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New Seed-Collection Zones for the Eastern United States: The Eastern Seed Zone Forum

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Abstract

Reforestation and restoration efforts have traditionally relied on "local" seed sources as planting stock. The term "local" has different meanings in different locales, since no single set of seed-collection zones has yet been widely adopted across the eastern United States. Given concerns about mitigating the effects of climate change, forest managers are increasingly seeking to move seed sources in a process called assisted migration, which would be facilitated if a common set of seed-collection zones were available. We developed a map of 245 seed-collection zones for 37 states by combining two ecologically important layers: plant hardiness zones and ecoregions. These new seed-collection zones should be used by seed collectors and nurseries to describe the origin of seed for plants and trees in the eastern United States. Common garden studies remain the gold standard for determining how far to move seed from any particular seed-collection zone. For species that have not been field-tested, seed movement that is limited either within a seed-collection zone or between adjacent seed-collection zones is a reasonable general guideline.

Keywords: Seed-collection zone, seed transfer, assisted migration, plant-hardiness zones, ecoprovinces

Trees are long-lived perennials that can persist on a landscape for decades, if not centuries. Regeneration success at a given site is optimized if plant material is matched to current and anticipated climates at the site. Land managers require copious amounts of seed to accomplish their goals: in 2017, over 1 billion conservation-grade tree seedlings alone were planted across the US (Hernández et al. 2018). ("Conservation grade" is generally understood to include seedlings that are used in reforestation or restoration plantings and are grown from wild or improved seed sources, as bare root or containerized stock types. This definition generally excludes cultivars, forbs, shrubs, and plants used for ornamental purposes.) Seed is a critical resource, since nearly all conservation-grade seedlings, both understory plants and trees, are grown from seed (as opposed to cuttings or other clonally propagated material). The process of collecting seed is both an art and a science, requiring that skilled workers scour forests, natural areas, seed orchards, and native seed beds to find, collect, and process seed.

The use of locally adapted seed is a key step for any restoration program (Erickson et al. 2012, Jones 2013). Most commercial seed collectors operate across

Management and Policy Implications

We developed a new set of seed-collection zones for use by land managers across the eastern United States to define origin of seed planted in restoration and reforestation projects. The seed-collection zones may be used to define seed origin for most plants and tree species that are used in reforestation or restoration work. These seed-collection zones may be used with existing seed-transfer guidelines or may motivate development of new common garden studies to evaluate seed transfer among collection zones. Finally, new seed-collection zones should have practical importance for seed transfer to mitigate climate-change impacts, for example, assisted migration.

multiple states, selling to different nurseries across a broad geographic area. However, information on the genetic and adaptive backgrounds of plant material is often lacking in restoration plantings (Kramer et al. 2019), despite its importance for the success of the restoration effort. The risks of using inappropriate seed sources can be pervasive: seed that originates from distant locales may be mismatched in terms of bud break (growth initiation in the spring), bud set (cessation of height growth in the summer/fall), flower production, or cold hardiness, among other characteristics. These mismatches may be triggered by excessive cold temperatures at the planting site (i.e., early-season frosts, or nadir temperatures in the coldest winter months that exceed the plant's cold hardiness), but also by different day lengths (photoperiod) between origin and planting site. The effects of this mismatch may be visible immediately or not until many years later. These mismatches can reduce the successes of reforestation and restoration, because new plants may be unable to survive, or may not reproduce successfully.

Seed Zone or Seed-Collection Zone?

Two concepts are key to matching the seed source to the planting site: the seed-collection zone, which defines the origin of the seed, and the seed-use guideline, also known as the seed-transfer rule, which describes where seed from a particular location can be planted. In the Eastern United States (land area east of the Great Plains), seed-transfer guidelines have been developed for a few workhorse species such as the southern pines (Schmidtling 2001), but guidelines for determining the best genetic sources for a particular planting site are not available for most taxa. Because seed-transfer guidelines are generally not available, the paradigm "local is best" has been widely used in the past (Sackville 2001, Erickson et al. 2012).

