

# Composition-climate paper

*Simon Goring et al.*

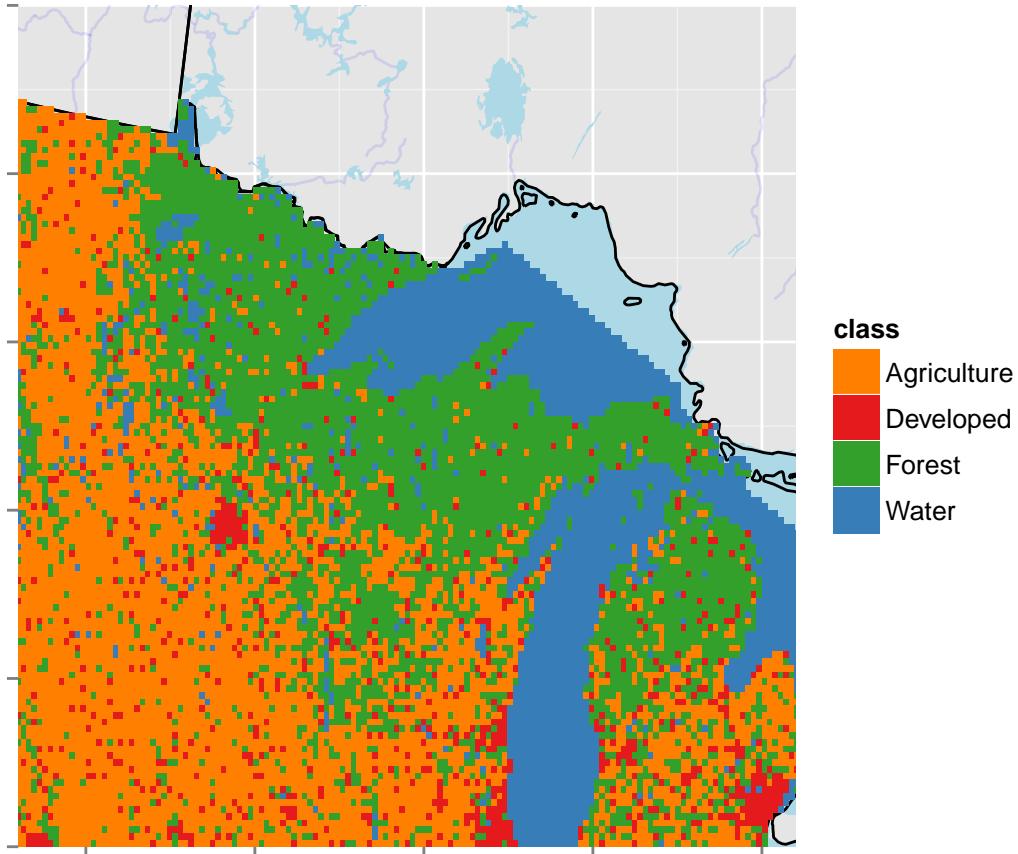
## Land use patterns and historical contingency change climate optima for key forest genera in the Northeastern United States.

*Historic land use and forest change over the centuries since Euroamerican settlement have significantly changed the structure and composition of forests in the upper Midwestern United States. The extent to which this change has affected the realized climate niche for key taxa is less well known.*

*Predictions for future species range shifts are predicated largely on correlative models that relate modern species distributions to climate parameters in the modern era. Given the extent of regional forest change and recent losses to key forest taxa including Hemlock, Elm and Chestnut it is possible that certain taxa have shifted with respect to climate change over the last century. The additional pressure of climatically biased land use conversion for agriculture along the western and southern border of the upper Midwest means that the shift in climate space may be most pressing in a region of climate space that is critically important for understanding future species responses to climate change.*

## Introduction

Over the past 200 years centennial scale climate variability and land use change have interacted to transform the forests of the northeastern United States. There are clear indications that modern forests, as represented by the Forest and Inventory Analysis show greater homogeneity and significantly different species associations than pre-settlement forests (Schulte et al. 2007, Goring et al. in review). This shift has occurred over a period during which climate has begun to show the effects of anthropogenic warming, and a period in which we have increasingly used the relationship between modern tree species distributions and climate to understand future responses of tree species and forest assemblages to climate change (Iverson and Prasad 1998, Iverson and McKenzie 2013). One of the most significant changes to forest tree distributions in the upper midwest is the loss of extensive cover through land use change (Rhemtulla et al. 2009), particularly along the historical prairie and savanna margins of the region (Figure 1), where extensive land use conversion has left little natural land.



