PLANT ECOLOGY

Trees have overlapping potential niches that extend beyond their realized niches

Daniel C. Laughlin[1,2]*† and Brian J. McGill[2,3]†

Tree species appear to prefer distinct climatic conditions, but the true nature of these preferences is obscured by species interactions and dispersal, which limit species' ranges. We quantified realized and potential thermal niches of 188 North American tree species to conduct a continental-scale test of the architecture of niches. We found strong and consistent evidence that species occurring at thermal extremes occupy less than three-quarters of their potential niches, and species' potential niches overlap at a mean annual temperature of ~12°C. These results clarify the breadth of thermal tolerances of temperate tree species and support the centrifugal organization of thermal niches. Accounting for the nonrealized components of ecological niches will advance theory and prediction in global change ecology.

Predicting species' responses to rising global temperatures requires knowledge of their thermal tolerance niches; yet, our current understanding is informed primarily by the more limited realized niches. Realized niches are observed distributions of species along environmental gradients that reflect all of the forces acting on the distribution, including abiotic constraints such as climate, biotic interactions, and dispersal limitation (*1*–*3*). The realized niche differs from the fundamental niche, which is the complete set of conditions in which a species can sustain itself in the absence of biotic interactions (*2*, *4*). Difficulties in measuring the fundamental niche have rendered it one of the most well-known yet least-quantified concepts in ecology. Potential niches, on the other hand, are the complete set of conditions that allow species to survive and grow but where recruitment rate is unknown (*5*–*7*). Potential niches are measurable and informative for organisms with a slow pace of life because adult survival is a more influential fitness component compared with fecundity (*8*, *9*). If a species' potential niche is larger than its realized niche, then it can tolerate a greater range of environments. Predictions of how species respond to climate change will be biased if based solely on the realized niche.

Competitive interactions are known to contract realized niches into less favorable environments at local spatial scales (*10*, *11*), but whether interspecific competition contracts realized distributions at macroecological scales remains an open question. The Eltonian noise hypothesis assumes that the importance of competition decreases at broader spatial scales (*12*) and therefore predicts that realized niches are roughly equivalent to potential niches. If true, this would justify current methods in species distribution modeling that use present-day realized niches to predict future responses to climate change (*13*). But this assumption of near equivalence is virtually untested and is increasingly contradicted by available evidence: The study of invasions (*14*, *15*), experimental transplants of species outside their geographic range (*16*), and cultivation in botanical gardens (*5*–*7*) all show that many species can grow and survive outside of their current realized niches.

It is increasingly clear that we should reject the simple, convenient assumption of niche equivalence, but we still do not know the most basic architectural relationships between potential and realized niches. Hypotheses about these relationships (*17*–*21*) have gained urgency in light of efforts to predict species range shifts in response to climate change (*22*, *23*). Such efforts have problematically treated the realized niche of today as if it was the fundamental niche and only possible future realized niche (*24*–*26*). In this work, we leverage global inventories of arboreta to empirically estimate present-day potential niches of 188 tree species to conduct a continental-scale test of the architectures of ecological niches.

Architectures of ecological niches

Potential niches could exhibit three distinct architectures in relation to their corresponding realized niches, each driven by different mechanisms (Fig. 1). Following established terminology, potential niches could exhibit (i) distinct preferences, (ii) shared preferences, or (iii) centrifugal organization (*1*, *18*–*20*). First, if the potential niche of each species covers distinct environmental conditions, then potential niches would be centered over their realized niches and would likewise inhabit distinct portions of an environmental gradient (Fig. 1A). Second, a trade-off between competitive ability and abiotic tolerance of more-stressful conditions could generate distinct realized niches despite all species sharing a preference for one end of the environmental gradient (Fig. 1B). Under these conditions, competitive species would dominate the preferred environment at one end, and more tolerant species would be relegated to suboptimal environments at the other end (*7*, *11*, *18*, *19*, *27*, *28*). Third, trade-offs generated by distinct physiological tolerances of two opposing abiotic extremes could also generate distinct realized niches along a gradient. Under these conditions, potential niches would overlap in the central core, but their realized niches would be pushed toward the peripheries to avoid competition (Fig. 1C). Centrifugal organization was originally proposed for two or more orthogonal gradients that define the same core habitat (*20*, *29*), but this third model is a special case of centrifugal organization, where trade-offs in tolerating lethal conditions at opposite ends of the same gradient (e.g., cold-tolerant species are not heat tolerant) can also contract realized niches toward the climate extremes. The idea that differences between potential and realized niches are driven by competition has been the primary hypothesis to date (*18*, *20*, *21*, *29*), although other mechanisms are conceivable. In this work, we only test for the differences but do not directly test the mechanisms.

