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Climate-Smart Seed Sourcing for Resilient Pennsylvania Forests

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Seedlings at Tree Pittsburgh Heritage Nursery | Laura Leites

RESTORATION, REFORESTATION, AND SUPPLEMENTAL PLANTINGS ARE BECOMING CRITICAL TO ENSURE FOREST SUSTAINABILITY

Many forests in Pennsylvania have been degraded due to high-grading, insect infestations, diseases, invasive plants, and climate change. These challenges threaten the health and longevity of forests on which we depend for ecosystem services and wood commodities. Degraded forests are generally characterized by low tree species diversity, few vigorous seed trees, and low stocking levels. In those cases, tree plantings to supplement natural regeneration will likely be needed to achieve desired species composition in the future forest. In addition, challenges in regenerating certain species, such as oak species, will also lead to an increase in planting to maintain existing forest types.

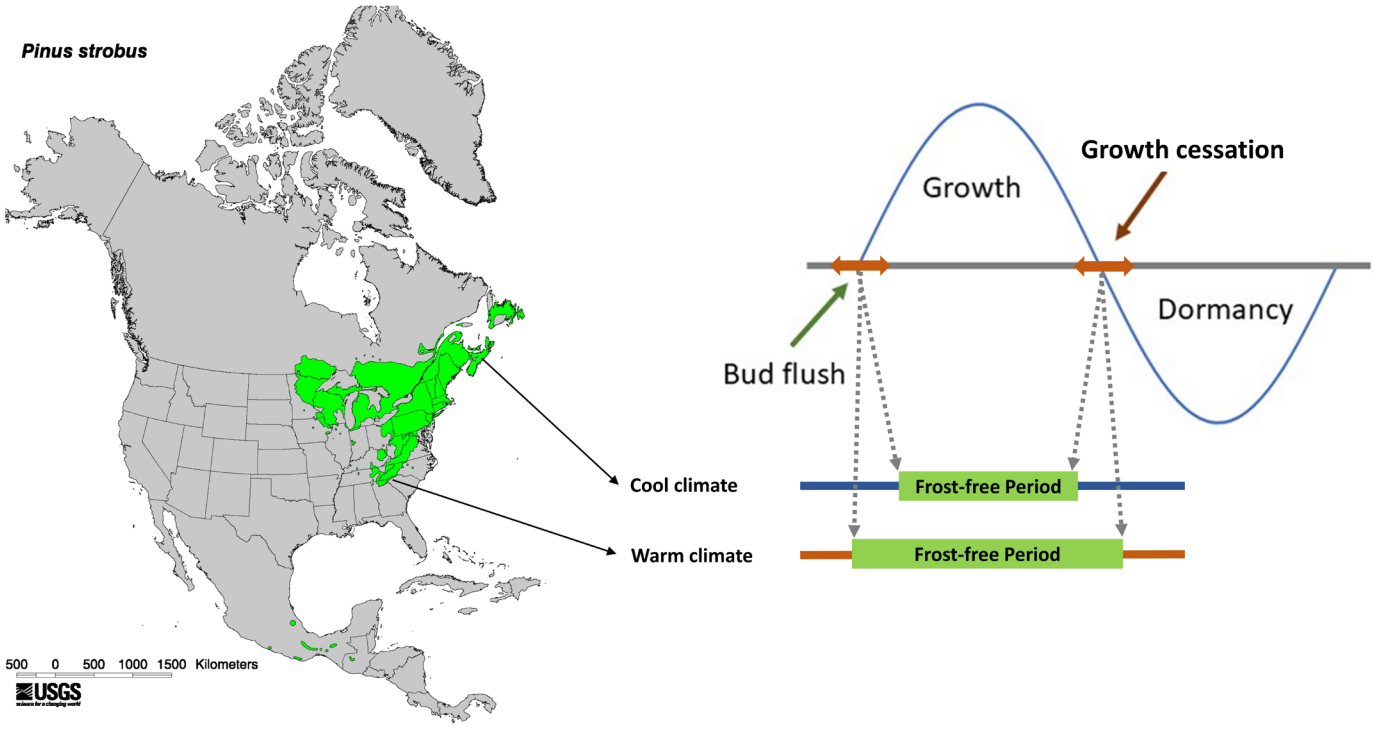
Planting of seedlings to restore, reforest, and supplement natural regeneration, is likely to continue to increase in importance in our region as a management strategy to ensure forest health and productivity now and in the future. As any experienced forester or landowner will attest, choosing the appropriate seed sources is extremely important. A seed source that is genetically well adapted to the planting site's climate and environmental conditions is critical to ensure planting success and future forest productivity.

