Strategies for seed transfer and assisted migration

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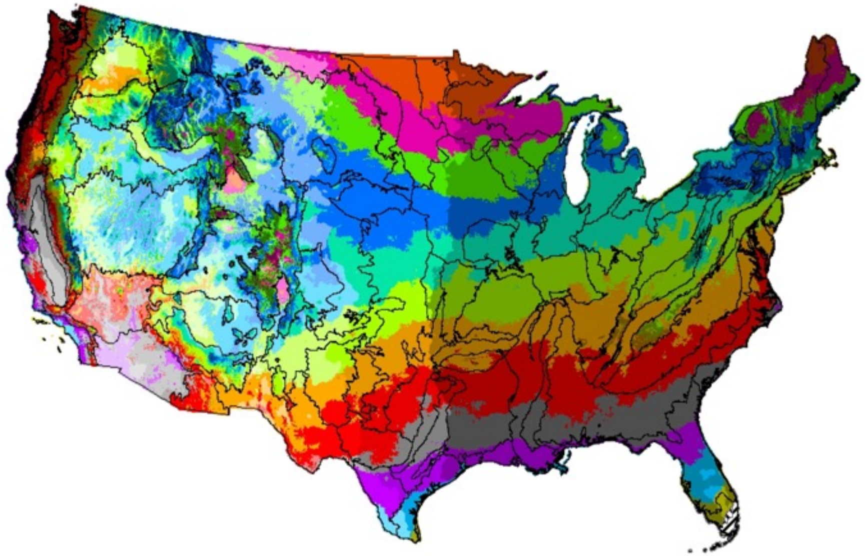
Need and history of seed zones

- Population-level genetic adaptation ubiquitous
- In plants, adaptation is primarily affected by climate
- Most commercial tree species are managed using seed transfer zones based on adaptive traits
- Climate change will upend reliance on static seed transfer zones
- Dynamic seed transfer approaches are need to evaluate assisted migration for rapidly changing mid-century climates

Key concept: two approaches to seed transfer

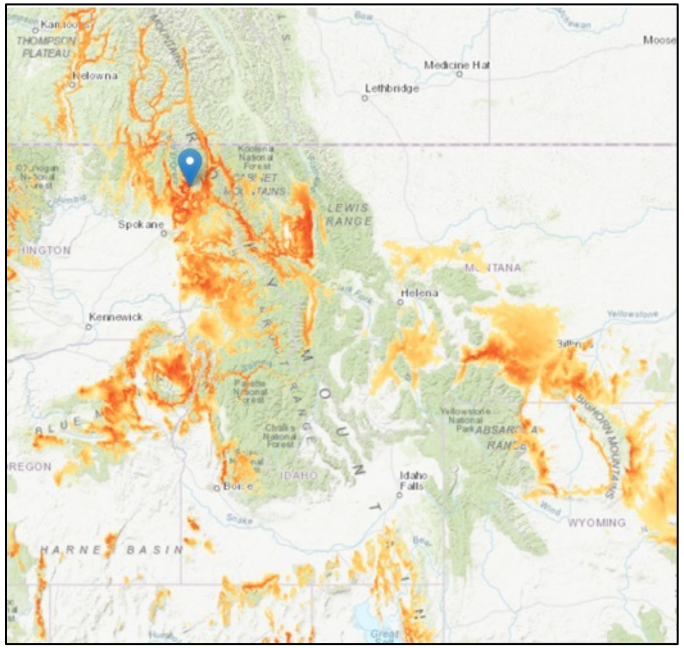
- Zonal: places regular limits across the climatic spectrum or along genetic function
- Focal point: draws limits based on a specified point

ZONAL



CONUS Generalized zones (Bower et al. 2014)

FOCAL POINT



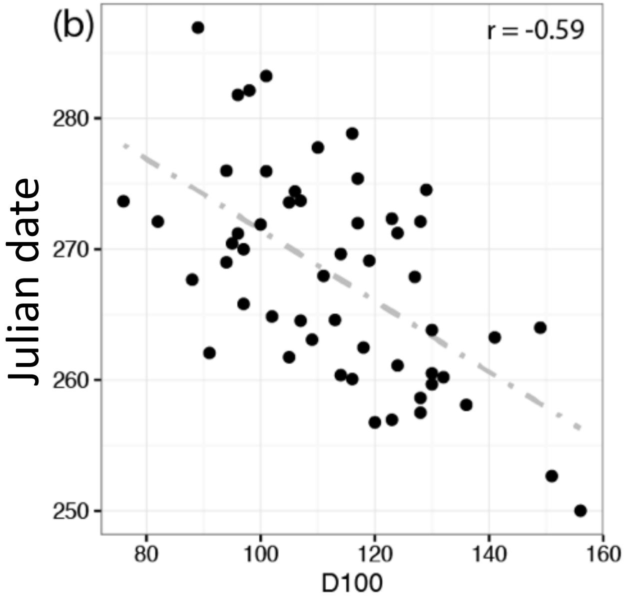
Pros and cons to zonal versus focal seed transfer

Approach	Pros	Cons
Zonal	• Easy to implement	• Less accurate, especially near zone boundaries • Increasingly complex and ephemeral with climate change
Focal	• More accurate • Dynamic and accommodate climate change projections	• Difficult to implement without a webtool