These three conceptual models generate testable relationships between temperature and three niche metrics (Fig. 1): (i) potential niche width, (ii) the ratio of the realized-to-potential niche widths (R:P ratio), and (iii) niche contraction. The R:P ratio ranges from 0 to 1 because the realized niche is contained within the potential niche. Niche contraction measures the directional contraction of the realized niche into different regions of the potential niche and ranges from –1 to 1, where, in this study, positive values indicate contraction of the realized niche from cooler climates into warmer climates, and negative values indicate contraction from warmer climates into cooler climates (Fig. 1). Evidence for each of the three models can be distinguished by distinct geometric signatures encoded in the architectures of the potential niches (Fig. 1, D to F). First, the distinct preference model would be supported if none of these metrics vary significantly with realized niche positions—i.e., the location of each species along the gradient calculated as the median temperature of the realized niche (Fig. 1G). Second, shared preference of warm temperatures would be supported if potential niche widths decrease with rising temperature, causing the R:P ratio to increase and causing niche contraction to increase from more negative values to less negative values if realized niches contract from warmer into cooler climates (Fig. 1H). Note, the directions of these relationships and the signs of the metrics would differ for other environmental contexts. Third, centrifugal organization would be supported if potential niche

---

[1]Department of Botany, University of Wyoming, Laramie, WY 82071, USA. [2]School of Biology and Ecology, University of Maine, Orono, ME 04469, USA. [3]Mitchell Center for Sustainability Solutions, University of Maine, Orono, ME 04469, USA.
*Corresponding author. Email: daniel.laughlin@uwyo.edu
†These authors contributed equally to this work.

