	57	276	Yavapai	AZ	0.7919
Quercus geminata	FL	Madison	60	292	Alachua	FL	0.7931
Quercus sinuata	TX	Sutton	52	270	Greene	AL	0.8073
Fraxinus velutina	UT	Washington	63	334	Yavapai	AZ	0.8106
Sideroxylon salicifolium	FL	Martin	20	105	Miami-Dade	FL	0.8123
Hesperocyparis nevadensis	CA	Colusa	35	190	Kern	CA	0.8139
Nestegis sandwicensis	HI	Maui	33	237	Hawai`i	HI	0.8607

Downloaded from https://academic.oup.com/jof/advance-article/doi/10.1093/jofore/fvad058/7517008 by USDA APHIS HQ Library user on 27 February 2024

Table 7. The year of observation, state, county, height, circumference, partial points (PPoints), map symbol, and search area grouping for twelve large specimens of *Pinus virginiana*; eleven from the FIADB and one from the National Register of Champion Trees.

Symbol	Year	State	County	Height	Circumference	PPoints	Source	Search Area
A	2018	AL	Jackson	91	80	171	FIADB	I
B	2020	GA	Walker	122	70	192	FIADB	I
C	2021	GA	White	105	74	179	FIADB	I
C	2018	GA	White	109	72	181	FIADB	I
D	2018	GA	Habersham	114	53	167	FIADB	I
E	2003	SC	Greenville	114	80	194	FIADB	II
F	2017	TN	Polk	115	54	169	FIADB	I
G	2017	NC	Rockingham	118	46	164	FIADB	II
H	2018	NC	Rowan	102	64	166	FIADB	II
I	2016	KY	Bullitt	103	61	164	FIADB	III
J	2018	VA	Henry	109	57	166	FIADB	II
K	2017	VA	Fairfax	91	108	199	NRCT	IV



Symbol	County	State
A	Jackson	AL
B	Walker	GA
C	White	GA
D	Habersham	GA
E	Greenville	SC
F	Polk	TN
G	Rockingham	NC
H	Rowan	NC
I	Bullitt	KY
J	Henry	VA
K	Fairfax	VA

Figure 1 The approximate county locations for twelve large *Pinus virginiana* trees listed in Table 6, including the current national champion in the NRCT, the largest tree measured since 1997 in FIADB (also included in Table 3), and the ten largest trees (by partial points) measured after 2015 in the FIADB.

from probability samples that could be used for the same purpose, perhaps after some adaptation to our procedure. For instance, a focused search in a limited number of urban areas could be conducted using the Urban DataMart FIA database (available at https://apps.fs.usda.gov/fia/datamart/datamart.html). Although there are many challenges to tree growth in urban environments, such as root restrictions and elevated air pollution levels, (Dervishi et al. 2022; Franceschi et al. 2023; Hurley and Heinrich 2023; Sand et al. 2018; Shi et al. 2023) some studies have found plant growth to sometimes be greater in urban environments (e.g., Briber et al. 2015, and Gregg et al. 2003). Additionally, some urban trees are treasured and protected, allowing them to grow quite large.

The species listed in Table S1 would have a Z_s statistic of 1 if we assumed $PPFIA_S = 0$ for these species, as they have not been observed by FIA on forested sample plots. As noted, ninety-four of these species are listed as potentially observable by FIA so they must be relatively rare on forest land to not have been observed at all by FIA since 1998. An exception to this would be for species that are rare but known to be clustered in small geographic areas. An adaptive sampling design as suggested in Roesch (1993) would be less helpful for the species listed in Table S1, as such a design does require the first observance of a species. Nevertheless, FIA could intensify its sample in areas where the species has been found and listed in the NRCT and the various state champion tree lists. We note that FIA has intensified its sample to achieve better estimates of attributes of special interest through various mechanisms in the past, most notably through the incorporation of a macro-plot to increase the sample of very large trees in the Pacific Northwest (Gray et al. 2012; Roesch and Van Deusen 2010; Tinkham et al. 2018).