Key concept: Generalized vs. empirical seed transfer

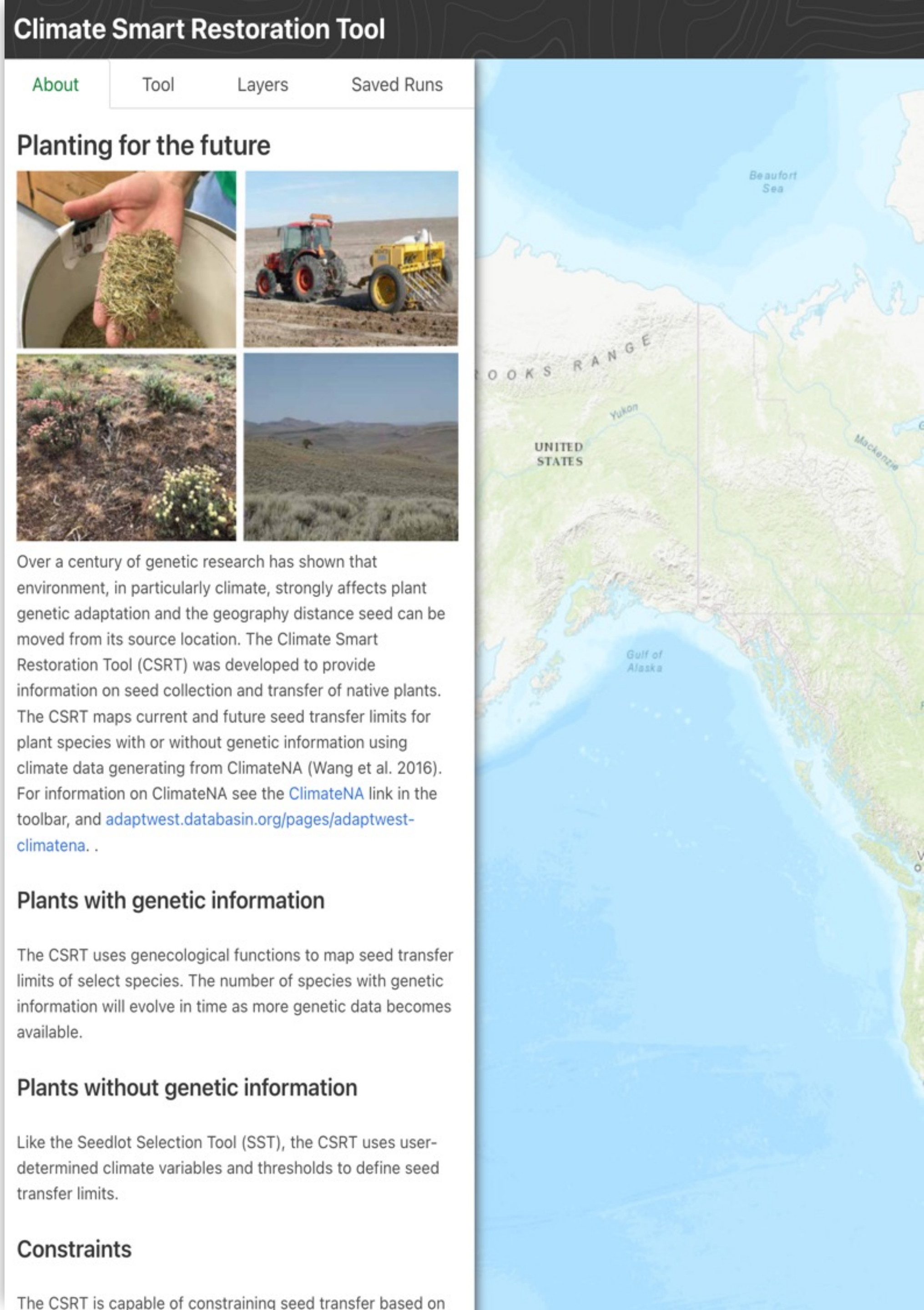
- Generalized: seed transfer limited based on solely environmental variables (i.e., climate).
- Empirical: relationship between traits (growth, phenology, etc.) and the environment. Species specific but requires > 5 years.

Sally Aitken



Climate smart restoration tool (CSRT)

- https://climaterestorationtool.org/csrt/
- More information:
- Seedlot Selection Tool and Climate-Smart Restoration Tool: Web-based tools for sourcing seed adapted to future climates. *Ecosphere*, *13*(5). https://doi.org/10.1002/ecs2.4089



Climate Smart Restoration Tool

Planting for the future

Over a century of genetic research has shown that environment, in particularly climate, strongly affects plant genetic adaptation and the geography distance seed can be moved from its source location. The Climate Smart Restoration Tool (CSRT) was developed to provide information on seed collection and transfer of native plants. The CSRT maps current and future seed transfer limits for plant species with or without genetic information using climate data generating from ClimateNA (Wang et al. 2016). For information on ClimateNA see the ClimateNA link in the toolbar, and adaptwest.databasin.org/pages/adaptwest-climatena. .

Plants with genetic information

The CSRT uses genecological functions to map seed transfer limits of select species. The number of species with genetic information will evolve in time as more genetic data becomes available.

Plants without genetic information

Like the Seedlot Selection Tool (SST), the CSRT uses user-determined climate variables and thresholds to define seed transfer limits.