See glossary on last page for definitions of terms used throughout this document.

WHY DO WE NEED GENETICALLY ADAPTED AND ECOLOGICALLY APPROPRIATE MATERIAL FOR PLANTING?

Tree species with wide native geographic ranges, such as eastern white pine (*Pinus strobus*, Fig. 1) and northern red oak (*Quercus rubra*), are composed of populations adapted to different segments of a species' climate range through different physiological and phenological mechanisms (e.g., timing of bud burst and bud set). Over many generations, populations become genetically adapted, and highly synchronized, to the climate they inhabit (Fig. 1). One important mechanism is the alignment of the annual growth cycle with the frost-free period. This alignment occurs through natural selection, a process that favors trees that complete their active growth when conditions are favorable. Over many generations, forest trees develop a suite of traits and attributes that are best suited to local climatic conditions. In temperate forest tree species of the northern hemisphere, trees growing along the southern part of their range are adapted to warmer climates and tend to be less cold tolerant than northerly populations. In common gardens, southerly populations also tend to have higher growth rates than local sources, but these southerly populations are less cold tolerant than locally sourced seed.

FIG. 1



Species with wide geographic ranges are composed of populations adapted to different segments of the species climate. One important mechanism is the alignment of the annual growth cycle of the trees with the frost-free period of the site they inhabit.

When choosing seed for tree planting, matching the seed source (i.e., the population) to the planting site's climate, both current and future, will enhance planting success by ensuring that the annual growth cycle of the tree matches the frost-free period of the site.

Seeds are a small cost of regeneration activities but choosing the right seed source is a defining factor of planting success and forest resilience and productivity. **Using climate-adapted seed sources is a first and critical step in achieving these goals.**

Utilizing seed sources from places that are climatically different from the planting sites may result in:

- low rates of seedling establishment,
- decreased survival rates,
- suppressed growth and reproductive success,
- increased susceptibility to insects and diseases, and
- increased mortality in older trees as environmental stress accumulates.

No amount of forest management practices compensates for the loss of vigor of a mismatched seed source. The effects of a mismatched seed source may be observed within the first year or may not be visible until decades later. Tree planting failures have occurred despite high survival and tree growth for the first several years or decades. These failures may be related to average climate conditions, but, more often, they are related to the infrequent climate, pest, or disease events to which the trees were not adapted. In many of these failures, nearby natural stands did not suffer setbacks of the same magnitude.

Two black walnut trees growing in a common garden in State College, Pennsylvania. The seed origin for the tree on the left is from a climate similar to the planting site, while the seed origin for the tree on the right is from a much warmer climate. For reference, both signs are of the same size.

Black walnut (*Juglans nigra*) growth comparison | Laura Leites

SEED COLLECTION AND TRANSFER ZONES: WHAT THEY ARE AND HOW WE USE THEM TO HELP MINIMIZE THE RISK OF MALADAPTATION

To help minimize the risk of maladaptation, or misalignment, to climate and facilitate matching seed sources to planting sites, foresters have relied for decades on *seed collection zones* and *seed transfer zones*:

Seed collection zones provide information about where the seed was collected. Ideally, the nursery would provide information on the seed collection zone for your acquired seedlings.

