Garden plants get a head start on climate change

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Conservation biologists are concerned that climate change will cause widespread extinctions because limited capacity for migration could compromise species' ability to adjust to geographic shifts in habitat condition. However, commercial plant nurseries may provide a head start for northward range shifts among some plant species. To investigate this possibility, we compared the natural ranges of 357 native European plant species with their commercial ranges, based on 246 plant nurseries throughout Europe. In 73% of native species, commercial northern range limits exceeded natural northern range limits, with a mean difference of ~ 1000 km. With migration rates of ~ 0.1–5 km per year required for geographic ranges to track climate change over the next century, we expect nurseries and gardens to provide a substantial head start on such migration for many native plants. While conservation biologists actively debate whether we should intentionally provide "assisted migration", it is clear that we have already done so for a large number of species.

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By the end of the 21st century, anthropogenic climate change is projected to cause global temperatures to rise by 1.8–4.0°C (IPCC 2007a). This rise is expected to increase the risk of extinction for 20–30% of plants and animals that have been examined to date, with profound consequences for global biodiversity (IPCC 2007b; see also Thomas *et al.* 2004). For any particular species, extinction risk will increase if suitable habitat conditions either disappear entirely (Williams *et al.* 2007) or, as is more probable, if habitats shift more rapidly than resident species can migrate (Parmesan 2006). This prospect has contributed to the debate over "assisted migration"; to what degree should humans intervene to prevent extinctions by transporting species to locations where suitable conditions exist (McLachlan *et al.* 2007)?

In a nutshell:

- The horticulture industry is the source of many exotic plant species, but may also facilitate expansions of species' ranges on their native continents
- Of 357 native European plant species investigated, 73% are being sold hundreds or even thousands of kilometers north of their natural geographic range limits, where climate change is expected to create suitable habitat in the future
- While debate continues about whether humans should actively assist the migration of species in the face of climate change, it is clear that the horticulture industry has already done so for hundreds of species

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As climate change outpaces some species' abilities to migrate, human-mediated exotic species introductions have allowed other species to migrate rapidly across the globe, in some cases causing tremendous ecological and economic harm (Sax *et al.* 2005). For plants, the horticulture industry provides a major pathway for the cross-continental establishment and invasion of non-native species (Reichard and White 2001). However, nurseries also carry many species that are native to the continents where plants are sold, with possible benefits for migration within continents. To date, climate change has allowed many species to shift their geographic ranges northward (Walther *et al.* 2002; Parmesan 2006), in some cases facilitated by the presence of plants in gardens (Walther *et al.* 2002, 2005, 2007), and there is an expectation that gardeners in northern regions will be able to grow many new plant species in the future, thanks to a warmer climate (Bisgrove and Hadley 2002). Here, we investigate the potential for commercial nurseries to provide a head start for northward range shifts of native European plant species in the face of ongoing climate change, and address the question: to what degree have we already inadvertently assisted plant migrations?

Methods

We used national and international websites and databases (eg www.ppp-index.de; www.plantfinder.com) to collect information on commercial plant nurseries in the study area, which comprised most of Europe (Austria, Belgium, Denmark, France, Germany, Ireland, Italy, Luxemburg, Norway, Portugal, Spain, Sweden, the Netherlands, and the United Kingdom). A total of 246 nurseries were selected for this study, based on their geographical location (ie situated along a north–south gradient and more or less evenly spread over countries) and commercial activities (large, non-specialized, localized plant nurseries; Figure 1). We excluded plant nurseries that specialized in only one or two genera (eg *Rosa* spp, *Rhododendron* spp) and large nurseries that export to locations outside the region.

All 246 plant catalogues were digitized in a tabular database. Plant names and synonyms were checked, corrected, and standardized twice: first in a (semi-) automatic way, using computer algorithms, and later by hand to check for inconsistencies. Only species and sub-species were selected for further analysis. Forms, varieties, cultivars, and hybrids were excluded from analysis under the assumption that intensive breeding programs may reduce the ability of plants to persist and reproduce without human assistance (see Kitajima *et al.* [2006] for an exception). This resulted in a data matrix of 246 plant nurseries and 12 424 species and sub-species.

