

Soil properties constrain predicted poleward migration of plants under climate change

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Summary

- Many plant species are predicted to migrate poleward in response to climate change. Species distribution models (SDMs) have been widely used to quantify future suitable habitats, but they often neglect soil properties, despite the importance of soil for plant fitness. As soil properties often change along latitudinal gradients, higher-latitude soils might be more or less suitable than average conditions within the current ranges of species, thereby accelerating or slowing potential poleward migration.
- In this study, we built three SDMs – one with only climate predictors, one with only soil predictors, and one with both – for each of 1870 plant species in Eastern North America, in order to investigate the relative importance of soil properties in determining plant distributions and poleward shifts under climate change.
- While climate variables were the most important predictors, soil properties also had a substantial influence on continental-scale plant distributions. Under future climate scenarios, models including soil predicted much smaller northward shifts in distributions than climate-only models (c. 40% reduction).
- Our findings strongly suggest that high-latitude soils are likely to impede ongoing plant migration, and they highlight the necessity of incorporating soil properties into models and predictions for plant distributions and migration under environmental change.

Introduction

Climate warming is expected to prompt the migration of many plant species to more poleward latitudes (Coelet & Westcott, 2013). Species distribution models (SDMs) are widely used to assess future suitable habitats (e.g. Thuiller, 2007; Thuiller *et al.*, 2011; Guisan *et al.*, 2017), but relatively few SDM studies have incorporated soil properties (e.g. Iversen *et al.*, 2008; Bertrand *et al.*, 2012; Beauregard & de Blois, 2014; Walther & Meier, 2017), despite major effects of soil on plant performance (Larcher, 2003). Because soil properties can change substantially with latitude (Fig. 1; Hengl *et al.*, 2017), soil properties may play an important role in determining plant distributions at large spatial scales (regions to continents), constraining plant latitudinal ranges. Assuming that climate warming shifts suitable climatic conditions poleward, then if soil conditions beyond previous climatically determined range limits are more suitable than average conditions within the range, range shifts ('migration') might occur faster than predicted by a climate-only model. By contrast, if soil conditions beyond the range are relatively unsuitable, poleward migration would be impeded. However, these possibilities have been rarely tested in predictive models (Laffleur *et al.*, 2010; Bertrand *et al.*, 2012). SDMs neglecting soils might thus misrepresent species–environment relationships and therefore projections of future suitable habitats (Bertrand *et al.*, 2012).

It has been claimed that soil properties are unlikely to influence plant distributions across continents, given that they vary more at fine than broad spatial scales (Siefert *et al.*, 2012). However, the major influences on soil – geology, climate, and vegetation, age – can vary greatly at continental scales (Weil & Brady, 2013), so this assumption seems unlikely to hold in general. In Eastern North America (ENA), cold and young postglacial soils at high latitudes lead to shallow, water-logged conditions (Cryosols), or humid, acidic, nutrient-poor conditions (Podzols). By contrast, soils in more southerly temperate forests are more fertile with higher pH (Luvissols; Weil & Brady, 2013). Globally, soil microbial diversity and composition also vary across latitudes (Bahram *et al.*, 2018). Thus, soil properties change greatly with latitude (Fig. 1) and may have a major influence on continental plant distributions. Some recent SDM studies have found significant effects of soil properties on plant distributions (e.g. Bertrand *et al.*, 2012; Beauregard & de Blois, 2014; Walther & Meier, 2017), although spatial extent of these studies was defined largely by political borders (e.g. Switzerland, France, and Quebec) with a focus on temperate forests. Given that climate warming can induce migration across biomes at the continental scale (Lenoir & Svenning, 2014), predicting future distributions will require quantitatively evaluating the relative importance of soil and climate properties at larger spatial scales across multiple biomes.

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