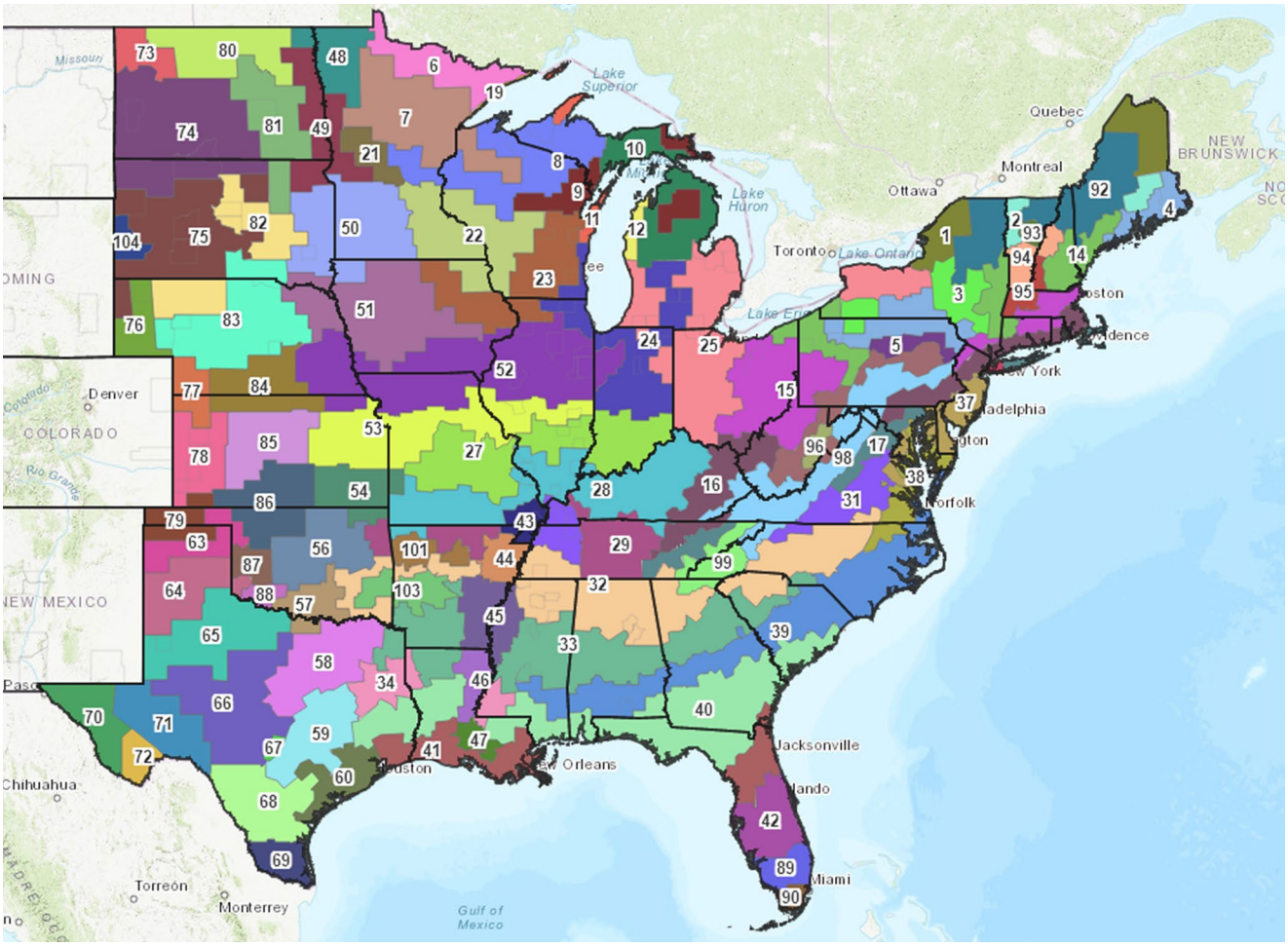
Seed transfer zones (also called seed deployment zones) provide information on how to match seed sources to planting sites. Historically, seed sources from within a zone were appropriate to plant in planting sites within that zone with little risk of climate maladaptation.

Red pine (*Pinus resinosa*) seedling | Carrie Pike

Until now, seed collection zones and seed transfer zones were synonymous because climate was considered static (not warming). The old adage, "local is best," guided foresters and landowners to use local seed sources. In both seed collection and seed transfer zones, each zone represents a geographic area with similar climate. It is important to understand that these zones are delineated to represented areas of climatic similarity but that they do not account for a species' soil, light, and other abiotic site factor preferences. It is up to the forester and/or landowner to take these aspects into consideration when selecting a species for a particular site.

Fig. 2 illustrates a seed collection zones map for the eastern US developed by the US Forest Service and collaborators (Pike et al. 2021). These zones can be used by nurseries and other seedling suppliers to provide you with information about the climate and other environmental characteristics of the seed origin.

FIG. 2



Seed collection zones for the Eastern United States. US Forest Service Eastern Seed Zone Forum (see www.easternseedzones.com for latest version, and Pike et al. 2021).