Constraints

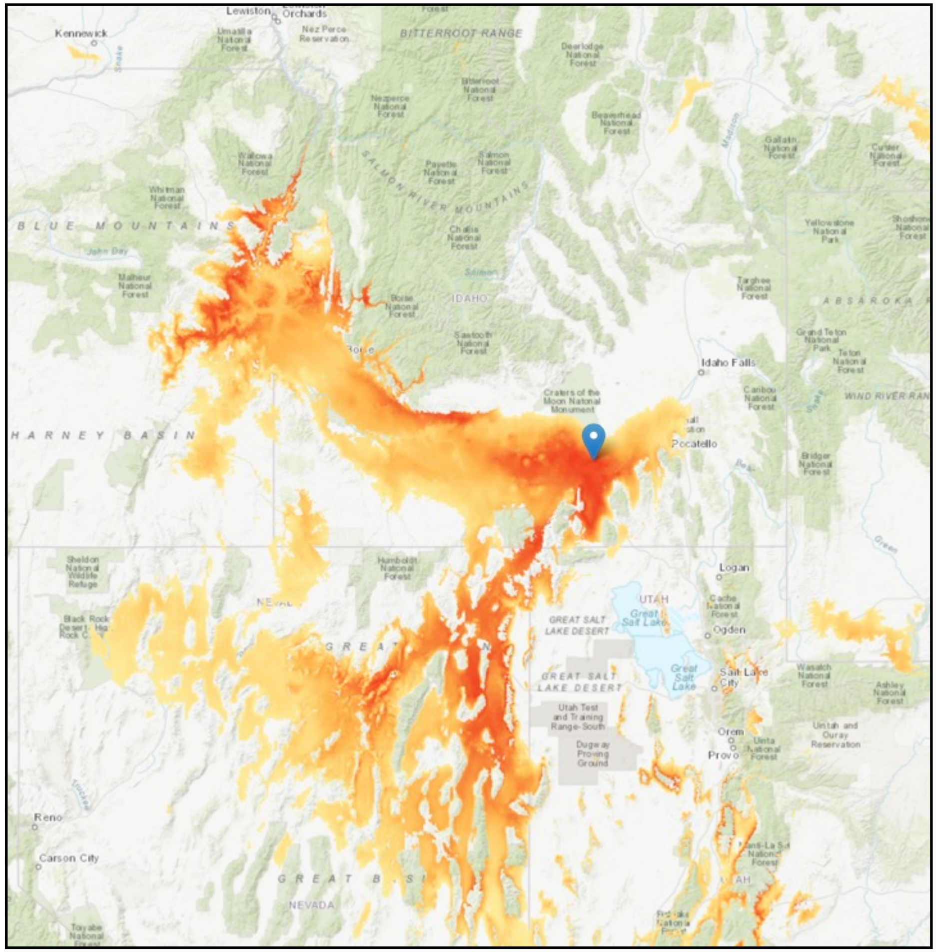
The CSRT is capable of constraining seed transfer based on

Empirical: Craters of the Moon target site

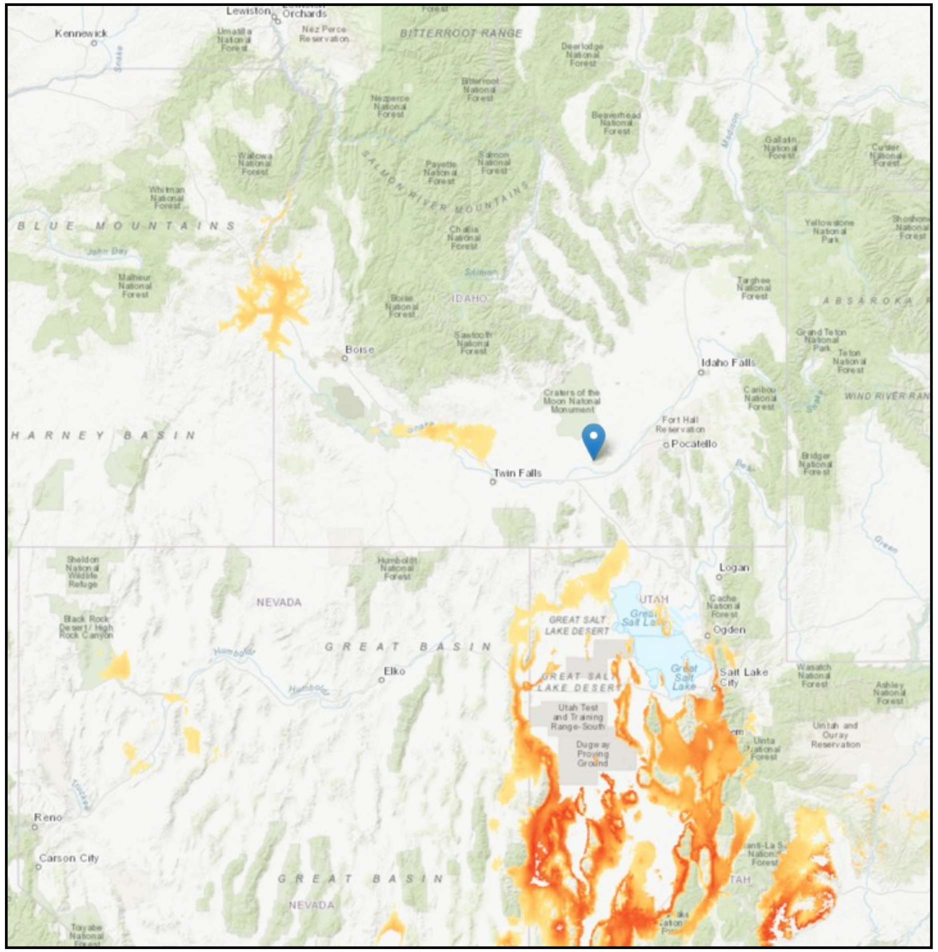
Wyoming Sagebrush quantitative seed transfer distance: cold hardiness + flower phenology

Yellow to red gradient shows climate similarity (yellow = low; red = high)

WY sagebrush current (1981 to 2010)