Many land-management organizations maintain locally adapted plant populations by collecting seed from, and planting seedlings into, the same seed-collection zone. Although this approach has generally been successful in the past, it has led to a blurring of the separate concepts of seed origin and seed deployment. Many practitioners simply refer to a "seed zone," which they use as an unofficial shortcut to describe both the geographic area in which seed was collected and the geographic area where it can be safely transferred without compromising adaptation. Confounding these separate concepts in this way creates several problems. First, practitioners differ in how far they are willing to move seed: some are willing to move seed a long distance, whereas others find this too risky. Second, species differ in how far they should be moved. Although some species such as jack pine (*Pinus banksiana*) should be moved only relatively short distances (Jeffers and Jensen 1980), other species such as red oak (*Quercus rubra*) can safely be moved longer distances (Leites et al. 2019). Third, climate change will eventually invalidate the rule of thumb that local seed sources are best. Some land managers may already prefer to choose to combine seeds from a nonlocal seed source that is adapted to an anticipated future climate, a process known as assisted migration, with a local seed source that is adapted to past and current climates (Havens et al. 2015). Knowing the seed-collection zone of the seedlot's origin is a necessary precursor to employing assisted migration as a strategy to offset the effects of climate change.

Knowing the origin of seed is the first step to determining where the seed should be deployed. It would be complex and contentious to develop a set of seed-transfer guidelines for all land owners and all species, but it is possible to develop a system to describe seed origin that would be useful in most situations, and to create some generalized seed-transfer recommendations based on the best available science (e.g., Giencke et al. 2018). A number of organizations have developed ways to define seed origin that have worked for them in the past. The USDA Forest Service established seed-collection zones in the Midwest, Northeast, and Southeast that classify lands only on national forests.

The states of Minnesota, Wisconsin, and Tennessee have each used a set of seed-collection zones that apply to lands only within those states. Going forward, we can expect that seed transfer across ownerships and political boundaries will become even more common than it is today. There is a need for a system to describe the climatic and ecological characteristics of seed origin that would apply across all of the eastern United States and could be extended to Canada as well. The decision on where seed from a particular origin should be deployed will be left to the individual land owners and land managers. Developing standard seed-collection zones could assist in making more dynamic seed-transfer decisions to mitigate climate change (Potter and Hargrave 2012, Giencke et al. 2018).

Formation of the Eastern Seed Zone Forum (ESZF)

In 2015, the USDA Forest Service began to assemble a team to develop seed-collection zones for all of the eastern United States. The group included Forest Service technical experts in State and Private Forestry, the Southern Research Station, and the National Forest System. Southern Regional Extension Forestry provided website expertise and hosted webinar forums as part of a cooperative agreement with State and Private Forestry. The group adopted the name ESZF and grew to include others within, and external to, the USDA Forest Service. The mission of the ESZF is to develop a tool to describe the origin of seed, develop common nomenclature, and set a standard for defining locality in native plants and trees.

One of the earliest tasks of the ESZF was to clearly define the parameters of a seed-collection zone. Seed-collection zones are most often designated with abiotic (climate) variables that are key drivers of natural selection, such as minimum temperature, annual or growing-season precipitation, and elevation, which is used as a surrogate for climate variables. Typically, some combination of these variables are overlaid, and common areas are delineated as a seed-collection zone. We decided to develop one set of seed-collection zones, from which transfer recommendations (movement among seed zones) could be developed for each taxon or group of taxa at a later time. As such, ESZF seed-collection zones are smaller than those traditionally used to describe seed origin for many tree taxa, but also serve as a reasonable delineator of origin for herbaceous plants (such as grasses and forbs) that are important in ecosystem-restoration efforts, because ecoregions and climate are both useful in delineating seed zones for plants (e.g., Gibson and Nelson 2017).

A pragmatic map of the seed-collection zone and a user guide are needed to serve all sectors of the nursery industry including seed dealers and private and public land managers across the eastern United States. This will only be achievable if all sectors of the plant material economy are willing to adopt the zones in all phases of their operations: seed collection, cleaning/processing, storing, planting, selling, and ordering plant material. To work toward a consensus among these sectors, we set up a website www.easternseedzones.com and hosted a monthly webinar series in 2018 to increase engagement by public and private sectors. All 13 webinars are archived on the website and may be viewed online at no cost. The webinars were presented by scientists and covered a number of topics including seed source trials, climate, ecological classification, and generalized zones established in the western United States.