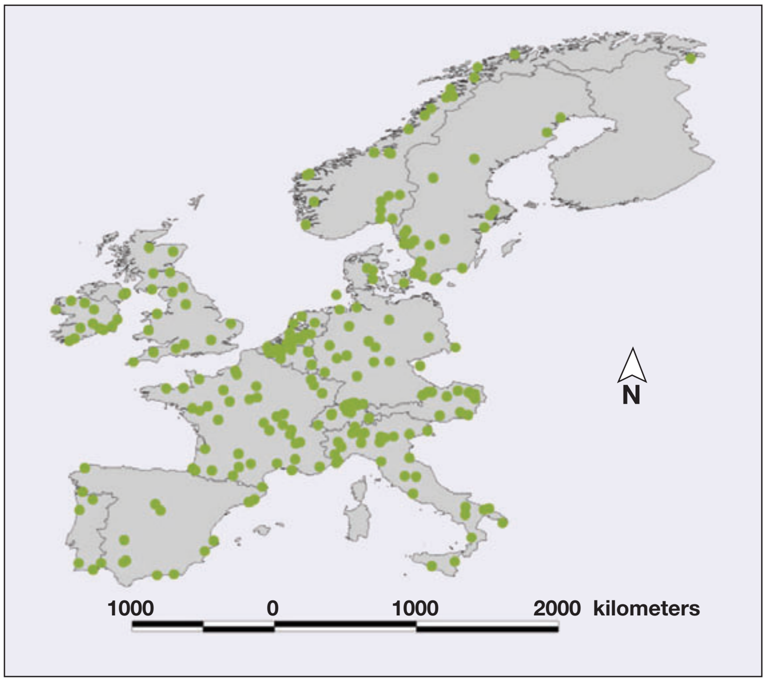

Figure 1. *Map of the study area in Europe, showing the locations of the 246 plant nurseries (green dots).*

Given that successful establishment of introduced species is strongly influenced by propagule pressure (Lockwood *et al.* 2005) – estimated for horticultural plants as the number of nurseries where a species is sold (Dehnen-Schmutz *et al.* 2007) – we restricted our analysis to (sub-) species that were sold in at least 25 plant nurseries (~ 10% of our sample). This reduced the data matrix to 575 (sub-) species, including both natives and exotics, and focused the analysis on a set of species particularly likely to escape from gardens into natural habitats, given suitable conditions. (Only eight of these 575 were listed as sub-species, so we did not conduct a separate analysis for species versus sub-species; henceforth, for the sake of brevity, we refer to all [sub-] species simply as "species".) For all species native to Europe (n = 357 or 62%), we calculated the distance (in km) between the northern edge of each species' "commercial range" (defined as the northernmost plant nursery in which the plant was sold) and the northern edge of each species' "natural range", estimated from regional floras (Jalas and Suominen 1972–1994; Hultén and Fries 1986). To test for the influence of individual nurseries on the determination of commercial range edges, we recalculated commercial northern range limits using the mean latitude of the three and five most northerly plant nurseries. Finally, to test whether certain families were over- or underrepresented in commercially grown species relative to the broader native European flora, we conducted a chi-squared test, comparing these two groups with respect to the proportion of species in each family, with at least ten species in both datasets.

Results

Of 575 species or sub-species sold in at least 10% of nurseries, 357 (62%) were native to Europe. Of these native species, 260 (73% of 357) were sold in at least one nursery located north of the natural northern geographic range limit. The commercial northern range limit exceeded the natural northern range limit by a mean of 1009 ± 632 km (mean ± sd) for these 260 species, and 588 ± 900 km for all 357 native species (Figures 2 and 3). When we recalculated these measures using the mean latitude of the three and five most northerly plant nurseries for those species with commercial range limits north of natural range limits, the difference was reduced from 1009 ± 632 km to 891 ± 570 km and to 806 ± 591 km, respectively. We base our conclusions on the value calculated using the single northernmost nursery, as this represents a minimum estimate of the commercial northern range edge. This is because we did not exhaustively survey every nursery in Europe, and because some of the gardens where species are planted will be even farther north than the nurseries.