Besides assisting in the quest for the biggest trees, this suite of tables can provide valuable information to the National Forest Inventory (NFI) effort in the United States. We have already mentioned the quality control potential that use of the NRCT has for FIA. Additionally, the NFI will become increasingly concerned with all tree species, which might someday require a change in the sample design to capture more of these "outlier" species as general interest in rare events increases. So far, all we can say about the species listed in Table S1 is that they are too rare on forest land for the FIA sample to have observed them, whereas it is often the extremes of a population that are of the greatest interest. One reason for this

Downloaded from https://academic.oup.com/jof/advance-article/doi/10.1093/jofore/fvad058/7517008 by USDA APHIS HQ Library user on 27 February 2024

is that changes in the extremes can serve as a harbinger or even as the "canary in the coal mine" as we try to assess the full effects of climate change. That is, most of these species are rare because their environmental requirements are very limited and specific, and minute changes in one or more environmental measures might have a large impact, either positive or negative, on the abundance of these rare species first.

Conclusion

Natural resource professionals are well trained in formal scientific investigatory methods but are often less familiar with the many ways in which citizen science efforts can and do further our understanding of our environment. These efforts are universally beneficial as they keep scientists and their communities engaged with each other. Here, we have shown how two seemingly disparate efforts can complement each other, synergizing the commonalities between the probability sample conducted by the Forest Service's FIA program and the citizen science effort associated with the NRCT. Although the inputs, attributes, and goals of these efforts differ greatly, the strengths of each can contribute to and further the objectives of the other.

Finally, we note that, with little to no modification, the approach we have used here could be used in many other countries, because many have both a champion tree citizen science effort, often known as a monument tree program, and an NFI. A few examples of the former can be found in Moore and Hughes (2014), Lai et al. (2019), and Sladonja et al. (2023), whereas nationally compatible examples of the latter are found in Gschwantner et al. (2022), Mackenthun (2011), MPIGA (2018), NFI (2021), Pelz and Cunia (1985), and Zeng et al. (2015).

Supplementary Material

Supplementary data is available at *Journal of Forestry* online.

Acknowledgments

Two anonymous reviewers and an associate editor provided valuable comments that led to the improvement of this manuscript.

Funding

This research was funded by the USDA Forest Service, Southern Research Station, Forest Inventory and Analysis Program.

Conflict of Interest

The authors have no conflicts of interest to declare.

Data availability

The data underlying this article came from two publicly available databases. The Forest Inventory and Analysis Database (FIADB) can be accessed at https://apps.fs.usda.gov/fia/datamart/datamart.html, and the National Register of Champion Trees can be accessed at https://www.americanforests.org/champion-trees/champion-trees-registry/.

Appendix 1: In this appendix, we include the latest URL found for a website leading to information for each state's champion tree program.