In May 2018, a seed zone summit was hosted by the University of Kentucky in Lexington to provide a space for in-person discussion among the diverse partners who attended. From those discussions, we chose to develop seed zones based on a combination of Bailey's ecoregions (Cleland et al. 2007) and USDA Plant Hardiness Zones (USDA ARS 2012). We selected Bailey's system, over Omernik's level III ecoregions (Omernik 1987), because it is widely used in the East by state and federal agencies. We chose USDA Plant Hardiness Zones (PHZ) developed in 2012 by the USDA Agricultural Research Service (ARS 2012) because they are easy to understand and widely used in the plant material industry, and cold temperatures during winter are known to drive adaptation to climate (reviewed by Aitken and Bemmels 2016). Some measure of precipitation was considered, although few studies have demonstrated a clear role of precipitation regimes in adaptation within species in the East. Additionally, the map that resulted from the addition of a precipitation layer contained numerous, very small potential seed-collection zones that would be difficult to implement. We decided that differences in precipitation were adequately captured by the province scale in the ecoregion hierarchy in Bailey's system and were not necessary as an additional layer. Lastly, we chose to align the zones with county boundaries because most counties in the eastern United States are relatively small and easily defined/mapped, and seed collectors are already accustomed to designating seed source by county.

Derivation of the Latest Seed Zone Map

We developed the map using ArcGIS software (ESRI ArcMap version 10.5.1). To create the map, the counties were separately assigned to the hardiness zone and ecoregion that encompassed the largest area within the county (Figures 1–2), and then these were combined. Preliminary seed-collection zones were formed from areas that shared a province and hardiness zone designation. The final map contained 16 different hardiness zones ranging from 3a (minimum temperature –40 to –35° F) to 9b (minimum temperature 25–30° F), 21 different ecological provinces, and 112 different ecological sections (the next smaller unit in the ecoregion hierarchy than provinces). Sections may be important for tracking the origin of plants on a relatively small geographic scale for gene-conservation purposes, but are not included on the map. The initial overlay resulted in version 1.0 that contained 103 different seed-zone demarcations. This map was reviewed by a team of experts who determined that additional revisions were needed in some areas of the map, but in general, the team determined that the seed zones were appropriately sized: zones are large enough for bulking seed for commercial seed collectors, but small enough to delineate important differences in adaptation for most taxa.

Version 2.1 (the current version on the website, Figure 3) was created after reassigning the seed-zone designations of 163 counties, based on local knowledge, with the goal of broadening the size of the seed zones, and keeping them as continuous as possible. For example, 13 counties in Indiana border the Ohio River in the southern part of the state. On V2.1, 11 of those 13 counties were assigned to one seed-collection zone, whereas the other two were assigned to a different zone because of slight differences in hardiness zones for those counties. We revised the seed-zone demarcations for the two counties so that all 13 along the Ohio river in Indiana belonged to the same seed zone. We tried, when possible, to maintain the PHZ when reassigning a county to a different seed zone, but this was not always possible. In Indiana, the two counties that were matched to neighboring counties were moved to a cooler PHZ. Across all states, 71 counties were reassigned to a seed zone with a cooler PHZ. In 34 cases, the county was reassigned to a seed zone with a warmer PHZ; one was reassigned to an entirely different province and PHZ (Franklin County, AR). These reassignments are likely to have a minimal impact on the maps' utility, because the map does not account for variation in temperature within a county, and the changes never exceed more than one PHZ. Four counties out of 2,702