We found significant differences in the frequency of species across plant families between commercially grown native plants and the entire European flora (χ^2 [6] = 27.8, P = 0.0001). The proportions of the 260 commercially grown species (and of the full European flora, composed of 13 298 species) in each family were as follows: Lamiaceae 0.081 (0.048); Asteraceae 0.077 (0.126); Ranunculaceae 0.062 (0.026); Rosaceae 0.046 (0.029); Caryophyllaceae 0.038 (0.058); Scrophulariaceae 0.038 (0.04); and other 0.658 (0.675).

Discussion

The presence of plant species in nurseries hundreds of kilometers north of their natural range limits should provide a head start for migration in the face of anthropogenic climate change. For plant species in the north-

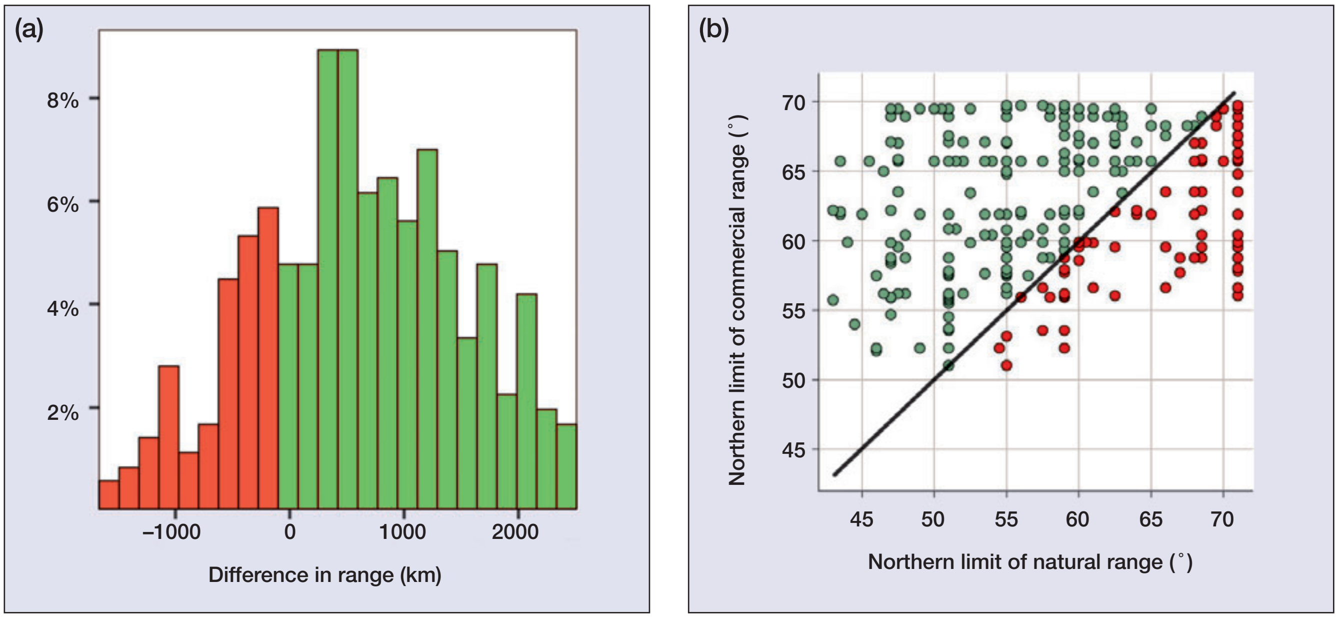

Figure 2. *(a) Histogram and (b) scatter plot with black 1:1 line showing the distance between the northern edges of commercial and natural ranges for 357 native European plant species. Species with commercial northern range limits exceeding natural northern range limits are shown in green; species with natural northern range limits exceeding commercial northern range limits are shown in red.*

ern temperate zone, estimates of migration rates required for geographic ranges to track climate change over the next 1–2 centuries are typically on the order of 0.1–5 km per year (Iverson and Prasad 2002; Malcolm *et al.* 2002; Ohlemüller *et al.* 2006). Thus, extending range limits through horticulture, as demonstrated here, may have a profound impact on the northward movement of the range boundary within which plants grow without direct human assistance. In some cases, this may allow extinction to be averted.