State	Website URL
Alabama	https://forestry.alabama.gov/Pages/Management/Champion_Tree.aspx
Alaska	Has been managed by Don Bertolette (donbertolette@me.com) Alaska's Big Tree Coordinator
Arizona	https://dffm.az.gov/arizonas-magnificent-trees
Arkansas	https://www.agriculture.arkansas.gov/forestry/champion-trees/
California	https://californiabigtrees.calpoly.edu/
Colorado	https://www.coloradotrees.org/champion-tree-program
Connecticut	http://oak.conncoll.edu:8080/notabletrees/Champs-ByScientificName.jsp
Delaware	https://news.delaware.gov/2019/05/21/new-big-trees-of-delaware/
Florida	https://www.fdacs.gov/Forest-Wildfire/Our-Forests/Florida-Champion-Trees
Georgia	https://gatrees.org/learn-explore/champion-trees/
Hawaii	https://dlnr.hawaii.gov/forestry/info/big-tree/
Idaho	https://www.uidaho.edu/extension/forestry/big-trees
Illinois	https://univofillinois.maps.arcgis.com/apps/Shortlist/index.html?appid=090997c-75b2e4ca39dd7d35db4328962
Indiana	https://www.in.gov/dnr/forestry/forestry-publications-and-presentations/indiana-big-tree-register/
Iowa	https://www.iowadnr.gov/Portals/idnr/uploads/forestry/Big%20Trees%20of%20Iowa%20Web-ready.pdf
Kansas	https://www.kansasforests.org/discover_kansas_forests/championtrees.html
Kentucky	https://eec.ky.gov/Natural-Resources/Forestry/ky-champion-trees/Pages/default.aspx
Louisiana	https://www.laforestry.com/champion-trees-in-louisiana
Maine	https://digitalmaine.com/for_docs/265/
Maryland	https://dnr.maryland.gov/forests/Pages/trees/bigtree.aspx
Massachusetts	https://www.mass.gov/guides/massachusetts-legacy-tree-program
Michigan	https://michiganbotanicalsociety.org/big-tree
Minnesota	https://www.dnr.state.mn.us/trees_shrubs/bigtree/big-tree-champions.html
Mississippi	https://www.mfc.ms.gov/2016/02/new-champion-trees-discovered/
Missouri	https://mdc.mo.gov/trees-plants/champion-trees
Montana	https://dnrc.mt.gov/Forestry/Forest-Management/montana-big-trees-program
Nebraska	https://nfs.unl.edu/registry
Nevada	http://forestry.nv.gov/nevadas-big-tree-program
New Hampshire	https://extension.unh.edu/natural-resources/forests-trees/trees/nh-big-trees
New Jersey	https://www.nj.gov/dep/parksandforests/forest/big-trees/treesofinterest.html
New Mexico	https://www.emnrd.nm.gov/sfd/urban-and-community-forestry/find-or-register-a-big-tree/
New York	https://www.dec.ny.gov/animals/5248.html

Downloaded from https://academic.oup.com/jof/advance-article/doi/10.1093/jofore/fvad058/7517008 by USDA APHIS HQ Library user on 27 February 2024

State	Website URL
North Carolina	https://ncforestservice.gov/Urban/nc_champion_big_trees_overview.htm
North Dakota	https://www.ag.ndsu.edu/ndfs/documents/north-dakota-champion-tree-register-2021.pdf
Ohio	https://ohiodnr.gov/discover-and-learn/safety-conservation/about-ODNR/forestry/champion-trees
Oklahoma	https://ag.ok.gov/championtrees/
Oregon	https://www.championtreeregistry.com/championtreeregistry
Pennsylvania	https://www.pabigtrees.com/
Rhode Island	https://ritree.org/champion-tree/
South Carolina	https://www.clemson.edu/cafls/champtree/index.html
South Dakota	https://danr.sd.gov/Conservation/Forestry/TreesofSouthDakota/BigTreeRegister/default.aspx
Tennessee	https://naturalresources.tennessee.edu/champion-tree/
Texas	https://texasforestinfo.tamu.edu/BigTreeRegistry/
Utah	https://utahurbanforest.org/amazing-trees/big-tree-directory
Vermont	https://fpr.vermont.gov/forest/vermonts-forests/vermont-big-trees
Virginia	https://bigtree.cnre.vt.edu/
Washington	https://www.championtreeregistry.com/championtreeregistry
West Virginia	https://wvforestry.com/big-tree-program/
Wisconsin	https://dnr.wisconsin.gov/topic/forests/championtrees
Wyoming	https://wsfd.wyo.gov/forestry-assistance-programs/community-forestry/champion-tree-program

Literature Cited

American Forests. 2023. "The National Champion Trees Program." *Insights & Learning*. https://www.americanforests.org/champion-trees/.

Briber, B.M., L.R. Hutyra, A.B. Reinmann, S.M. Raciti, V.K. Dearborn, C.E. Holden, and A.L. Dunn. 2015. "2015 Tree Productivity Enhanced with Conversion from Forest to Urban Land Covers." *PLoS One* 10 (8): e0136237. https://doi.org/10.1371/journal.pone.0136237.