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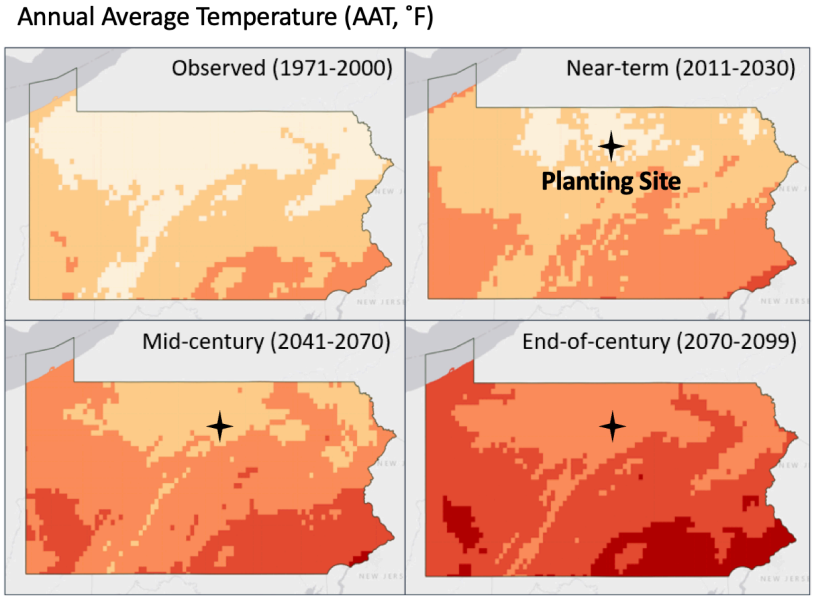
Seed transfer zones are climatically similar geographic areas within which seed could be transferred with a relatively low risk of maladaptation. Be mindful that they do not compensate for mismatched soil, site, or species light preferences.

IS LOCAL STILL BEST? A CHANGING CLIMATE IS SEPARATING SEED COLLECTION AND SEED DEPLOYMENT ZONES

Given current climate and emission scenario projections, the climate at planting time will not be the same as the climate at stand maturity, decades or centuries into the future (Fig. 3). This brings important challenges for foresters and landowners needing to match seed sources with planting sites. First, "local is best" is no longer true for the entire lifespan of the trees. Second, seed transfer zones will now change through time and will need to be regularly updated. So, how do we match seed sources to a planting site with a changing climate?

FIG. 3

Illustration of changes in climate projected to occur through the lifetime of trees planted today.



Planting Site Annual Average Temperature

Current	*Future*	
	~ 30 years	*~ 70 years*
43-47 ˚F	47-52 ˚F	52-56 ˚F

Source: PENNSYLVANIA CLIMATE IMPACTS ASSESSMENT 2021

SEED SOURCING STRATEGIES: SELECTING SEED SOURCES TO BE WELL ADAPTED NOW AND IN THE FUTURE

Because of the trees' long lifespan and the uncertainty in climate projections, uncertainty is now the main characteristic of the task of matching seed sources to planting sites. However, there are two important guideposts to aid in this process:

1. Recognize that seed collection zones are now different from seed transfer zones. That is, where seed is collected is not necessarily where it should be planted to be climatically matched to current and future climate. Therefore, knowing the climate characteristics of the collection zone is now more important than ever.

2. Remember that genetic diversity is key: not only is it the raw material for evolution but it is also critical to safeguard a certain level of planting success and future productivity. Within each seed source (population) there is high genetic variability, and some genotypes are likely to be adapted to either current or future climate. Increasing the genetic variability by using more than one seed source will increase the chances of more seedlings being able to survive and grow well through time.

A proposed strategy to match seed sources with planting sites under a changing climate, called "climate-adjusted provenancing" (Fig. 4 on page 9), is to mix:

One local seed source, i.e., a seed source from within the seed transfer zone where the planting site is located