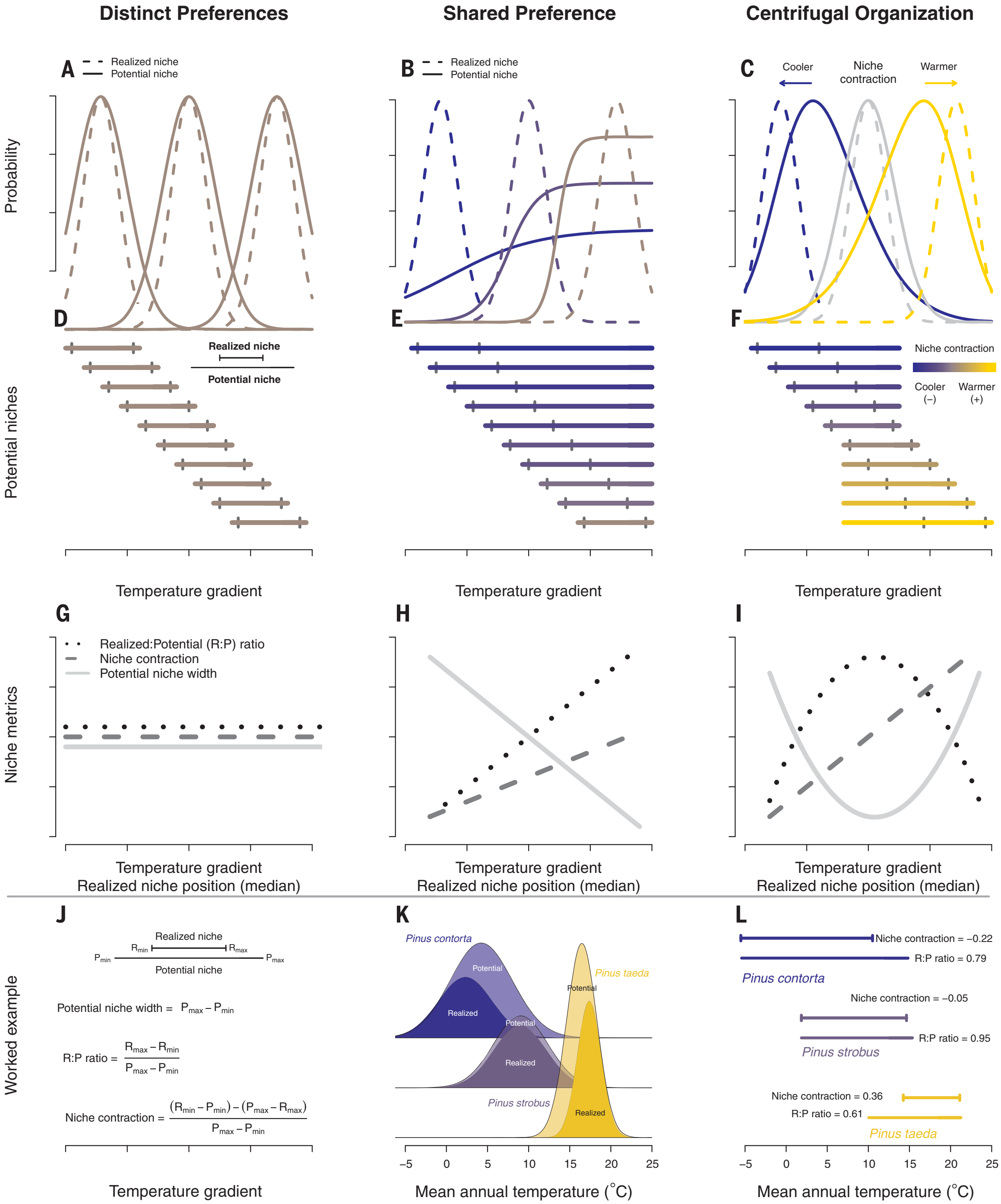

Fig. 1. Three testable models of the architecture of ecological niches. (**A** to **C**) Realized niches (denoted as dashed lines) that are distinct and arrayed sequentially along an environmental gradient may differ from potential niches (denoted as solid lines), even though realized niches are nested inside of potential niches. Potential and realized niches can be organized three different ways. Potential niches will exhibit either distinct preferences among species centered on their realized niches (A), a shared preference among species where potential niches share the same extreme value (B), or centrifugal organization where species overlap in the middle despite opposing abiotic tolerances (C). (**D** to **F**) Each model generates distinct geometric signatures in the potential niches, whereas the realized niches remain constant. Consider an idealized set of 10 potential niches stacked on top of each other and ordered by increasing realized niche minima: Distinct preferences would generate an orderly progression of similar potential width niches along the gradient (D), shared preferences would generate a set of decreasing potential niche widths along the gradient that all share the same niche maxima (E), and centrifugal organization would generate a skewed hourglass where potential niche width is lowest at intermediate locations along the gradient (F). (**G** to **I**) These signatures generate specific testable relationships between realized niche position (medians) and three niche metrics: potential niche width [see equations in (J)], the ratio of the realized-to-potential niche width (R:P ratio), and the directional contraction of the realized niche into cooler or warmer regions of the potential niche (niche contraction). (**J** to **L**). Worked example of how niche metrics were computed for three *Pinus* species, where we quantified niche widths as the distance between 0.01 and 0.99 quantiles for both realized occurrences (BIEN and Little's range maps) and potential occurrences (a combination of realized occurrences plus arboreta occurrences). (J) The niche contraction metric is a directional index that quantifies how realized niches are contracted subsets of the potential niches. (K) Probability densities of realized and potential niches using occurrence data along a gradient of MAT for three *Pinus* species. (L) The realized niche of *Pinus contorta* is contracted into cooler climates, *Pinus strobus* is not noticeably contracted in either direction, and *Pinus taeda* is contracted into warmer climates.