**Figure 1.** Patterns of land use change in the upper Midwestern United States. Data from the NLCD (Jin et al. 2013).

The interaction of land use change and climatic change has been of interest to conservation managers and scientists (e.g., Pyke 2004) since managed natural areas often represent a biased selection from the available environmental space (Scott et al. 2001). Pyke (2004) lays out a useful framework for assessing the interaction of climate and land use change. By delimiting three types of interaction, compounding, confounding and contradicting, it is possible to understand both the nature of the interaction and the potential effect on species resilience and response to broader regional change.

Compounding effects occur when both climatic change and land use change are biased in the same direction, e.g., warming climate is compounded by land use change that is biased towards warmer environments. In the case of warming a species may lose climatic suitability along the warmest margins of its range at the same time as land use pressure increases, hastening decline in response to warming. Confounding effects may cause little overall effect on species distributions since in this case the land use pressure falls within the central distribution for the environmental variable, they may increase the variability of predictive models, but do little to the overall envelope. Contradicting effects result in a narrower climate niche for taxa, where warming forces the distribution mean higher as populations in the warmer tail of the distribution experience greater environmental pressure, and, secondarily environmentally biased land use pressure in the cooler end of the tail excludes the taxa from those regions.

In the midwestern United States we see a strong gradient of temperature and precipitation that results in two major ecotones, one from prairie/savanna to closed forest, in an approximately west to east direction, and one from conifer dominated, sub-boreal forests to deciduous forest in a north to south direction. Goring et al (Goring et al. in review) have shown that land use change has significantly changed the strength and

structure of this ecotone, but did not examine how these shifts might affect the relationships between climate and distribution for individual taxa. Given that much of the land use change within the region occurs in the south, where agricultural conversion has largely eliminated open forests, we might expect to see that species with more southerly distributions would show greater impacts of land use change on their distributions in climate space, assuming no shift in regional climate. Conversely, species in the north should show little change if we expect that pre-settlement trees show similar regeneration patterns (with respect to simple presence/absence) following widespread logging.

Interaction between environmental gradients and land use patterns vary by region and environmental variable. We might expect that species in the north experience a confounding land use effect with respect to temperature, but, with respect to precipitation, particularly toward the forest-prairie margin, where land use conversion continues (Wright and Wimberly 2013) we would expect this effect to be compounding. For southern tree species land use conversion is primarily, and has primarily occurred along the southern margins of the region, parallel to temperature and precipitation gradients. This should result in contradicting land use effects for all taxa with distributions in the region, resulting in narrower species distributions due to the twin effects of land use change and regional climate change.

Critically, given the importance of modern distributional datasets for predicting species range shifts, contradicting land use effects may result in the impression of narrower climatic tolerances. For species that reach their northern or western range limits in the upper Midwestern United States (e.g., hemlock, beech, &tc.) this may be critical, since a narrowing of the apparent environmental envelope may result in underprediction of species resilience to climate change.

We use gridded climate data products and estimates of pre-settlement vegetation to develop climate-vegetation relationships for 15 major tree taxa in the upper Midwestern United States to understand how climate and land use change have interacted since Euro-American settlement to affect species distributions in the region, and to examine the possible implications of these shifts to future estimates of species resilience to climate change across the region.