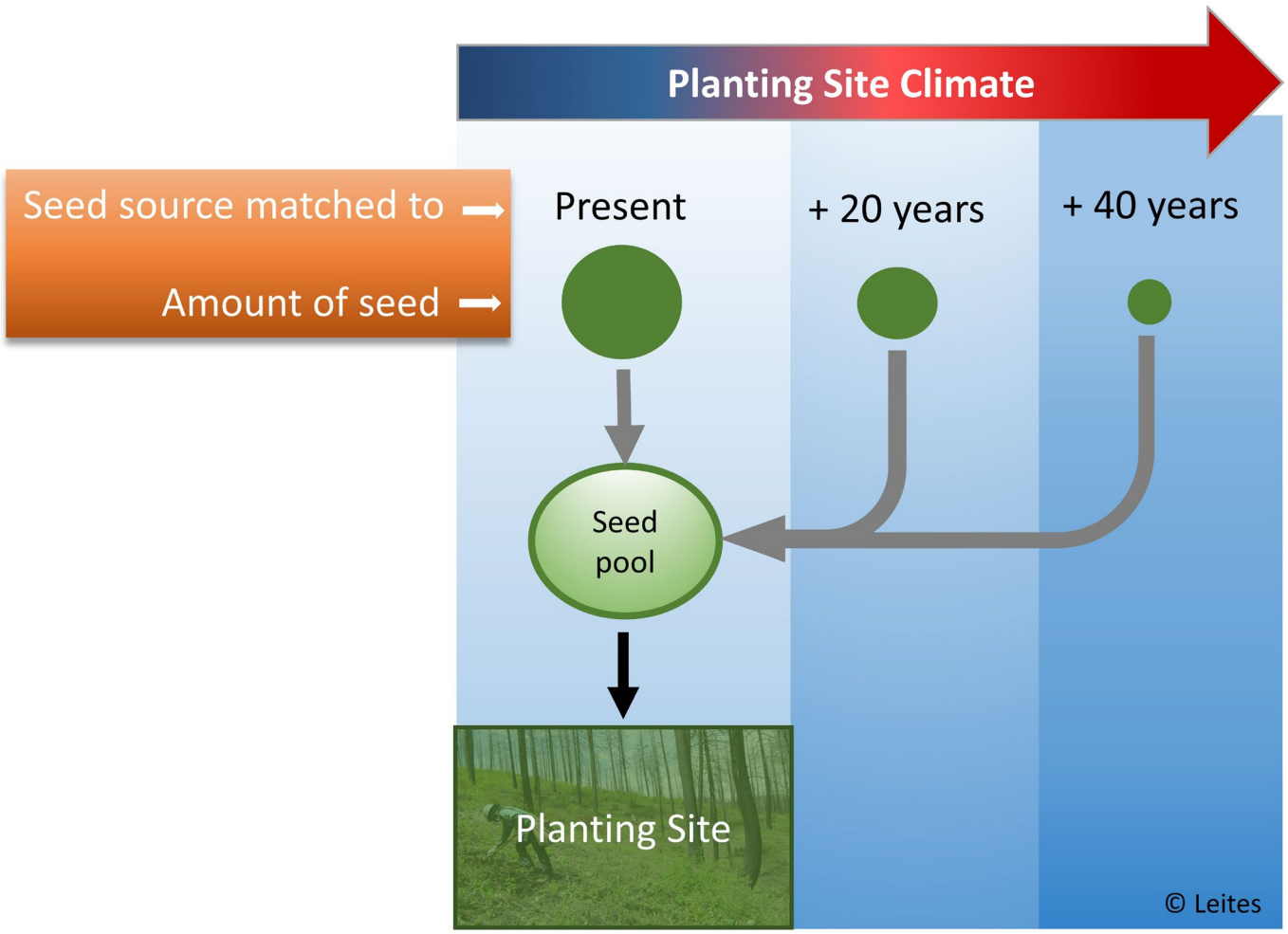
&

One or more seed sources pre-adapted to future climates, i.e., seed sources from seed transfer zones warmer than that of the planting site.

Seed sources adapted to warmer climates are not as cold tolerant as seed sources adapted to cooler climates, so care must be taken not to use seed sources from extreme warmer zones. This is because seedlings would need to survive and grow the first decades under the current cooler climate. In fact, choosing which time horizon to target for matching warmer seed source to future planting site climate is the focus of current studies. In general, and while no better information is available, a reasonable target for the selection of the seed source adapted to warmer conditions is to match the seed to the planting site's projected climate about 1-2 decades later. Favoring near-term future climate at the planting site is important to ensure reasonable adaptation during the vulnerable seedling and sapling stages.

FIG. 4

Illustration of the climate-adjusted provenancing strategy.