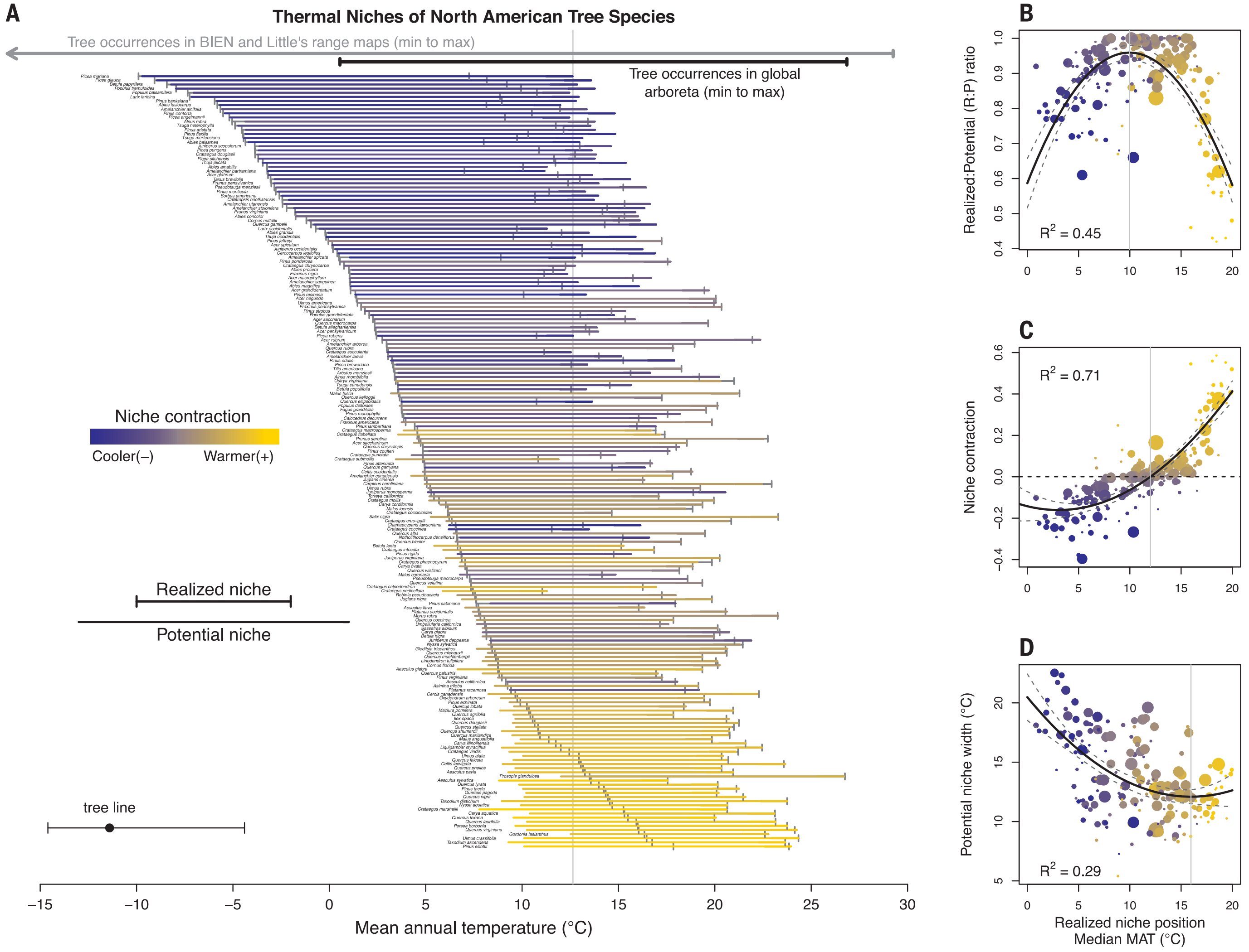

Fig. 2. Realized and potential thermal niches of North American tree species along a gradient of MAT. (**A**) Empirical estimates of realized and potential niches of 188 North American tree species along a MAT gradient. Realized niches (denoted by hash marks) are subsets of potential niches. Species are ordered by increasing realized niche minima from top to bottom. Niche minima and maxima are defined as the 0.01 and 0.99 quantiles of their distributions along MAT to remove effects of extreme outliers. Species with realized niches contracting to cooler temperatures are shown in blue, and species with realized niches contracting to warmer temperatures are shown in gold. Almost all species (94%) have a potential niche that overlaps the central temperature (solid gray vertical line) of 12.6°C. The gray horizontal line denotes the range of temperatures sampled by BIEN and Little's range maps (note, the cold end is cut off and continues further), and the black horizontal line denotes the range of temperatures of the arboreta. (**B**) Relationship between realized niche position (median MAT) and the realized-to-potential niche width ratio (R:P ratio). (**C**) Relationship between realized niche position and niche contraction, which is a directional index of contraction of the realized niche into warmer (positive) or cooler (negative) climates. (**D**) Relationship between realized niche medians and potential niche widths. All three relationships support the centrifugal organization of thermal niches for North American tree species. Symbols in (B), (C), and (D) are sized in proportion to the number of occurrences in arboreta, but these were not used to weight observations in the regression analyses. The vertical line in (A) represents the mean value of the estimated maximum, *x*-intercept, and minimum from (B), (C), and (D), respectively.

width is lowest at an intermediate temperature, causing the R:P ratio to peak at this intermediate temperature and causing niche contraction to switch sign from negative to positive with increasing temperature (Fig. 1I). A worked example of these niche metrics is illustrated in Fig. 1, J to L.

We quantified the empirical support for each of the three hypotheses by estimating realized and potential thermal niches for 188 North American tree species. Realized niches were quantified using natural occurrence records in the Botanical Information and Ecology Network (BIEN 4.1) (*30*) and Little's species range maps (*31*) (fig. S1). We quantified potential niches by supplementing native occurrence records with 17,180 occurrence records from 447 arboreta around the world provided to us by Botanic Gardens Conservation International (BGCI) (*32*), including dozens to hundreds of occurrence records for each species (fig. S2). Arboreta can be used to quantify potential niches because they eliminate dispersal limitation and minimize effects of competition (*5*–*7*). We used CHELSA V.2 (*33*) to determine minimum, mean, and maximum temperatures (1980 to 2010) for all occurrence records to estimate thermal niches. Both the natural and arboreta occurrence data show broad coverage of a range of current climates for estimating present-day potential niches (fig. S1).

Thermal niches of North American tree species

We found strong and consistent support for centrifugal organization of thermal niches of

North American tree species (Fig. 2 and table S1). The R:P ratio for mean annual temperature (MAT) exhibited large variation among species, ranging from 0.42 to 1.0, with a median value of 0.91 (Fig. 2B). This in itself is an unexpected finding—that several species occupy less than three-quarters of their potential niche, whereas others occupy nearly 100%. In fact, the R:P ratios were not randomly distributed across the temperature gradient but rather exhibited a significant hump-shaped relationship with MAT [adjusted coefficient of determination (R^2_{adj}) = 0.45; $F_{2,185}$ = 76.9; $P < 0.0001$], reaching a maximum at 10.0°C (Fig. 2B). Species with realized niches near this maximum exhibited similar realized and potential niche widths (i.e., R:P ratio ~ 1). These central species approximately conform with the predictions of the Eltonian noise hypothesis, but species at both temperature extremes contradict the predictions.

The directional niche contraction metric exhibited a strong positive relationship with MAT (R^2_{adj} = 0.71; $F_{2,185}$ = 225; $P < 0.0001$). The switch from niche contraction into cooler sites (blue colors in Fig. 2) to contraction into warmer sites (gold colors in Fig. 2) occurred at 12.0°C (Fig. 2C). Potential niche width exhibited a significant U-shaped relationship with MAT (R^2_{adj} = 0.29; $F_{2,185}$ = 37.6; $P < 0.0001$), where potential niche width reached a minimum at 15.9°C (Fig. 2D). We estimated the centrifugal center value as the mean of three critical values: the maximum, *x*-intercept, and minimum of the fitted regression models in Fig. 2, B, C, and D, respectively. The estimated centrifugal center was 12.6°C (denoted by the vertical line in Fig. 2A; table S1). Notably, 176 of 188 species (94%) were observed to be growing and surviving in arboreta at 12.6°C even though only 64% of these species occurred at this temperature in their native ranges (Fig. 2A and table S1).