Burrill, E.A., A.M. Wilson, J.A. Turner, S.A. Pugh, J. Menlove, G. Christiansen, B.L. Conkling, and W. David. 2018. "The Forest Inventory and Analysis Database: Database Description and User Guide Version 8.0 for Phase 2." *Forest Inventory and Analysis DataMart*. Last modified December 4, 2023. https://apps.fs.usda.gov/fia/datamart/datamart.html.

de Carvalho, M. 2016. "Statistics of Extremes: Challenges and Opportunities." In *Extreme Events in Finance: A Handbook of Extreme Value Theory and Its Applications*, edited by F. Longin. Hoboken, NJ: Wiley. https://doi.org/10.1002/9781118650318.ch9.

Dervishi, V., W. Poschenrieder, T. Rötzer, A. Moser-Reischl, and H. Pretzsch. 2022. "Effects of Climate and Drought on Stem Diameter Growth of Urban Tree Species." *Forests* 13 (5): 641. https://doi.org/10.3390/f13050641.

Franceschi, E., A. Moser-Reischl, M. Honold, M.A. Rahman, H. Pretzsch, S. Pauleit, and T. Rötzer. 2023. "Urban Environment, Drought Events and Climate Change Strongly Affect the Growth of Common Urban Tree Species in a Temperate City." *Urban Forestry & Urban Greening* 88 (October 2023): 128083. https://doi.org/10.1016/j.ufug.2023.128083.

Gray, Andrew N., Thomas J. Brandeis, John D. Shaw, William H. McWilliams, and Patrick D. Miles. 2012. "Forest Inventory and Analysis Database of the United States of America (FIA)." *Biodiversity and Ecology* 4 (2012): 225–231.

Gregg, J.W., C.G. Jones, and T.E. Dawson. 2003. "Urbanization Effects on Tree Growth in the Vicinity of New York City." *Nature* 424 (6945): 183–187.

Gschwantner, T., I. Alberdi, S. Bauwens, S. Bender, D. Borota, M. Bosela, O. Bouriaud, et al. 2022. "Growing Stock Monitoring by European National Forest Inventories: Historical Origins, Current Methods and Harmonisation." *Forest Ecology and Management* 505 (February 2022): 119868. https://doi.org/10.1016/j.foreco.2021.119868.

Hurley, A.G., and I. Heinrich. 2023. "Assessing Urban-Heating Impact on Street Tree Growth in Berlin with Open Inventory and Environmental Data." *Urban Ecosystem* (October 2023): 1573–1642. https://doi.org/10.1007/s11252-023-01450-9.

Kerson, R. 1989. "Lab for the Environment." *MIT Technology Review* 92 (1): 11–12.

Lai, P.Y., C.Y. Jim, G.D. Tang, W.J. Hong, and H. Zhang. 2019. "Spatial Differentiation of Heritage Trees in the Rapidly-Urbanizing City of Shenzhen, China." *Landscape and Urban Planning* 181 (January 2019): 148–156.

Leverett, B., and D. Bertolette. 2014. "Measuring Guidelines Handbook. National Register of Champion Trees." *American Forests*. https://www.americanforests.org/wp-content/uploads/2014/12/AF-Tree-Measuring-Guidelines_LR.pdf.

Little, E.L., Jr. 1979. *Checklist of United States Trees (Native and Naturalized). Agriculture Handbook No. 541*. Washington, DC: USDA Forest Service, Washington Office.

Mackenthun, G.L., ed. 2011. "European Champion Tree Forum Arboretum Park Härle, Bonn, Germany, 7th to 9th October 2011." https://www.treeregister.org/files/resources/germany-bonn-2011.pdf.

May, D.M. 1990. *Big Trees of the Midsouth Forest Survey*, 17. Research Note SO-359. New Orleans, LA: USDA Forest Service, Southern Forest Experiment Station.

Moore, G., and S. Hughes. 2014. "The National Trust of Australia (Victoria), Register of Significant Trees: Now Protecting Community Assets and Heritage with Smartphone Technology." *Arboricultural Journal* 36 (1): 3–17.

Montreal Process Implementation Group for Australia (MPIGA). 2018. "Montreal Process Implementation Group for Australia and National Forest Inventory Steering Committee, 2018." In *Australia's State of the Forests Report 2018*. Canberra, Australia: Australian Bureau of Agricultural and Resource Economics and Sciences, Department of Agriculture and Water Resources. www.agriculture.gov.au/abares/forestsaustralia/sofr/sofr-2018.