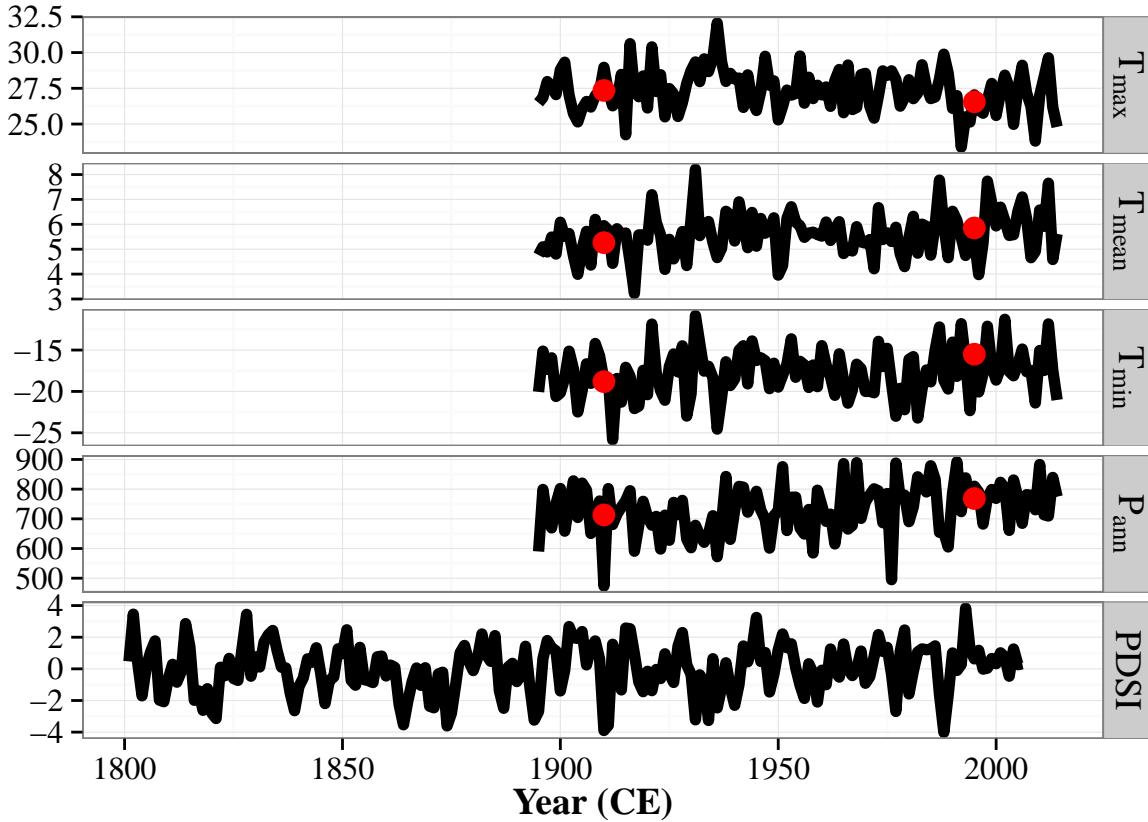
## Methods

We pair pre-settlement vegetation data from the Public Land Survey System aggregated to a 64km<sup>2</sup> grid (Goring et al. in review) with annually resolved climate data for the region. PLSS vegetation data contains no reported uncertainty, however it is spatially discontinuous, particularly in the south where digitization of PLSS records has occurred at a slower rate. Additionally, data in the northeastern United States (Thompson et al. 2013) from town Proprietor Surveys is recorded arially, with no variance within township polygons. To accommodate these different data sources a conditional autoregressive model was applied to the data, providing the ability to obtain uncertainty estimates across the domain (Paciorek et al. 2015).

The analysis follows a blocked sampling method. We generate probability density functions for actual PLSS presence, by taxon, at the settlement era and for the same PLS taxa (and point locations) in the modern era. We also generate climate data for the FIA presence, and we generate climate space for modern land use. In this way we can test how much of the change in shape is the result of changing land use vs changing climate since the early part of the century.

We also develop estimates of the modern climate space that taxa would occupy if they remained in place, with only climate changing, and vice versa (need better explanation here).