Similar results were obtained for maximum temperature of the warmest month and minimum temperature of the coldest month. Centrifugal organization was supported in all three statistical tests of maximum temperature with a center at 25.5°C (Fig. 3, fig. S3, and table S1), and 100% of species could tolerate this central maximum temperature (fig. S3). Centrifugal organization was also supported in two of three statistical tests for minimum temperature (Fig. 3, fig. S4, and table S1). In the one exception, potential niche width of minimum temperature declined nonlinearly with increasing realized niche position, supporting a shared preference for a higher temperature above freezing. The propensity of evidence indicates that a low temperature center exists at −3.2°C and that 97% of species could tolerate this central minimum temperature.

Overall, these results falsify the model of distinct thermal preferences and support the centrifugal organization of potential thermal niches. They also clarify the true breadth of thermal tolerances of North American temperate tree species, showing that many species occupy only a fraction of their potential niche, and confirm that trees can tolerate surprisingly large ranges in temperature (*14*, *34*).

Centrifugal organization of thermal niches

Tree species inhabit distinct environments in nature, but two results seem counterintuitive to this observation. First, many species have potential temperature tolerances much greater

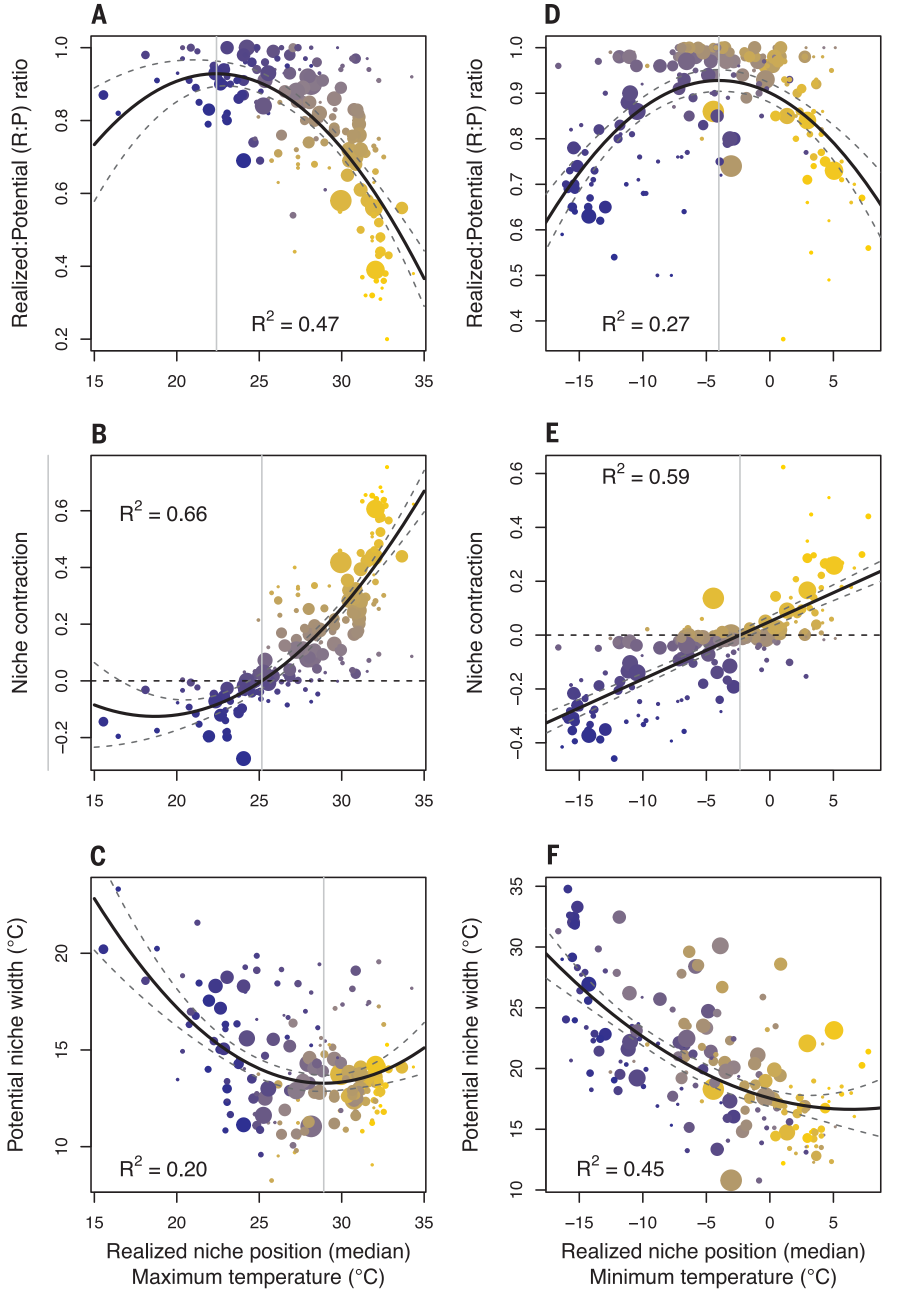

Fig. 3. Relationships between three niche metrics and realized niche position for North American tree species along gradients of maximum and minimum temperatures. (**A** to **C**) Relationships between realized niche position (median maximum temperature of the warmest month) and the realized-to-potential niche width ratio (R:P ratio) (A), niche contraction (B), and potential niche width (C). Niche contraction is a directional index of contraction of the realized niche into warmer (positive) or cooler (negative) climates. Species with realized niches contracting to cooler temperatures are shown in blue colors, and species with realized niches contracting to warmer temperatures are shown in gold colors. (**D** to **F**) Relationships between realized niche position (median minimum temperature of the warmest month) and the realized-to-potential niche width ratio (R:P ratio) (D), niche contraction (E), and potential niche width (F). Symbols are sized in proportion to the number of occurrences in arboreta, but these were not used to weight observations in the regression analyses.