National Forest Inventory (NFI). 2021. "Canada's National Forest Inventory Business Process, Version 8.0." *General Documentation*. https://nfi.nfis.org/en/general.

Oswalt, C.M., S.N. Oswalt, and T.J. Brandeis. 2010. *Big Trees in the Southern Forest Inventory*, 33. Research Note SRS–19. Asheville, NC: USDA Forest Service, Southern Research Station.

Pelz, D.R., and T. Cunia, eds. 1985. *Forstliche Nationalinventuren in Europa - National Forest Inventory in Europe*, 85–3. Freiburg, Germany: Universität Freiburg, Department of Forest Biometrics.

Roesch, F.A., Jr. 1993. "Adaptive Cluster Sampling for Forest Inventories." *Forest Science* 39 (4): 655–669.

Roesch, F.A., and W.H. McWilliams. 2007. "Searching for American Chestnut – The Estimation of Rare Species Attributes in a National Forest Inventory. In *Proceedings of the Seventh Annual Forest Inventory and Analysis Symposium. October 3–6, 2005. Portland, Maine*, edited by R.E. McRoberts, G.A. Reams, P.C. Van Deusen, and W.H. McWilliams, vii + 319. General Technical Report WO-77. Washington, DC: USDA Forest Service, Washington Office.

Roesch, F.A., and P.C. Van Deusen. 2010. "Anomalous Diameter Distribution Shifts Estimated from FIA Inventories Through Time." *Forestry* 83 (3): 269–276.

Ruggles, R., and H. Brodie. 1947. "An Empirical Approach to Economic Intelligence in World War II." *Journal of the American Statistical Association* 42 (237): 72–91.

Downloaded from https://academic.oup.com/jof/advance-article/doi/10.1093/jofore/fvad058/7517008 by USDA APHIS HQ Library user on 27 February 2024

Sand, E., J. Konarska, A.W. Howe, Y. Andersson-Sköld, F. Moldan, H. Pleijel, and J. Uddling. 2018. "Effects of Ground Surface Permeability on the Growth of Urban Linden Trees." *Urban Ecosystems* 21 (4): 691–696.

Shi, F., Q. Meng, L. Pan, and J. Wang. 2023. "Root Damage of Street Trees in Urban Environments: An Overview of its Hazards, Causes, and Prevention and Control Measures." *Science of the Total Environment* 904: 166728. https://doi.org/10.1016/j.scitotenv.2023.166728.

Sladonja, B., D. Damijanić, M. Uzelac, and D. Poljuha. 2023. "Catalogue of Super-Trees in Istria (Croatia) Created as a Result of the Citizen Science Action." *Frontiers in Environmental Science* 11: 1154101.

Stearns, J. 1940. "Let's Find and Save the Biggest Trees." *American Forests* 1940 (September): 413.

Tinkham, W.T., P.R. Mahoney, A.T. Hudak, G.M. Domke, M.J. Falkowski, C.W. Woodall, and A.M. Smith. 2018. "Applications of the United States Forest Inventory and Analysis Dataset: A Review and Future Directions." *Canadian Journal of Forest Research* 48 (11): 1251–1268.

Visser, I., V.D. Schmittmann, and M.E.J. Raijmakers. 2006. "Markov Process Models for Discrimination Learning, Chapter 14." In *Longitudinal Models in the Behavioral and Related Sciences*, edited by K. van Monfort, J. Oud, and A. Satorra, 464. New York, NY: Routledge. https://doi.org/10.4324/9781315091655.

Zeng, W.S., E. Tomppo, S.P. Healey, and K.V. Gadow. 2015. "The National Forest Inventory in China: History, Results, International Context." *Forest Ecosystems* 2 (1): 23.

Downloaded from https://academic.oup.com/jof/advance-article/doi/10.1093/jofore/fvad058/7517008 by USDA APHIS HQ Library user on 27 February 2024