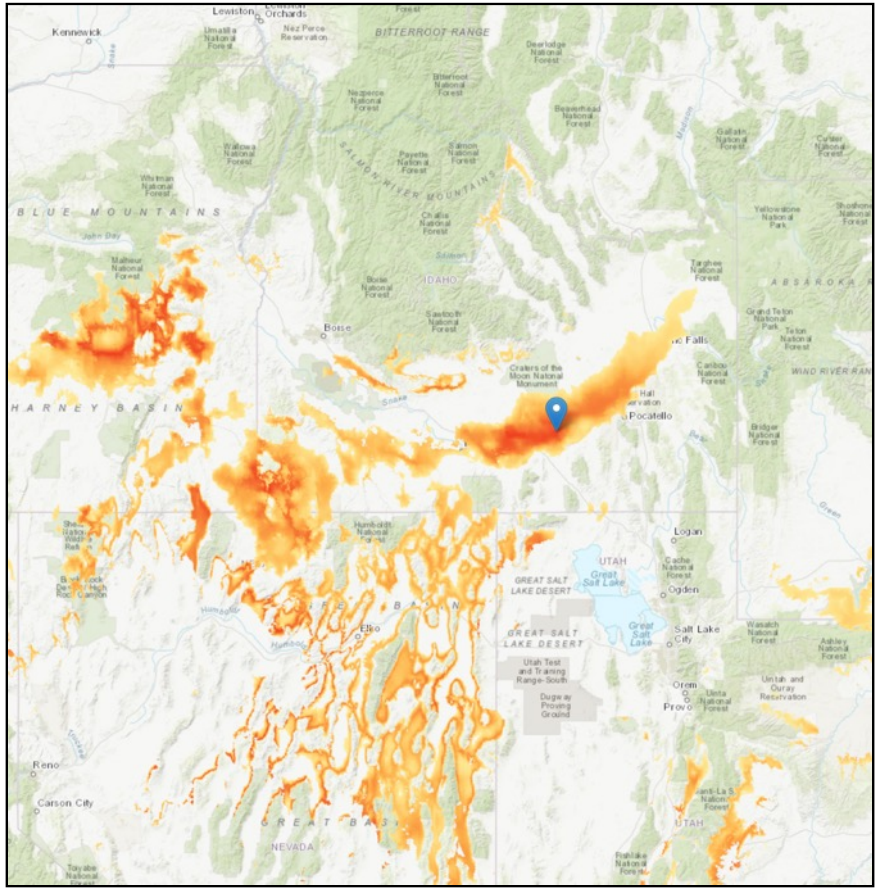
WY sagebrush mid-century (2041 to 2070)



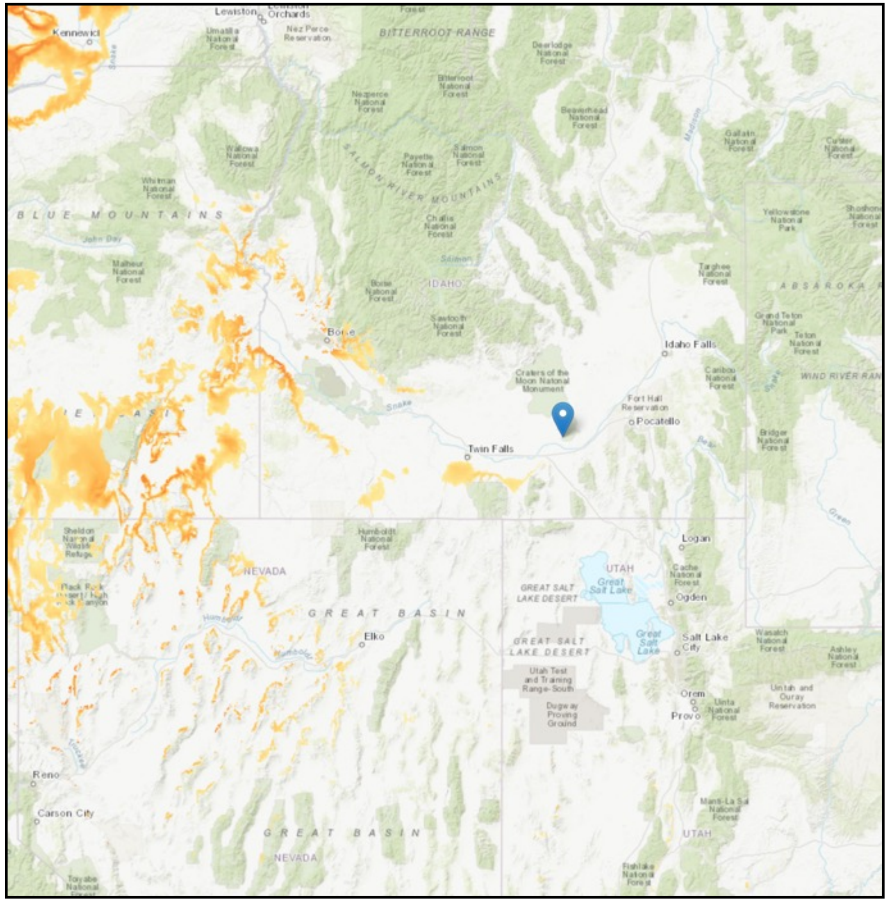
Empirical: Craters of the Moon target site

Bluebunch wheatgrass quantitative seed transfer distance
reproductive output + leaf width + phenology

Bluebunch current



Bluebunch mid-century



Problems with quantitative seed transfer

Genetic information:

- Actionable genetic information often limited for many species
- Research requires 3 to 6 years
- Short on time and fleeting opportunities to conserve genetic resources

Generalized seed transfer techniques:

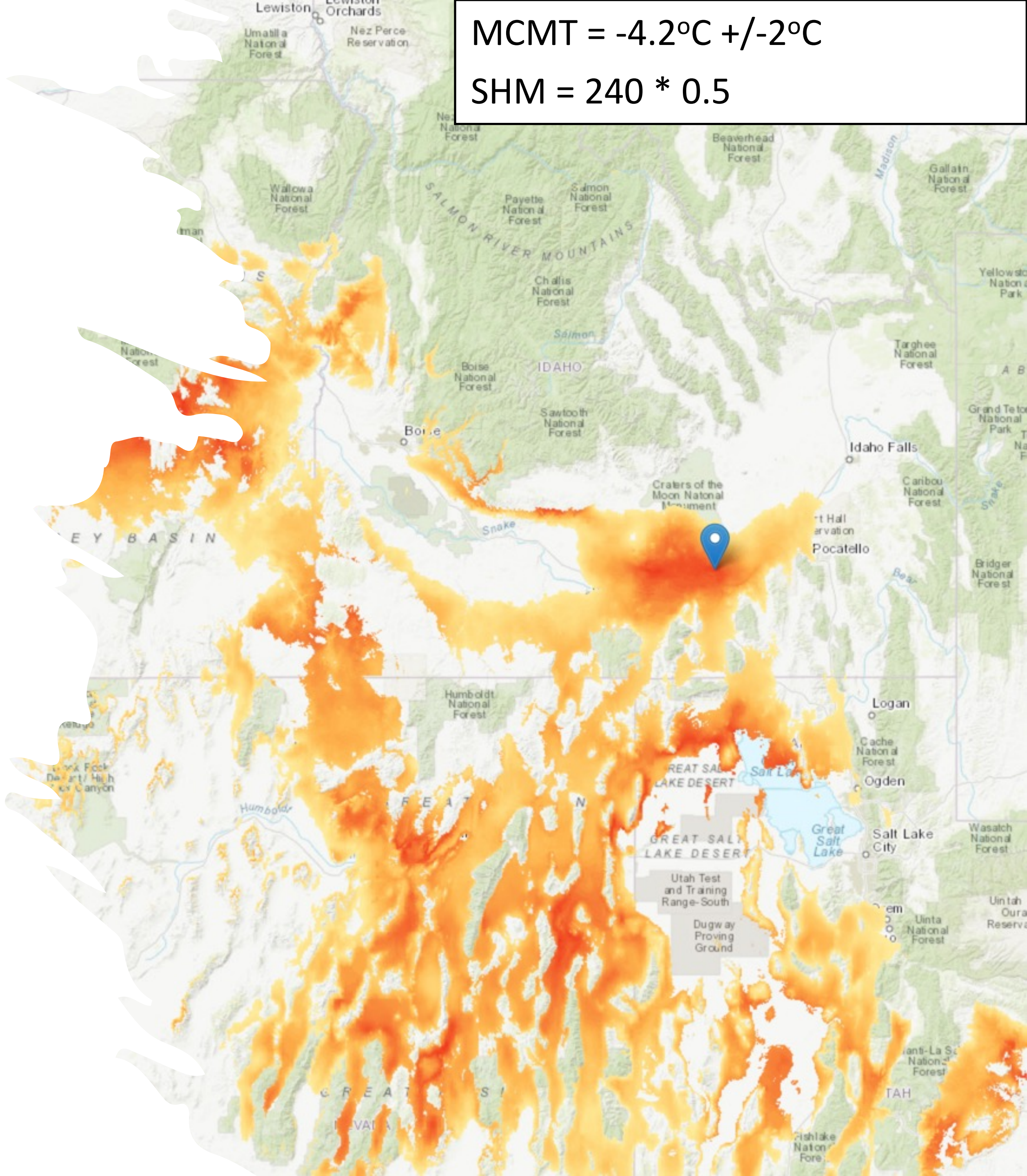
- Provide immediate results for seed transfer
- Can act as a stop-gap to start restoration programs for species that lack genetic research

Pros and cons of current generalized seed transfer

- Pros:
  - Can be used for all plants
  - Euclidean distance (standard metric for measuring climate differences)
  - a sandbox (i.e., flexible and useful for learning)
- Cons:
  - a sandbox (selecting climate vars and transfer limits are arbitrary/overwhelming)
  - recommended two-variable seed transfer limit projects large extraneous areas
  - Can over project seed transfer area

MCMT = -4.2^{o}C +/-2^{o}C

SHM = 240 * 0.5



Climate analog method

Focal point seed transfer approach: calculated from climate distances of 19 climate variables

Three climate distance thresholds (weak, moderate, and strong) are used to categorize analogs.

Nearest Neighbor algorithm used to find climate analog sites in databases of ~685K vegetative plots. Analog site are mapped according to their threshold.