than where they are observed to occur. Second, North American temperate trees share a single environment with a MAT around 12°C where they can grow and survive, even though we can clearly identify tree species that occur in nature only in colder or warmer temperatures.

Why do species have realized niches that span less than three-quarters of their potential niches? Our measurement of potential niches necessarily used data that could involve sampling biases, but these biases are all in the direction of not covering a large enough range of temperatures. Better sampling of potential niches could only expand them, so this cannot explain why species inhabit a small slice of their potential niches. A second possible explanation is that the definition of the potential niche only considers survival and growth of mature trees, not recruitment. Our results cannot prove that populations could indefinitely persist at the central temperatures because the fundamental niche additionally requires an ability to reproduce to maintain positive population growth rates (*4*, *35*, *36*). This seems unlikely to explain most of the unoccupied parts of the potential niche for two reasons. First, in tree populations that are not growing exponentially but have been in rough equilibrium, such as the trees of North America in recent millennia (*37*), elasticity analyses of population growth rates show that it is the survival of adults that is most important to fitness (*8*). Second, trees only need one or a short sequence of a few years in which successful reproduction and seedling establishment can occur, and this may occur at any point in the temporally variable, multidecadal reproductive phase of a tree (*36*, *38*). A third explanation for the failure to fully occupy the potential thermal niche is dispersal limitation. Although trees are certainly dispersal limited over even centennial timescales (*39*), and dispersal limitation has been invoked to explain the so-called occurrence holes found in present-day ranges (*40*), temperatures have been approximately stable for almost 10,000 years in North America. Fat-tailed dispersal kernels suggest that trees have the ability to move rapidly enough that it is unlikely that trees are still several degrees Celsius short of tracking their realized climate niche (*39*). Moreover, trees that now occupy the cold end of their potential thermal niche have clearly already dispersed to reach those colder locations since glaciation, abandoning the warmer locations that now compose the unoccupied portions of their potential thermal niche.

This leaves biotic interactions as the most likely explanation for why species do not fill their potential temperature niches. Although biotic interactions likely play out differently at large scales than they do in the small-scale competition studies that are most commonly used to study them, there is good evidence from closely related species that do not co-occur across part or all of their range that biotic interactions can limit species distributions at regional to continental scales (*41*, *42*). The centrifugal niche pattern observed has a clear explanation based in a competition-tolerance trade-off (*7*, *18*–*20*). In such a trade-off, some species allocate resources to being competitively dominant to occupy the central core habitat. Other species allocate resources to being tolerant of lethal environmental conditions, such as frost and drought. But it is likely that all forms of biotic interaction (i.e., competition, herbivory, disease, etc.) play a role.

The second result that requires explanation is the shared tolerance for intermediate temperatures around 12°C MAT. One explanation could be physiological. Thermal gradients are well known in biology for generating hump-shaped reaction rates (*43*, *44*). For example, C_3 photosynthesis is the dominant pathway in trees, and global average temperature response of photosynthesis peaks at 18°C (*45*). Moreover, radial growth rates of trees in the northeastern United States reach an optimum around 11.5°C (fig. S5). The full explanation likely involves temperature interacting with precipitation and CO_2 (*46*).

Evolutionary explanations, at first glance, would seem challenging: Selection should quickly evolve potential niches to match realized niches because there is no selection in nonrealized regions of the potential niche. A deeper time explanation involving extinction filters and niche conservatism (*47*) is possible. The 12°C is close to the warmest MAT found in North America at the last glacial maximum (LGM) (fig. S6) and is probably approximately similar to previous glacial maxima over the past 2 million years (Ma). The 12°C is also close to the coolest temperatures found in the same space 56 million years ago in the Paleocene-Eocene thermal maximum (PETM) (*48*), although uncertainties around these estimates are high. One could posit that cold-adapted trees unable to survive temperatures ≥12°C went extinct in the PETM and warm-adapted trees unable to survive temperatures ≤12°C went extinct in one of the glacial maxima. Furthermore, if the warm temperature tolerances of cold-adapted trees were conserved for 56 Ma, whereas the cold temperature tolerances of warm-adapted trees were retained for merely 2 Ma, which follows the documented asymmetry in niche conservatism of warm and cold limits (*49*), then this could explain the present centrifugal organization. But, one would have to explain why trees with refugia in Mexico maintained tolerance of 12°C. Overall, more work is needed to make this theory rigorous. Our results do provide a plausible explanation for the occurrence of no-analog communities. For example, *Picea* spp. and *Fraxinus* spp. have narrow co-occurrence today but co-occurred 12,000 to 17,000 years ago (*37*), which was possible because their potential niches overlap.