Given the global scope of the horticulture industry, we expect our main conclusion, that horticulture-mediated movement of plants will facilitate tracking of suitable habitat conditions, to apply at least qualitatively to native plant species from all continents. In temperate regions, suitable habitat conditions for a broad range of species are expected to move systematically toward the poles, while in tropical regions, suitable conditions for different species may shift more idiosyncratically (Parmesan 2006; Williams *et al.* 2007). Little is known about the degree to which gardens have already contributed to the migration of native species in response to recent climate change; however, there is some evidence that this has been the case for at least one native species, European holly (*Ilex aquifolium*; Walther *et al.* 2005), as well as many exotic species (Walther *et al.* 2002, 2007). Of the 534 ornamental species sold in Britain during the 19th century and examined by Dehnen-Schmutz *et al.* (2007), 27% were subsequently found growing outside of cultivation, and 30% of these had established populations, clearly demonstrating the potential for horticultural plants to spread into non-cultivated habitats (see Sullivan *et al.* 2005). More quantitative studies from across the globe will be needed to fully assess the role of horticulture in providing a head start for migration during climate change.

With interacting species migrating at potentially different rates and along somewhat different paths (Parmesan 2006), and with novel combinations of climatic conditions arising in some regions (Williams *et al.* 2007), the effects of climate change on range sizes and abundances will probably vary tremendously across species. Similarly, horticulture will not assist the migration of all native European plant species equally. First, although we consider 260 to be a large number of native species with commercial range limits north of their natural range limits, these species represent a relatively small proportion of the European flora. Second, we found significant differences in the frequency of species in different plant families – for example, an overrepresentation of species in the mint (Lamiaceae), buttercup (Ranunculaceae), and rose (Rosaceae) families. Thus, horticulture may cause the future native flora of northern Europe to be biased toward "desired" species in particular plant families. At the same time, some of the many exotic species that are not currently invasive, but which are sold in nurseries, may well begin to spread into natural habitats as novel climatic conditions arise (Walther *et al.* 2002).

Scattered horticultural centers and gardens far north of species' natural range limits essentially represent small outlying populations, and past range shifts during the Holocene inferred from paleoecological evidence support the importance of small, outlying populations during migration. Migration rate calculations based on the pollen record for northern temperate trees initially suggested extremely rapid post-glacial migration during the Holocene (Clark 1998), providing some hope that unaided migrations in the face of contemporary climate