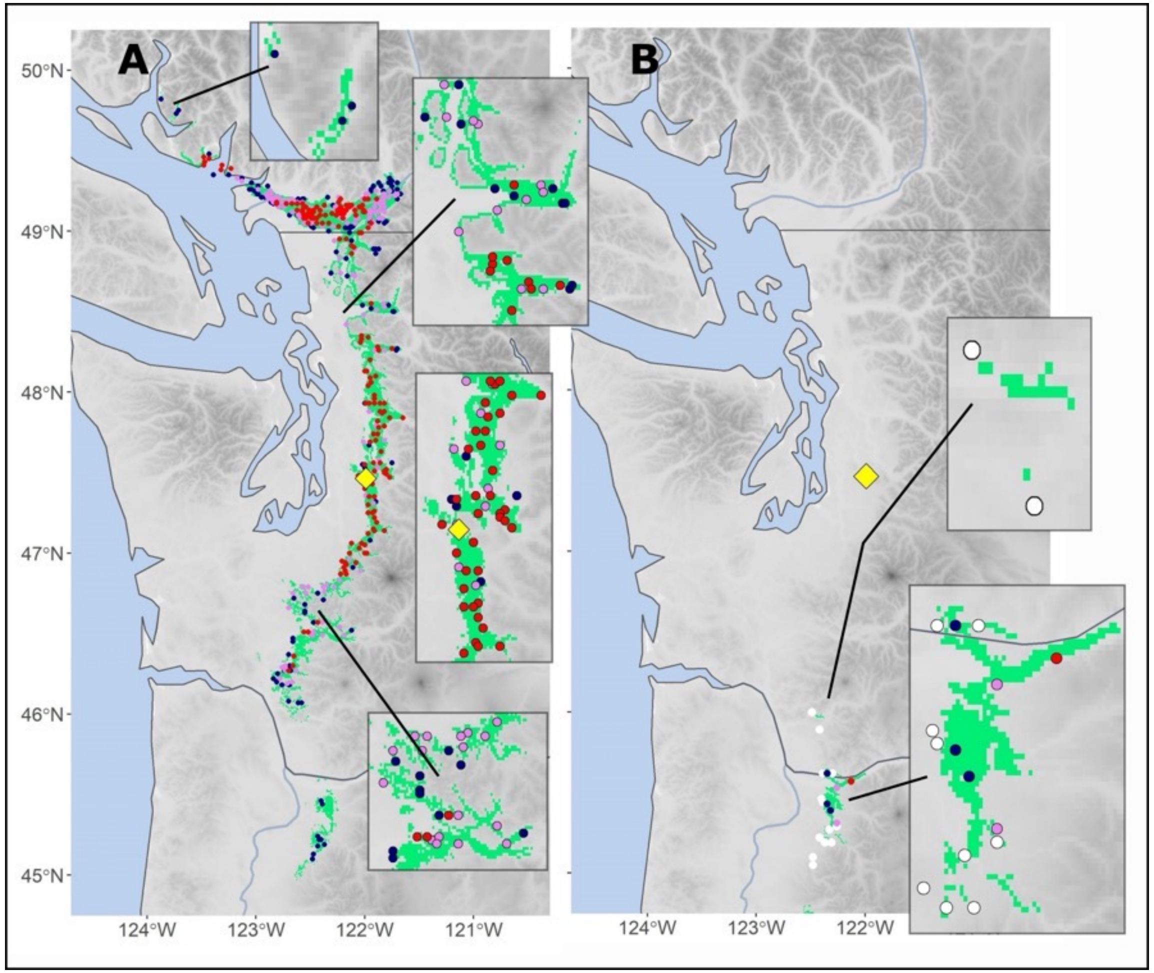
Available data: ~ 685,000 plots

Database	Basic unit	Species identification	Number of Records (K)	Complier
North America biomes	Shape file polygons	none	436.5	Rehfeldt et al. (2012)
West USA forest inventory	ground plots	Forest trees	101.0	Rehfeldt et al., (2006)
East USA & Eastern Canada forest inventory	ground plots	Select conifers and hardwoods	104.8	Joyce and Rehfeldt (2017)
Mexico forest Inventory	ground plots	conifers	20.7	Sáenz-Romero et al. (2012)
BLM Geospatial	ground plots	Selected shrubs and grasses	21.9	Herein[2]

Average 1 plot every 12 km

Mapped analog output

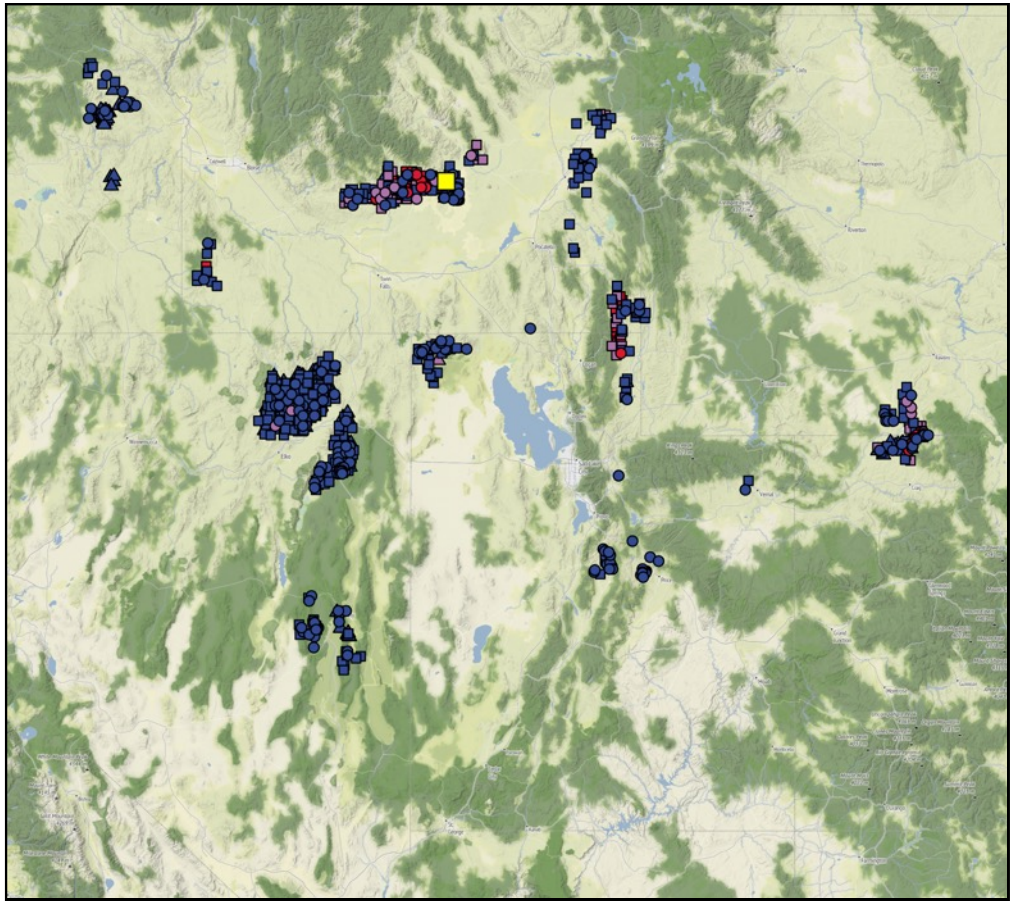
- Yellow diamond = reference point
- Green polygon = total area under weak threshold
- Points: Red = strong; Violet = moderate; Blue = weak; white = outside threshold margins