We rejected the shared preference model for temperature (Fig. 1B), but this does not preclude the possibility that there could be other nontemperature gradients along which distinct (Fig. 1A) or shared preferences (Fig. 1B) exist (Fig. 1B). In small-scale studies, shared preferences are common in coexisting plant species along consumable resource gradients (*19*), and animals have shown a strong propensity for distinct niche preferences along diet gradients (*19*). We note that centrifugal organization is often found when there are multiple dimensions of lethality (*21*, *29*) and that temperature effectively achieves this, with cold adaptation being very different from heat stress adaptation.

Implications for species' responses to a warming world

Centrifugal organization of potential thermal niches has substantial implications for efforts to predict and understand species' responses to climate change (*22*, *23*, *50*, *51*). If the potential niche is a representative analog of the fundamental niche, then the fact that many species occupy only a limited subset of their potential niche raises the possibility that their realized niche could change and occupy a different subset of their potential niche when abiotic conditions not present today become available. This breaks a core assumption of species distribution models.

Niche modeling must get serious about the distinction between realized niches and their potential and fundamental counterparts. On the one hand, niche modeling of tree species with realized niches centered on 12°C could be accurate because their realized and potential niches are so similar (i.e., R:P ratio ~ 1; Fig. 2A). On the other hand, the fact that potential niches of cold-adapted species extend to warmer temperatures whereas potential niches of warm-adapted species extend to cooler temperatures implies differential fates in a warming world. Cold-adapted species may not need to migrate to stay within their potential thermal niche, provided that they can survive changing disturbance and competitive regimes, whereas warm-adapted species will need to migrate to stay within their potential niche under warming temperatures. Trees that are actively shifting their ranges and experiencing exponential growth may flip to conditions where fitness will be most sensitive to the regeneration niche (*36*) because dispersal and recruitment rates drive the advancing range. We should not assume, however, that regeneration niches are identical to realized recruitment patterns on the basis of these results.

The long-standing recognition of the importance of fundamental niches has not been adequately addressed empirically. Our results show that realized niches are not trivial contractions of potential niches. Rather, they differ substantially in a systematic fashion, where realized niches contract away from an intermediate temperature into both the hot and cold ends of the thermal spectrum. Our findings challenge existing predictions of how ranges will shift under climate change and suggest a need for deeper exploration of the relationship between potential and realized niches, including the mechanisms driving these differences.