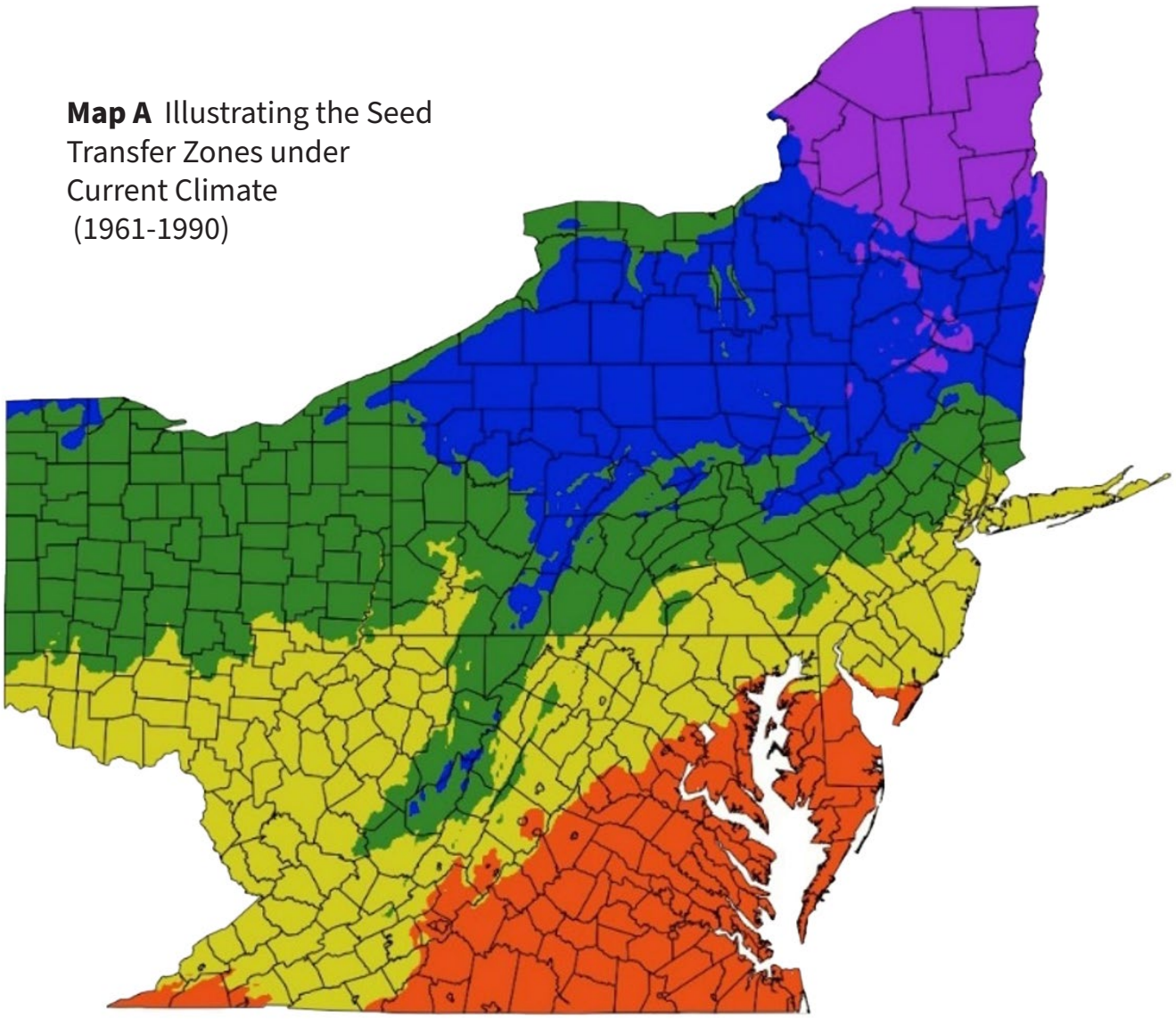
GENERIC SEED ZONES FOR PENNSYLVANIA, CURRENT AND FUTURE CLIMATES

Whenever possible, seed collection zones and seed transfer zones should be species specific because some tree species show stronger adaptation to local climate (thus populations can be moved shorter distances) than others. However, species-specific information is often not available as it requires specifically designed evaluations across a species' geographic range. In the meantime, provisional seed transfer zones, which are generalized for many forest tree species, can be utilized. Provisional seed transfer zones are delineated by defining areas with similar climate with regard to one or more variables that are known to be important in the adaptation to local climate in forest tree species.

For Pennsylvania, Leites and collaborators have used statistical algorithms to identify climatically similar (provisional) seed transfer zones for the state and its neighbors. The most important variable in the model, mean temperature of the coldest month, was used to develop provisional seed transfer zones. These zones can be used to match seed sources to planting sites under current climate and under future climate (Fig. 5). The future climate used is the projected climate for the period 2035-2045 (1-2 decades from current climate) and uses four different climate warming scenarios.