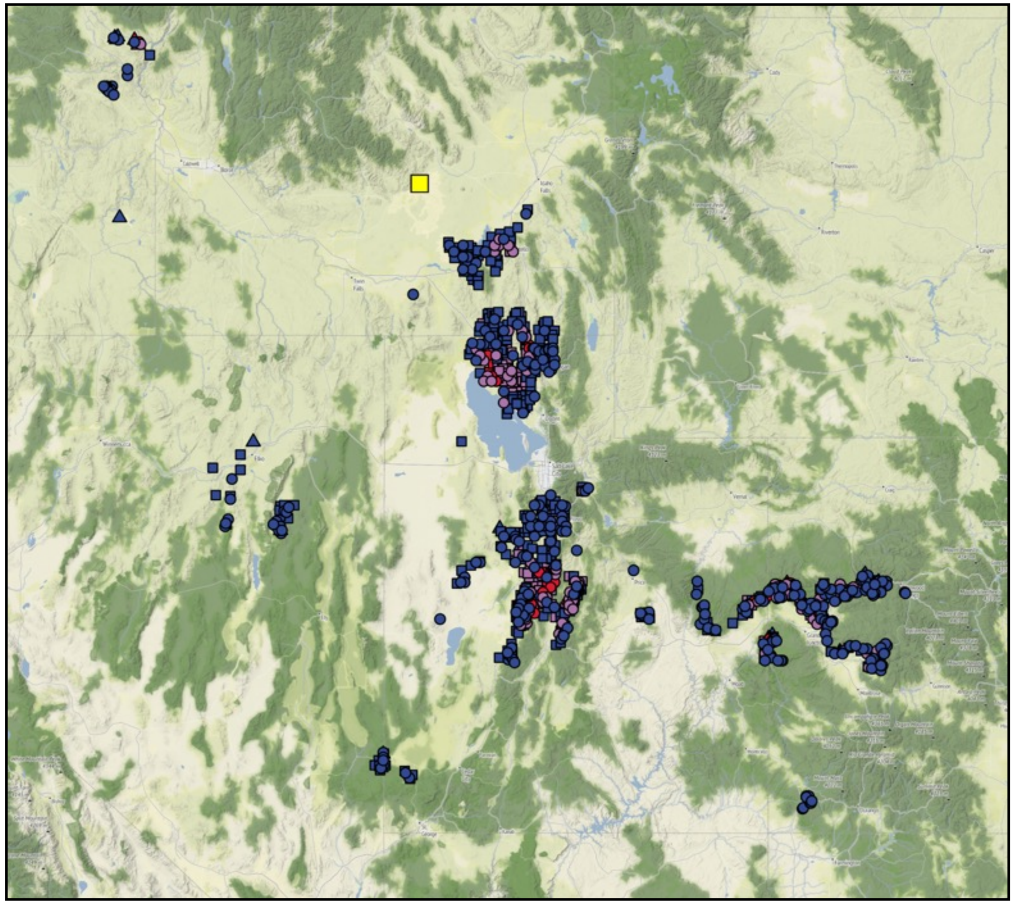
Tiger Mtn: A) Reference period analogs (1961-1990); B) Mid-century analogs (2055-2065)

Climate analog output: Craters of the Moon

Current



Mid-century



Craters target site
compiled AIM vegetative plot data (frequency of spp presence)

Species*	**type**	**current plot**	**future plot**	**Predicted change**
Phlox longifolia	forb	0.67	0.36	decline
Phlox hoodii	forb	0.66	0.17	decline
Crepis acuminata	forb	0.60	0.07	decline
Collinsia parviflora	forb	0.46	0.28	decline
Microsteris gracilis	forb	0.30	0.19	decline
Artemisia tridentata ssp. wyomingensis	shrub	0.67	0.32	decline
Artemisia tridentata ssp. vaseyana	shrub	0.29	0.06	decline
Artemisia arbuscula	shrub	0.28	0.01	decline
Artemisia tridentata ssp. tridentata	shrub	0.19	0.13	decline
Artemisia nova	shrub	0.10	0.01	decline
Poa secunda	grass	1.00	0.90	decline
Elymus elymoides	grass	0.88	0.36	decline
Pseudoroegneria spicata	grass	0.69	0.60	decline
Leymus cinereus	grass	0.54	0.25	decline
Achnatherum thurberianum	grass	0.49	0.18	decline

***Top five species for each plant type**

All native vegetation that matches the current climate is projected to decline by mid-century.

Craters target site
weeds

Species	**type**	**current plot**	**future plot**	**Predicted change**
Bromus tectorum	weed	0.90	0.96	increase
Poa bulbosa	weed	0.11	0.57	increase
Tragopogon dubius	weed	0.22	0.47	increase
Lactuca serriola	weed	0.12	0.44	increase
Sisymbrium altissimum	weed	0.20	0.40	increase