REFERENCES AND NOTES

1. B. J. McGill, B. J. Enquist, E. Weiher, M. Westoby, *Trends Ecol. Evol.* **21**, 178–185 (2006).
2. J. Soberón, *Ecol. Lett.* **10**, 1115–1123 (2007).
3. J. M. Chase, M. A. Leibold, *Ecological Niches: Linking Classical and Contemporary Approaches* (Univ. Chicago Press, 2003).
4. G. E. Hutchinson, *Cold Spring Harb. Symp. Quant. Biol.* **22**, 415–427 (1957).
5. D. F. Sax, R. Early, J. Bellemare, *Trends Ecol. Evol.* **28**, 517–523 (2013).
6. A. Bush *et al.*, *Glob. Ecol. Biogeogr.* **27**, 22–31 (2018).
7. O. R. Vetaas, *J. Biogeogr.* **29**, 545–554 (2002).
8. M. Franco, J. Silvertown, *Ecology* **85**, 531–538 (2004).
9. D. Doak, P. Kareiva, B. Klepetka, *Ecol. Appl.* **4**, 446–460 (1994).
10. J. Soberón, B. Arroyo-Peña, *PLOS ONE* **12**, e0175138 (2017).
11. J. H. Connell, *Ecology* **42**, 710–723 (1961).
12. J. Soberón, M. Nakamura, *Proc. Natl. Acad. Sci. U.S.A.* **106**, 19644–19650 (2009).
13. A. T. Peterson *et al.*, *Ecological Niches and Geographic Distributions* (Princeton Univ. Press, 2011).
14. T. Bocsi *et al.*, *Divers. Distrib.* **22**, 615–624 (2016).
15. R. Early, D. F. Sax, *Glob. Ecol. Biogeogr.* **23**, 1356–1365 (2014).
16. A. L. Hargreaves, K. E. Samis, C. G. Eckert, *Am. Nat.* **183**, 157–173 (2014).
17. M. P. Austin, in *Perspectives on Plant Competition*, J. B. Grace, D. Tilman, Eds. (Academic Press, 1990), pp. 215–239.
18. R. K. Colwell, E. R. Fuentes, *Annu. Rev. Ecol. Syst.* **6**, 281–310 (1975).
19. I. C. Wisheu, *Oikos* **83**, 246–258 (1998).
20. M. L. Rosenzweig, Z. Abramsky, *Oikos* **46**, 339–348 (1986).
21. P. A. Keddy, P. MacLellan, *Oikos* **59**, 75–84 (1990).
22. A. Guisan *et al.*, *Ecol. Lett.* **16**, 1424–1435 (2013).
23. L. R. Iverson, A. M. Prasad, *Ecol. Monogr.* **68**, 465–485 (1998).
24. A. J. Davis, L. S. Jenkinson, J. H. Lawton, B. Shorrocks, S. Wood, *Nature* **391**, 783–786 (1998).
25. K. B. Suttle, M. A. Thomsen, M. E. Power, *Science* **315**, 640–642 (2007).
26. S. T. Jackson, J. T. Overpeck, *Paleobiology* **26**, 194–220 (2000).
27. M. P. Austin, T. M. Smith, *Vegetatio* **83**, 35–47 (1989).
28. L. Birch, *Ecology* **34**, 698–711 (1953).
29. I. C. Wisheu, P. A. Keddy, *J. Veg. Sci.* **3**, 147–156 (1992).
30. B. S. Maitner *et al.*, *Methods Ecol. Evol.* **9**, 373–379 (2018).
31. E. L. Little, "Atlas of United States Trees, Volume 1, Conifers and Important Hardwoods" (US Department of Agriculture, Miscellaneous Publication 1146, 1971).
32. BGCI PlantSearch (2014); https://plantsearch.bgci.org.
33. D. N. Karger *et al.*, *Sci. Data* **4**, 170122 (2017).
34. C. Loehle, *J. Biogeogr.* **25**, 735–742 (1998).
35. P. J. Grubb, *Biol. Rev.* **52**, 107–145 (1977).
36. S. T. Jackson, J. L. Betancourt, R. K. Booth, S. T. Gray, *Proc. Natl. Acad. Sci. U.S.A.* **106**, 19685–19692 (2009).
37. J. W. Williams, S. T. Jackson, *Front. Ecol. Environ.* **5**, 475–482 (2007).
38. R. M. Turner, *Ecology* **71**, 464–477 (1990).
39. J. S. Clark *et al.*, *Bioscience* **48**, 13–24 (1998).
40. J. C. Svenning, F. Skov, *Ecol. Lett.* **10**, 453–460 (2007).
41. N. J. Gotelli, G. R. Graves, C. Rahbek, *Proc. Natl. Acad. Sci. U.S.A.* **107**, 5030–5035 (2010).
42. A. Paquette, A. L. Hargreaves, *Ecol. Lett.* **24**, 2427–2438 (2021).
43. J. I. Arroyo, B. Díez, C. P. Kempes, G. B. West, P. A. Marquet, *Proc. Natl. Acad. Sci. U.S.A.* **119**, e2119872119 (2022).
44. V. L. Arcus, A. J. Mulholland, *Annu. Rev. Biophys.* **49**, 163–180 (2020).
45. K. A. Duffy *et al.*, *Sci. Adv.* **7**, eaay1052 (2021).
46. R. F. Sage, D. A. Way, D. S. Kubien, *J. Exp. Bot.* **59**, 1581–1595 (2008).
47. J. C. Svenning, *Ecol. Lett.* **6**, 646–653 (2003).
48. J. E. Tierney *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **119**, e2205326119 (2022).
49. M. B. Araújo *et al.*, *Ecol. Lett.* **16**, 1206–1219 (2013).
50. J. Elith, J. R. Leathwick, *Annu. Rev. Ecol. Evol. Syst.* **40**, 677–697 (2009).
51. W. Thuiller *et al.*, *Perspect. Plant Ecol. Evol. Syst.* **9**, 137–152 (2008).
52. D. Laughlin, B. McGill, Data from: Trees have overlapping potential niches that extend beyond their realized niches, Dataset, Dryad (2024); https://doi.org/10.5061/dryad.0cfxpnw9f.

ACKNOWLEDGMENTS

We are grateful to the Botanic Gardens Conservation International (BGCI) for sharing their arboretum inventories with us. We dedicate this paper to the memory of Paul A. Keddy. **Funding:** This study was supported by National Science Foundation (NSF) DEB-1906243, NSF EPSCOR Track II grant no. 2019528, and a University of Wyoming Flittie Sabbatical Augmentation grant to D.C.L. and by US Department of Agriculture Hatch grant MAFES no. 1011538 and NSF EPSCOR Track II grant no. 2019470 to B.J.M. **Author contributions:** Conceptualization: B.J.M. and D.C.L. Analysis: D.C.L. and B.J.M. Writing: D.C.L. and B.J.M. **Competing interests:** The authors declare that they have no competing interests. **Data and materials availability:** All native species distribution data are freely available through the Botanical Information and Ecology Network (BIEN) (*30*) and Little's range maps (*31*). We obtained inventories of arboreta by request from the BGCI (*32*), which is a scientific nonprofit, and their data policies prevent us from publishing their location data, but the data can be made available to qualified researchers by request through their online data request form at https://www.bgci.org/. R scripts and climate data (scrubbed of arboretum location information) to reproduce results are available on Dryad (*52*).

SUPPLEMENTARY MATERIALS

science.org/doi/10.1126/science.adm8671
Materials and Methods
Figs. S1 to S7
Tables S1 and S2
References (*53*–*58*)

Submitted 9 November 2023; resubmitted 19 February 2024
Accepted 9 May 2024
10.1126/science.adm8671