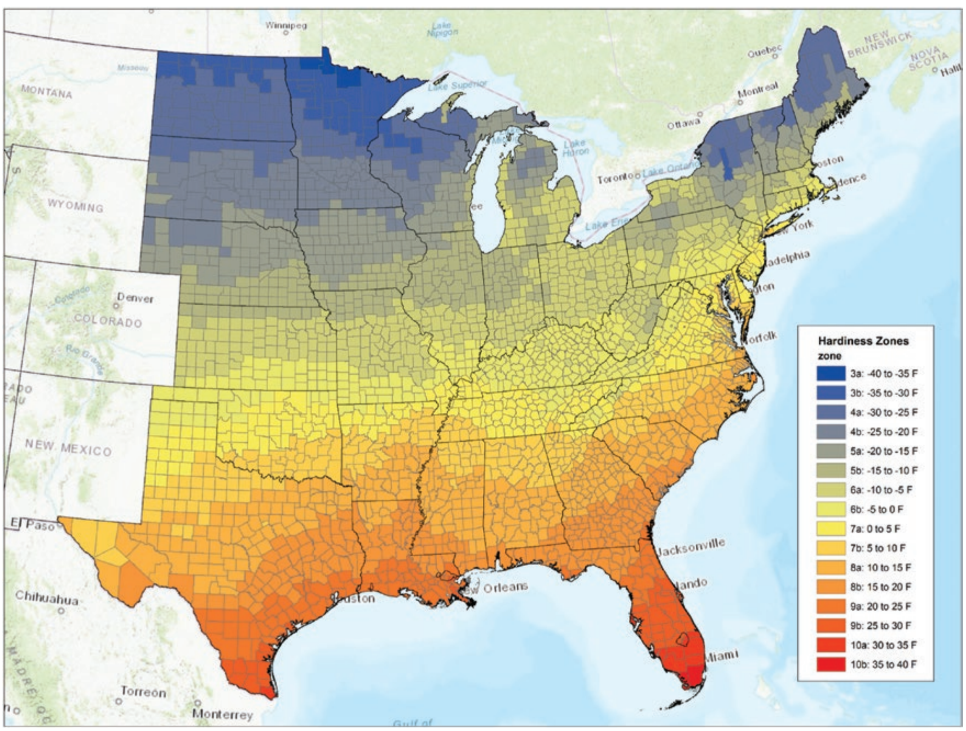

Figure 1. Plant hardiness zones (USDA Agricultural Research Service 2012) snapped to county lines. This map was used for the first layer of the seed zone map.

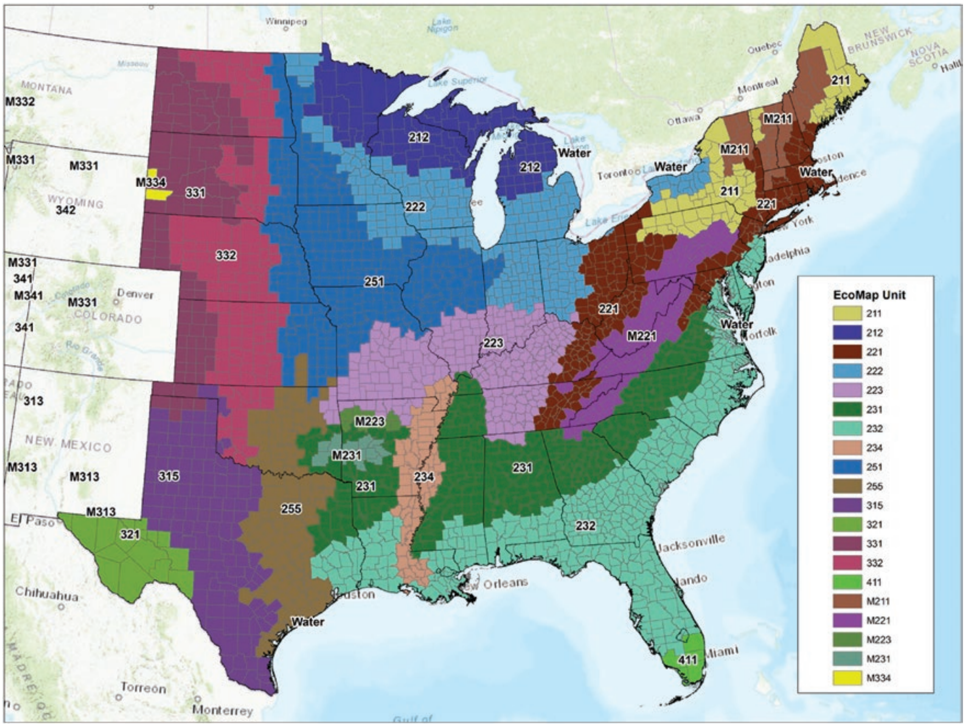

Figure 2. Bailey's ecoprovinces (Cleland et al. 2007) snapped to county lines. This was the second layer in the seed zone map.