## Results

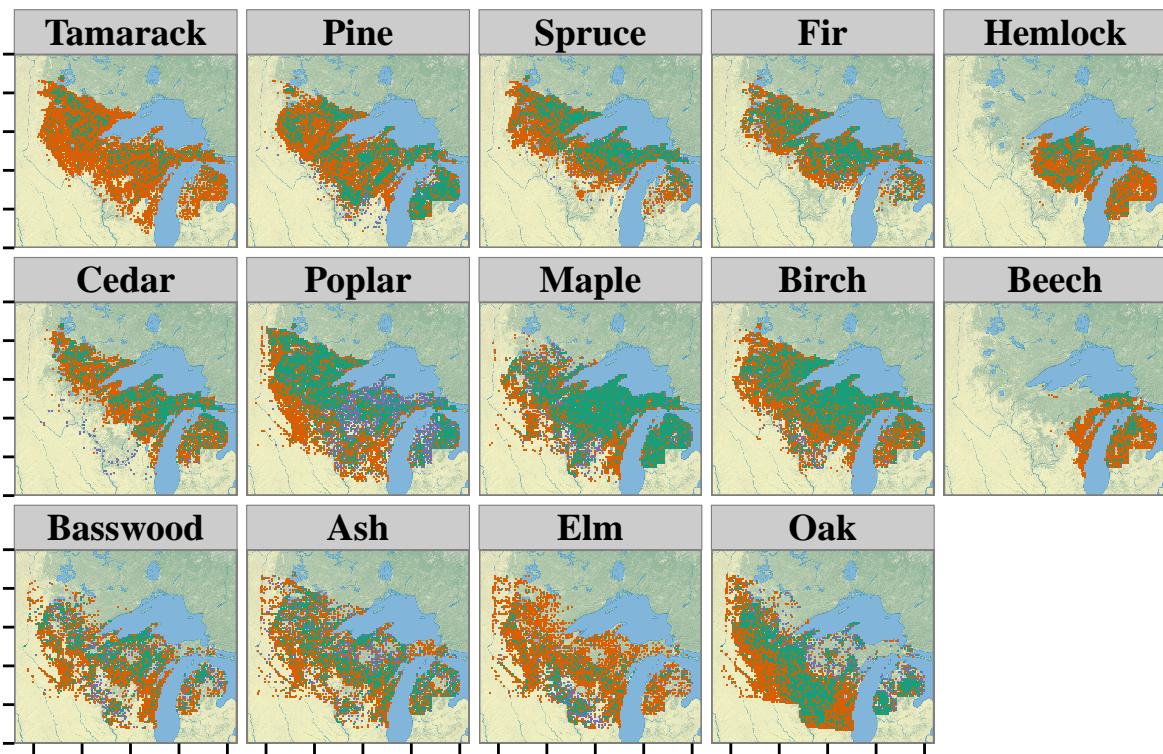


**Figure 2..** Climate change in the Upper Midwest over the last two centuries using PRISM data and North American Drought Atlas PDSI reconstructions. Low temperatures in the 1970s result in lower  $T_{\text{max}}$  during the modern era, but climate change has resulted in higher  $T_{\text{min}}$  values than the early-century normals, along with increasing  $A_{\text{ppt}}$ . PDSI shows strong coherence with  $A_{\text{ppt}}$  in this region.

The choice of a normal for the domain is potentially problematic. The time transgressive nature of the PLS Survey means that some of the PLS data comes from records sampled in the early 1800s, while other come from the early 1900s. Regardless, throughout this period climate variability exists (Figure 1d), and trees that were on the landscape from the 1830s to the 1880s are not expected to have been completely extirpated by annual scale climate variability in that same time period. As such the use of a ‘pre-settlement’ climate normal from 1895-1925 is likely a reasonable choice [ADD JULY temperatures here].

Mean temperatures in the region show an average increase of  $0.59^{\circ}\text{C}$  since the 1895-1925 normal. Annual precipitation has increased slightly (55mm), and maximum annual temperature has declined slightly ( $-0.79^{\circ}\text{C}$ ). The most significant change has been in annual minimum temperatures, which have increased by 3.3 since the 1895-1925 normal. This broad scale increase in winter temperatures is widely accepted, and results in an overall shift in the winter ‘climate space’ for the region.

The Public Lands data is spatially extensive, sampling occurred across the region in a regular pattern, while the FIA is limited to regions with forest cover. As such, the extent of points is not overlapping. Given the extensive use of FIA data in generating and estimating climate responses of tree taxa and forest types to changing climate, the use of the FIA data as an estimate for tree species distributions is acceptable for estimating shifts in climate space, and attributing the loss or gain of climate niche space due to land use and climate variability and change during the 20<sup>th</sup> century.