FIG. 5

Map A Illustrating the Seed Transfer Zones under Current Climate (1961-1990)

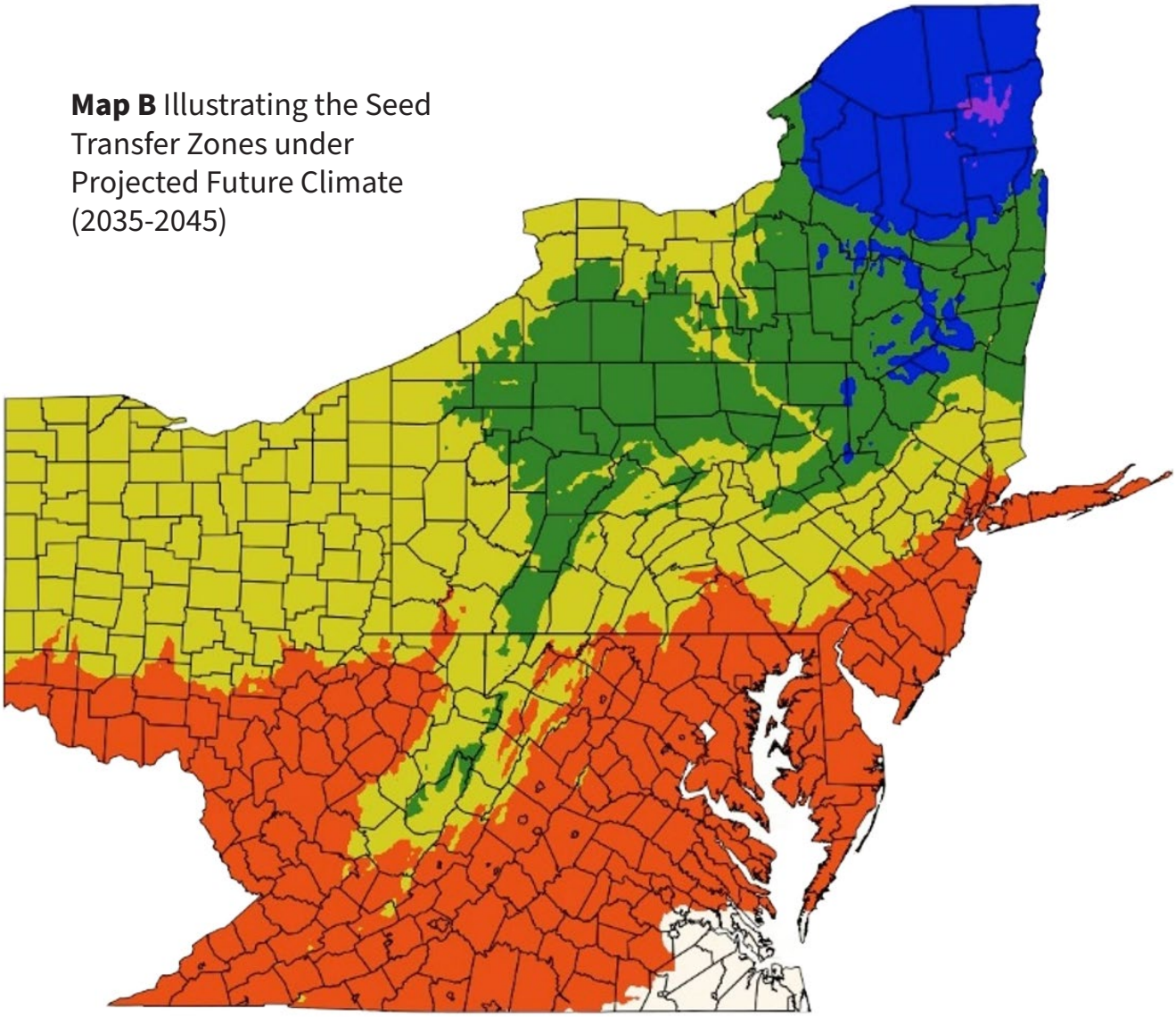


Zone

- 1: mtcm = -9.06
- 2: mtcm = -5.99
- 3: mtcm = -3.67
- 4: mtcm = -1.04
- 5: mtcm = 1.76

Provisional Seed Transfer Zones for Pennsylvania by Leites and collaborators (unpublished).

Note: mtcm refers to the mean temperature in the coldest month measured in ^{0}C.