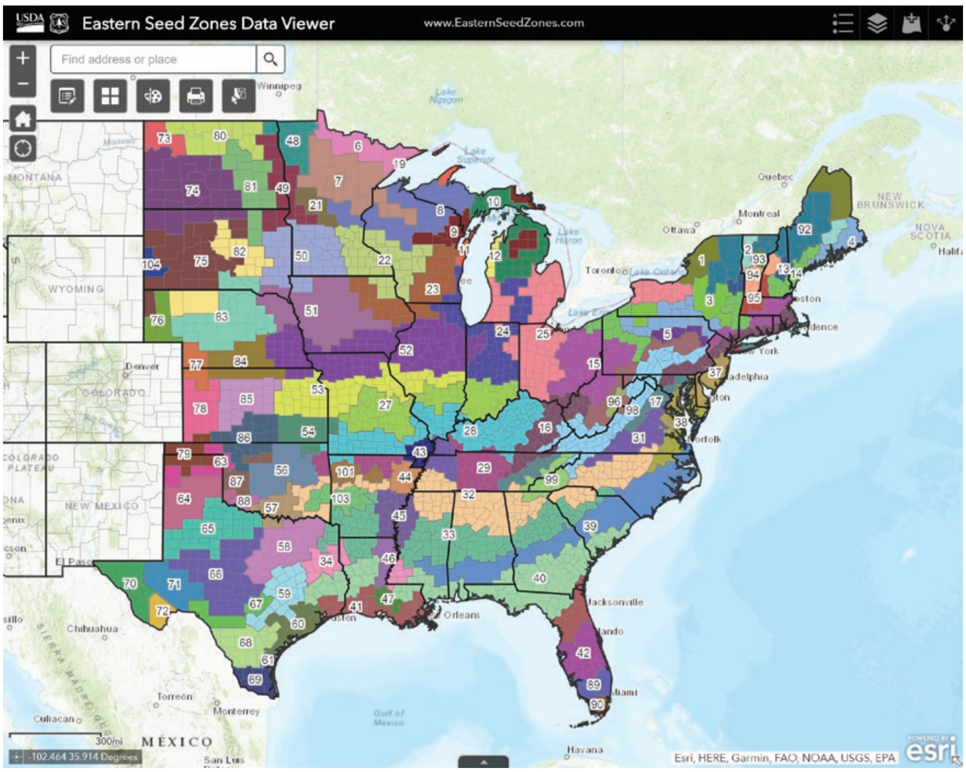

Figure 3. Latest version of the Eastern Seed Zone Forum map, version 2.1, available at www.easternseedzones.com.

were subdivided because of their large size: Houghton (MI), St. Louis (MN), Penobscot (ME), and Pennington (SD). In Minnesota, a seed-collection zone was created along the north shore of Lake Superior by separating it from the interior parts of three counties (St. Louis, Lake, and Cook Counties, Figure 4). At the end of this process, 94 different seed-collection zones (areas with the same hardiness zone and province) were defined across the 37-state area. These states span all of USDA Forest Service Regions 8 and 9, and parts of Regions 1 (North Dakota) and 2 (Kansas, Nebraska and South Dakota). The original (V 1.0) and revised maps (2.0 and 2.1) can be viewed at www.easternseedzones.com, at the link "*VIEW A DRAFT OF THE EASTERN SEED ZONE MAP*". The map does not require that ArcGIS software be installed.

Many of the seed zones span large geographic areas or are fragmented (occur in multiple noncontiguous places on the map). To improve the applicability of these seed zones, it is recommended to maintain information on the state origin of seeds whenever possible. For example, seed collected in Georgia's zone 40 should be labeled as GA-40, whereas seed collected from South Carolina in zone 40 should be described as SC-40 (Figure 5), resulting in two seed-collection zones from a single larger one. Designating states within seed-collection zones will limit long-distance transfers and mismatches that could arise. In total, 245 unique seed-collection zones, when including the state-based designations, were created for the 37 states in the eastern United States.