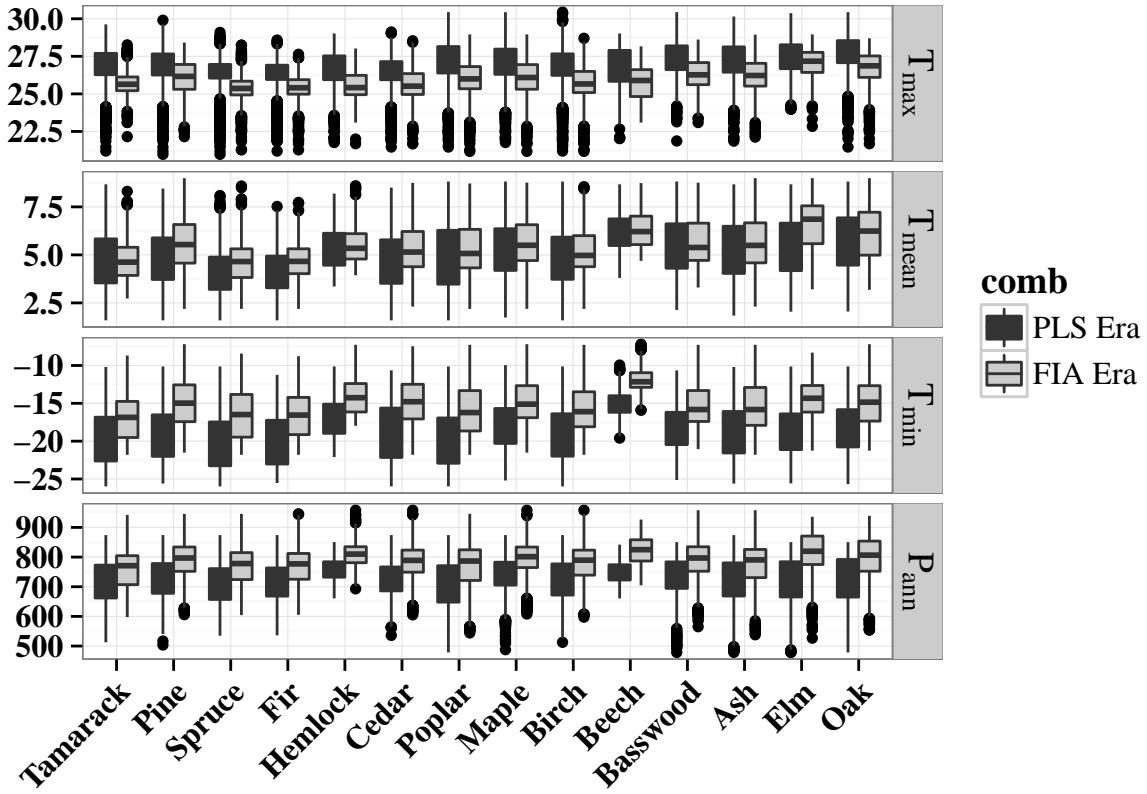
**Figure 3..** Gain loss and continuous presence for PLSS and FIA tree taxa. Continuous presence is indicated by dark green. For most taxa it is the central parts of their distribution that show continuous presence. Few taxa show novel presence (purple), although taxa such as poplar, ash and basswood do show gains of over 10%. Most taxa show significant losses in distribution (orange).