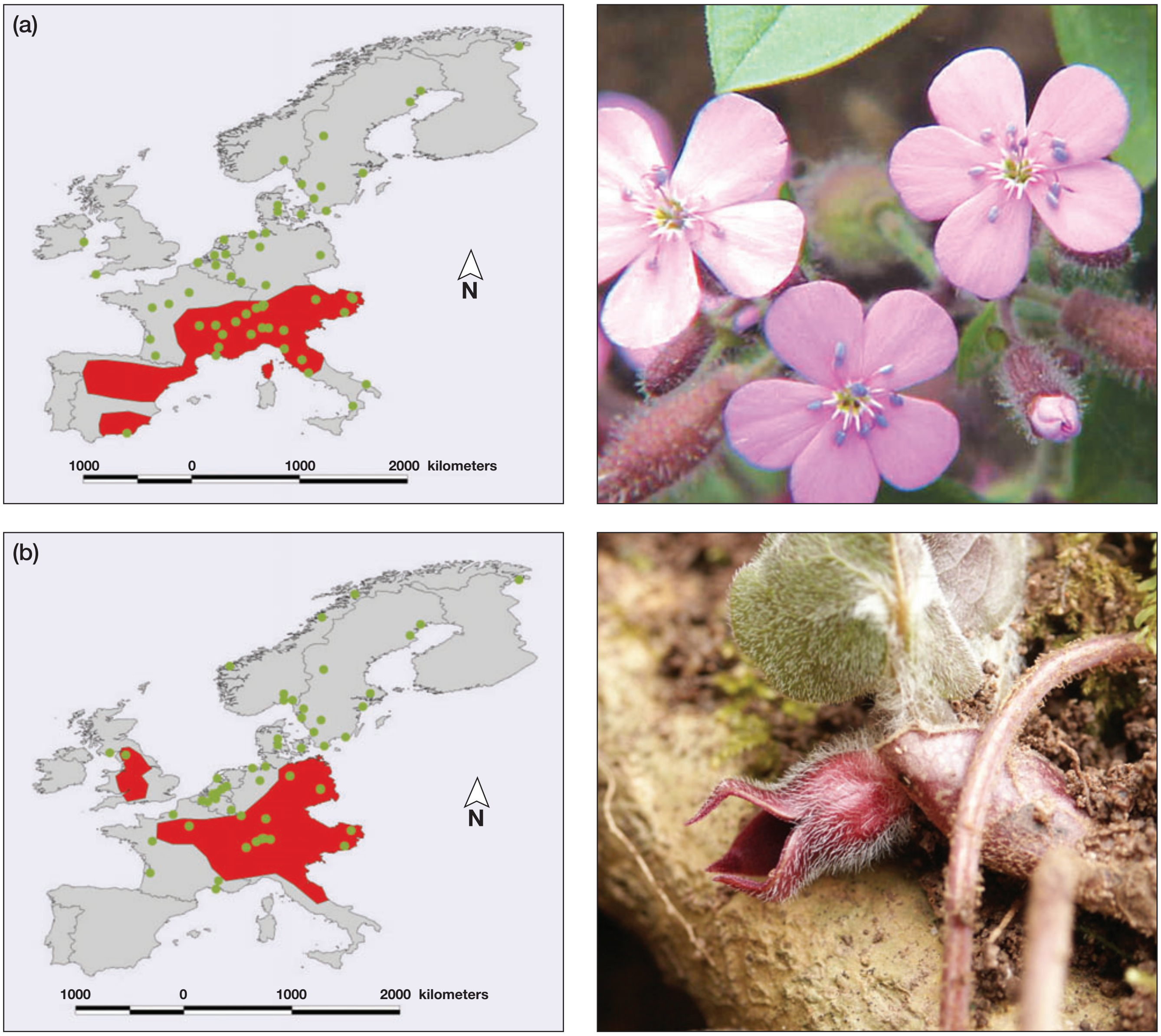

Figure 3. *Natural and commercial range limits of two native European plant species: (a)* Saponaria ocymoides *and (b)* Asarum europaeum*. Nurseries where the species were available are shown as green dots. The natural range limits, determined from* Atlas Florae Europaeae *(Jalas and Suominen 1972–1994) and Hultén and Fries (1986), are shown in red. (a) The northern commercial range limit of* Saponaria ocymoides *(69.46° N) exceeds the natural northern range (47.50° N) by > 2400 km. (b) The northern commercial range limit of* Asarum europaeum *(69.46° N) exceeds the natural northern range (55.00° N) by > 1600 km.*

change might be sufficiently rapid to prevent extinction. However, recent evidence indicates that these assessments overestimated rates of migration, given that small populations far north of the main center of abundance, which are typically ignored in traditional paleoecological analyses, appear to have provided critical foci for colonization and to have spread northward during the Holocene (McLachlan *et al.* 2005). We suggest that nurseries and gardens will play a similar role as foci of northward expansion in response to ongoing anthropogenic climate change.

In many cases, northward plant migrations during the Holocene also had important genetic consequences, such as reduced genetic variability in northern populations due to serial bottlenecks, or increased genetic variability in regions where populations from isolated refugia subsequently became mixed (Petit *et al.* 2003). In the same way, the genetic composition of populations of a species may differ between their exotic and native ranges, depending on the number and location of source populations (Vellend *et al.* 2007). This raises important questions concerning the genetic diversity and composition of native plants sold north of their natural ranges, for which we have few answers at present. Small outlying populations can reduce the impact of serial genetic bottlenecks that may otherwise occur during migration (McLachlan *et al.* 2005). In addition, if species show local adaptation to climatic conditions within their natural ranges (Davis and Shaw 2001), the potential for establishment and spread during climate change may depend in part on whether the plants sold in nurseries originate from similar or very different climatic conditions than those north of the natural range. This is an important area of future research.

Finally, the idea of "assisted migration" suggests that extinction of many species could be averted by helping species to keep pace with climate change, but it also potentially creates all of the risks typically associated with the introduction of exotic species, some of which ultimately become major pests (McLachlan *et al*. 2007). While the debate on assisted migration continues, it is clear that, across the planet, we have already given many species an unintentional head start on climate change.

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