Recommendations for Using this Map

The seed-collection zones developed by the ESZF are intended to be a midlevel descriptor of seed origin for trees and other plant taxa that may be used to succinctly label seed collections and facilitate seed-transfer decisions for nurseries and seed dealers. As an example, seed collected from across seven counties in Indiana zone IN-52 could be lumped together. This seed-collection zone is designated with a plant hardiness of 5b (minimum temperatures −15° to −10° F) and belongs to the Central Till Plains and Grand Prairies ecoregion province. Additional parameters to define the seed-collection zones to ecoregion/section levels, or other parameters as the collectors desire, may be needed for those who choose to delineate seed origin at a more localized level. In these cases, the seed-collection zone (IN-52) could be appended with additional information (IN-52-Wabash Riparian zone). For trees, it may

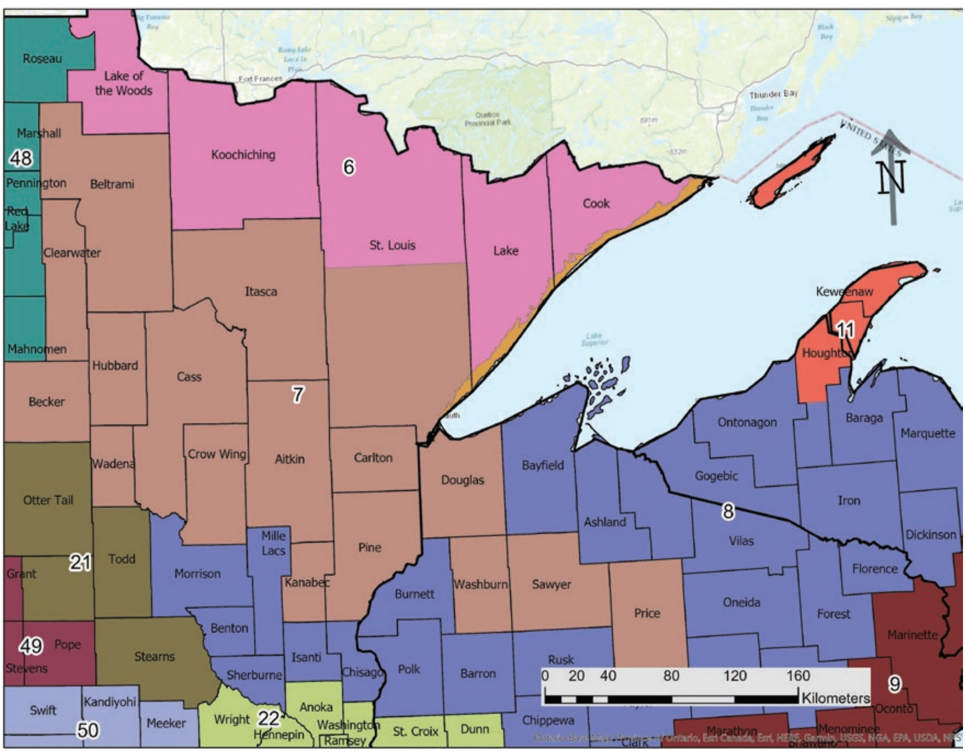

Figure 4. Seed zones for the Lake States region. St. Louis County (northeast Minnesota) and Houghton County (Michigan's Upper Peninsula) were subdivided. A new seed zone that follows a subsection along the north shore of Minnesota (19) was also added.