**Table 1.** Gain and loss of the various forest tree types of interest.

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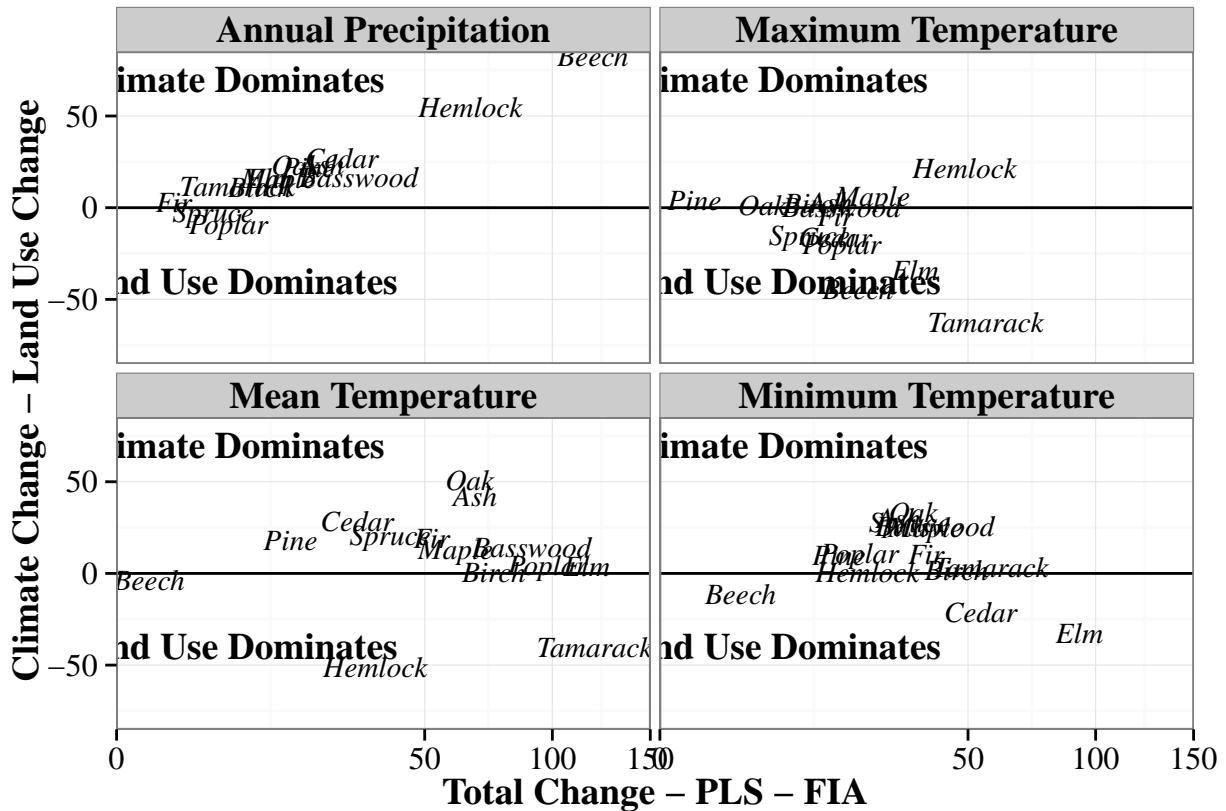
	Gain	Loss	Presence
**Tamarack**	0.004191	0.8086	0.1914
**Pine**	0.04076	0.5403	0.4597
**Spruce**	0.03769	0.5424	0.4576
**Fir**	0.04643	0.5243	0.4757
**Hemlock**	0.006298	0.6779	0.3221
**Cedar**	0.04157	0.5512	0.4488
**Poplar**	0.1972	0.4371	0.5629
**Maple**	0.08711	0.3341	0.6659
**Birch**	0.03449	0.4742	0.5258
**Beech**	0.007812	0.7375	0.2625
**Ironwood**	0.03808	0.9398	0.06018
**Basswood**	0.1294	0.6221	0.3779
**Ash**	0.1457	0.5601	0.4399

\*\*Elm\*\*      0.07377    0.785    0.215  
 \*\*Oak\*\*       0.09938    0.506    0.494



**Figure 4.** Changes in the overall climate space in the upper midwestern United States. The climate densities largely overlap, although it is possible to see the shifts in precipitation, mean and minimum temperatures, where FIA data (pink) has higher values), while the decline in maximum temperatures is also visible, largely at the very highest values.

While these changes in climate are visible across the whole range, we would expect that species with significant shifts in distribution as a result of land use change in the post-settlement era should show changes that supercede the changes resulting from climate alone. In particular, if the land use pressure is biased spatially or climatically then these changes should be even more dramatic. Hellinger distance is used to understand the difference in the shape of kernel densities. Using the distributions in climate space for each of the key taxa we can shift climate, or vegetation to understand the relative effects of land use change and climatic change across the region.



**Figure 5.** For each of the four variables examined we see...

The Hellinger distances reveal that while taxa may show the imprint of land use change on shifting climatic niches, this shift is not uniform across taxa nor climatic variables. Maximum temperature shows the greatest change attributed to land use change. Tamarack, elm, poplar, spruce, beech, cedar, and fir all show a greater influence for land use change than regional climate change.

The precipitation panel (Figure X) indicates that precipitation across the region has driven change in the species climate niche for this variable. Only spruce and poplar show a marginally greater effect of land use change than climate change, whereas taxa such as beech and hemlock show a strong climate signal.

Interestingly, since the pre-settlement era maximum temperatures have declined, while minimum temperatures have increased strongly.

## Discussion

### Figures

### References

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