Map B Illustrating the Seed Transfer Zones under Projected Future Climate (2035-2045)

HOW TO USE THE SEED TRANSFER ZONES MAPS

When you acquire seedlings from your local nursery or seedling supplier, it is important to request climate and other environmental characteristics of the seed origin, for example, a seed collection zone number from the EZSF classification (Fig. 2 on page 6). With that information at hand, you can use the seed transfer zones maps (Fig. 5 on pages 10 & 11), to decide which seed sources are appropriate for your planting site. Following are three examples of the use of the seed transfer zones maps for different areas of Pennsylvania and a climate-adjusted seed sourcing strategy:

EXAMPLE 1: A planting site located in Cameron County in north central Pennsylvania. In this site, seed from zone 2 (blue) can be planted with low risk of maladaptation to current climate (Fig. 5 on page 10, map A), while seed from zone 3 (green) could be chosen to match the projected climate of the planting site in 2035-2045 (Fig. 5 on page 11, map B). Using a climate-adjusted provenancing strategy (Fig. 4 on page 9), both seed sources would be combined to plant at the site.

EXAMPLE 2: A planting site located in Centre County, near State College in the center of the state. Observe that in this site, two zones exist within the county under current and future climate (Fig. 5 on pages 10 & 11, maps A and B). However, unless there is sharp topographic feature (which does not exist in Centre County) using seed from either zones 2 or 3 (blue or green) to match to the current climate of the site would be appropriate (Fig. 5 on page 10, map A). This is because these maps categorize continuous variation in climate, and so, the sharp lines between zones only exist when important orographic features exist (e.g., sharp changes in elevation in the Rocky Mountains). To match seed to the climate projected for 2035-2045 (Fig. 5 on page 11, map B), the same rationale can be used and either seed from zones 3 or 4 (green or yellow) could be used. Using a climate-adjusted provenancing strategy (Fig. 4 on page 9), seed sources could be combined to plant at the site (e.g., seed from zones 2, 3, and 4 in decreasing proportions).

EXAMPLE 3: For a planting site located in Franklin County in south central Pennsylvania, seed from zone 4 would match current and projected climate (Fig. 5 on pages 10 & 11, maps A and B).

Please remember these maps only help to match seed sources based on climate. Other species requirements need to be accounted for by the forester or landowner.

YOUR GOALS: ACHIEVING SUCCESS; AVOIDING FAILURE
OUR COMMON GOALS: REGENERATING RESILIENT AND PRODUCTIVE FORESTS FOR THIS AND FUTURE GENERATIONS

As those with reforestation and restoration experience will tell you: “The most expensive planting is a failed planting.” Matching seed source to planting site climate goes a long way to avoid “the most expensive planting.” As climate changes, matching seed source to current and future planting site climate is necessary to safeguard against uncertainty.

Due to our reliance on natural regeneration here in the northeastern US, we lack the developed tree planting pipeline needed to provide foresters and landowners with seedlings of known climatic origin. However, we need to urgently strengthen this pipeline so that we are prepared for the increasing reforestation, restoration, and supplemental planting needs. You can help by using the seed collection map (Fig. 2 on page 6) to request information about the seed origin from your nursery, and by using the seed transfer zones (Fig. 5 on pages 10 & 11) and a climate-adjusted seed sourcing strategy to match seed to planting site and regenerate resilient and productive forests. Future generations depend on us.

Oak saplings | Carrie Pike

Seedlings at Tree Pittsburgh Heritage Nursery | Laura Leites

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GLOSSARY

Cold tolerance — ability of trees to survive and grow under low temperatures.

Growth potential — the innate capacity of a tree to grow when environmental resources are not limiting.

High-grading — removal of the commercially most valuable trees, generally leaving a residual stand of trees of poor condition or species composition.

Maladaptation — failure to adjust adequately to the environment, reflected in poor growth or survival.

Phenological mechanisms — those related to the cyclic and seasonal phenomena in trees such as bud burst in spring and leaf senescence in autumn.

Physiological mechanisms — those related to the functioning of the tree such as photosynthesis.

Reforestation — the reestablishment of forest cover either naturally or artificially.

Restoration — the process of returning forests to their original structure and species composition.

Supplemental planting — artificial planting that supplements natural regeneration when the latter is scarce or not of the desire species composition.

Several of these definitions are or have been adapted from The Dictionary of Forestry (Helms, J. A Ed. 1998. The Dictionary of Forestry. The Society of American Foresters. ISBN 0-85199-308-7)

Front & back cover image: Seedlings at Tree Pittsburgh Heritage Nursery | Laura Leites

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