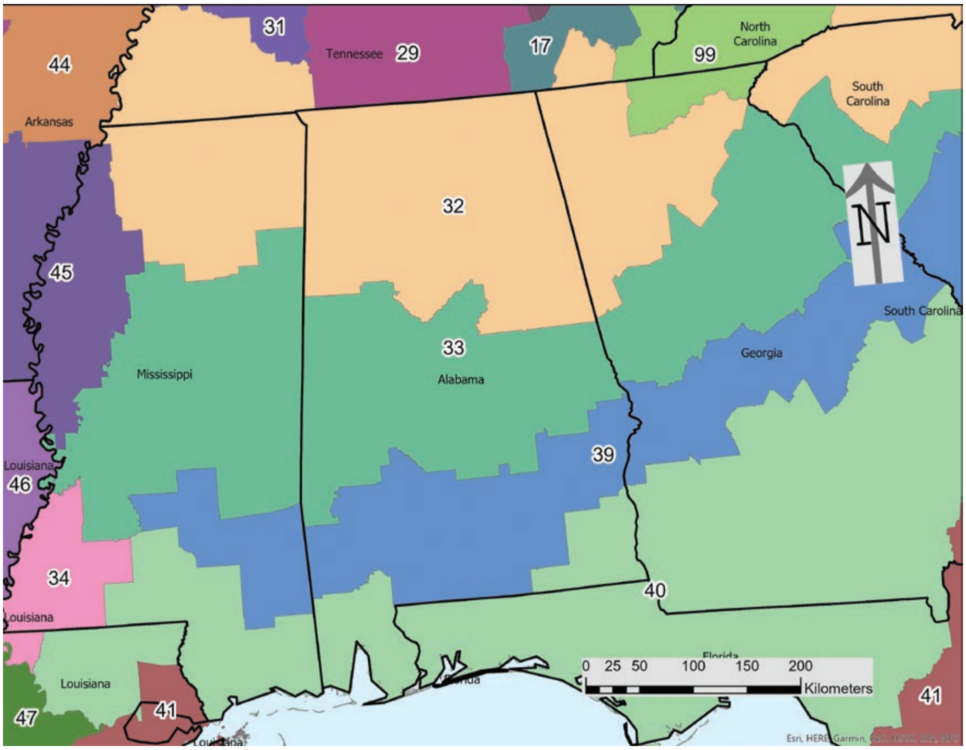

Figure 5. Seed zones for the southeast US: Mississippi, Alabama, Georgia and South Carolina. Seed zones 32 (tan), 33 (green), 39 (blue), and 40 (light green) traverse the southern region. For these multistate seed zones, seed should be labeled with the state and seed zone number.

be desirable to bulk seed with seed from an adjoining zone (e.g., IN-24 and IN-25) that has the same hardiness zone (also 5b).

Small, private vendors are the core of the seed industry across the US (White et al. 2018). The map and spreadsheet that accompany the map are intended for use by seed collectors and nurseries who grow source-identified seedlings for restoration or reforestation. Specifications for seed should, ideally, include the seed-collection zone of origin at a minimum. We encourage seed collectors to use either the seed zone designation (52) or the state-seed zone (IN-52) designation to label their seedlots. For seedlots that include seed from multiple states or seed zones, include all the zones and states encompassed (e.g., IN-52,54) on the label so the consumer has a general idea of the origin. Once nurseries purchase seed, they need to decide whether to bulk it with additional seedlots or maintain it separately, but ideally the seed-collection zone is retained for the consumer.

Future Needs

The seed-collection zones, once adopted, can serve several important uses for land managers. We are proposing to add these new Eastern Seed-Collection Zones to the Seedlot Selection Tool, a climate analog website hosted by the Conservation Biology Institute (CBI 2015). This would allow seed collectors or nurseries with labeled seedlots to market their plant material for climate-adaptation purposes. It is important to note that genetic considerations are not factored in the seed-collection zones because genetics are taxon-specific. Provenance trials and progeny tests for many tree species have been installed and are gaining new value for interpreting climate-change effects (Matyas 1994, 1996). Geneticists should take full advantage of data from these trials (Leites et al. 2019), many of which are no longer actively managed or may have been liquidated. The revitalization of these sites is an ongoing effort of the Northern Forest Genetics Association, an informal group of federal, state, and university-based geneticists. For some taxa, new trials should be installed to examine current seed-collection zone effectiveness, and to develop seed-transfer decisions in the future (St Clair et al. 2013, Giencke et al. 2018). Diligence with seed sourcing can increase the likelihood that a seed source is adapted to its local climate, but heightened extremes and variation in temperature and precipitation will create challenging conditions for the future of restoration efforts. Additional monitoring and maintenance of plantings may be necessary to ensure that planted seedlings will thrive and survive in the future.

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