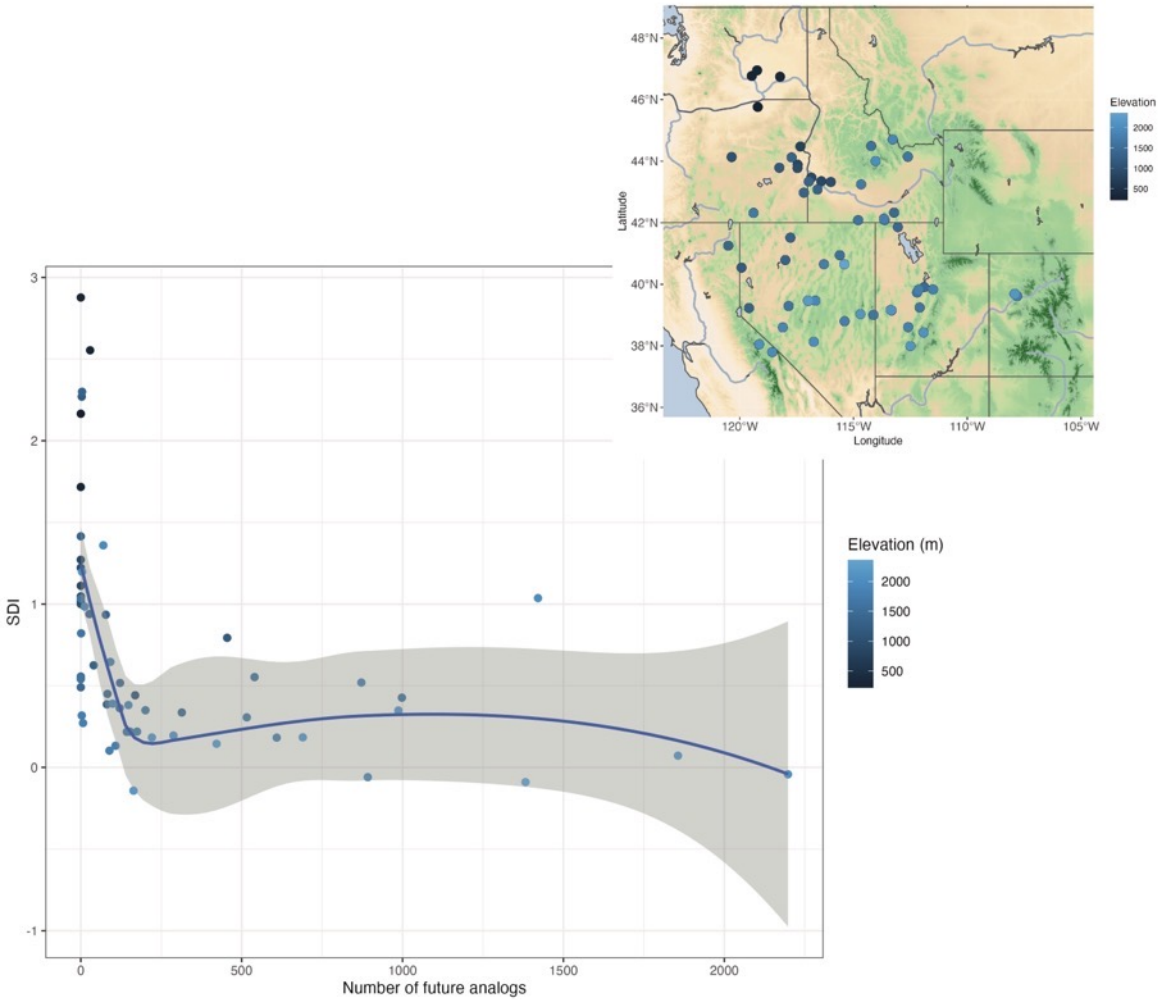
Non-natives predicted to increase.

Novel climate futures for lower elevation sagebrush steppe

Relationship between summer dryness index and future analogs

Summer Dryness Index ≈ 0.2 is the breakpoint between analog and no analog. Suggests restoration of sites < 0.2 is an uphill battle

Some native plants will likely adapt to no analog climates. Mojave-cold desert ecotone?



Summary

- The CSRT can be used to develop of proactive strategies to species and population selection
- Seed transfer guidance is available for all species, but the specific approach depends on the available research
- Local seed sources will become maladapted in the next 20 to 30 years
- Mixing local and future projected sources is a viable option to maintain adaptation, resiliency, and genetic diversity
- Warm-dry sites in the sagebrush biome are expected to transition to novel climates by mid-century
- Local knowledge is key: The tool doesn’t account for soils, or past fire and land usage that can affect restoration success and vegetation trajectories

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Literature

- St.Clair, J. B, Kilkenny, F. F., Johnson, R. C., Shaw, N. L., & Weaver, G. (2013). Genetic variation in adaptive traits and seed transfer zones for Pseudoroegneria spicata (bluebunch wheatgrass) in the northwestern United States. *Evolutionary Applications*, *6*(6), 933–948. https://doi.org/10.1111/eva.12077
- Richardson, B. A., Chaney, L., Shaw, N. L., & Still, S. M. (2017). Will phenotypic plasticity affecting flowering phenology keep pace with climate change? *Global Change Biology*, *23*(6), 2499–2508. https://doi.org/10.1111/gcb.13532
- Chaney, L., Richardson, B. A., & Germino, M. J. (2017). Climate drives adaptive genetic responses associated with survival in big sagebrush (Artemisia tridentata). *Evolutionary Applications*, *10*(4), 313–322. https://doi.org/10.1111/eva.12440
- Richardson, B. A., & Chaney, L. (2018). Climate-based seed transfer of a widespread shrub: population shifts, restoration strategies, and the trailing edge. *Ecological Applications*, *28*(8), 2165–2174. https://doi.org/10.1002/eap.1804
- Massatti, R., Prendeville, H. R., Larson, S., Richardson, B. A., Waldron, B., & Kilkenny, F. F. (2018). Population history provides foundational knowledge for utilizing and developing native plant restoration materials. *Evolutionary Applications*, *19*(7), 716–15. https://doi.org/10.1111/eva.12704
- St.Clair, J. B., Richardson, B. A., Stevenson-Molnar, N., Howe, G. T., Bower, A. D., Erickson, V. J., Ward, B., Bachelet, D., Kilkenny, F. F., & Wang, T. (2022). Seedlot Selection Tool and Climate-Smart Restoration Tool: Web-based tools for sourcing seed adapted to future climates. *Ecosphere*, *13*(5). https://doi.org/10.1002/ecs2.4089
- Richardson, B. A., Rehfeldt, G. E., Sáenz-Romero, C., & Milano, E. R. (2024). A climate analog approach to evaluate seed transfer and vegetation transitions. *Frontiers in Forests and Global Change*, *7*, 1325264. https://doi.org/10.3389/ffgc.2024.1325264