Gardens as drivers of native plant dispersal and conservation

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Abstract

1. Gardens hold untapped potential for participatory biodiversity conservation. Conservation gardening has recently emerged as a way to foster declining native plant species in urban and rural green spaces. But the impact of cultivating these species on population trends in the broader landscape remains underexplored.
2. Here, I study the effects of cultivating herbaceous native plants on species' long-term population trends and endangerment. I integrate the comprehensive cultivated flora of Rothmaler's "Herbaceous Ornamental and Crop Plants" in Germany, and the German Red List of 1998 and 2018. I ask whether cultivating native plants, particularly frequently cultivated ones, reduces their risk of endangerment; whether cultivated species, based on their cultivation frequency, tend to display more optimistic long-term population trends; and whether cultivation may even contribute to improving Red List statuses.
3. I find that cultivated species, especially those commonly grown in gardens, were less likely to be endangered. Moreover, commonly cultivated species had fewer declining and more positive long-term population trends compared to non-cultivated species. Some evidence suggests that commonly cultivated plants in 1998's Red List category are more likely to improve their status, yet still a considerable proportion is in decline.
4. These findings hint at a promising role of gardens as a means to support native species populations, but they also underscore the need for a nuanced understanding of which species are most likely to benefit from cultivation.

Introduction

Gardens, a ubiquitous part of both urban and rural landscapes, offer an intriguing avenue for biodiversity conservation (Maunder et al., 1998; Ismail et al., 2021; Segar et al., 2022). Recently, the concept of conservation gardening has emerged as a participatory approach for restoring biodiversity (Segar et al., 2022; Munschek et al., 2023). This approach focuses on the cultivation of declining native plant species in urban and rural green spaces and seeks to merge horticulture with nature conservation, encouraging public engagement and awareness about the biodiversity crisis (Segar et al., 2022). Gardens can serve as refugia for declining native plant species, offering suitable microhabitats, protection from disturbances, and managed environments where competitive plants can be controlled (Segar et al., 2022). Gardens could consequently serve as launchpads for dispersal to natural habitats, enhancing species' ability to track their ecological niches in a changing landscape. While the recognition of gardens as refugia and ex-situ conservation sites for declining plant species is increasingly accepted (Winter & Botha, 1994; Maunder et al., 1998; Planchuelo et al., 2020; Ismail et al., 2021), their potential as facilitators of native plant dispersal and promoters of connectivity into the broader landscape remains yet largely unexamined.

Gardens are widely acknowledged as pathways for non-native plant dispersal (Lambdon et al., 2008; Reichard & White, 2001; Marco et al., 2010; Van Kleunen et al., 2018; Guo et al., 2019). It is estimated that between 52% and 75% of the global naturalized non-native flora is grown in domestic gardens (Lambdon et al., 2008; Van Kleunen et al., 2018), suggesting substantial ties between horticulture and species gains and losses in more natural habitats. For instance, *Inula hirta* L., a medicinal plant, commonly cultivated in German monasteries until the 19th century, frequently escaped cultivation and naturalized along semi-natural woodland edges. But when cultivation ceased, seed supply diminished and the plant almost vanished from the wild (Jäger et al., 2016), illustrating the vital role of cultivation in shaping floristic changes. Conversely, despite the long-term cultivation of many crops over vast areas, numerous show minimal instances of escaping cultivation, likely due to their domestication (Chadoeuf et al., 1998; Jäger et al., 2016). Likewise, while many ornamental non-native plants are cultivated, many never escape from gardens. Among the escaping non-natives, some possess pre-existing local adaptations, while others owe their success to prolonged cultivation, resulting in the selection of specific ecotypes equipped to thrive beyond garden boundaries (Dlugosch & Parker, 2008; Oduor et al., 2016; Richards et al., 2006; Zenni et al., 2014). Recognizing the role of local adaptations in enabling plants to escape garden confines, gardens may indeed play a significant part in facilitating the dispersal of native plants that already possess such adaptations.

While distinct from cultivation within gardens, an expanding body of research focuses on the influence of green infrastructure (e.g., road verges, hedgerows, powerline corridors) on native plant dispersal (Damschen et al., 2019; Gilbert-Norton et al., 2010; Plue et al., 2022; Thiele et al., 2018). These studies underscore the potential significance of green infrastructure in bolstering functional meta-populations (Plue et al., 2022), reducing local extinction risks (Damschen et al., 2019), and facilitating colonization (Plue et al., 2019). For example, in a study involving the endangered plant species *Ranunculus nodiflorus* L., it was demonstrated that green corridors contributed to colonization and seed dispersal, resulting in diminished genetic differentiation among local populations within metapopulations (Kirchner et al., 2003). This underscores that the benefits of green corridors extend beyond typical, well-dispersing plants to encompass endangered species as well. Despite the growing exploration of green infrastructure's role in plant biodiversity conservation, the potential of cultivation and gardens—marked by a strong participatory, human component and economic feasibility—often stays overlooked. Exploring the significance of gardens as conduits for the dispersal of native, and also endangered, plant species could hold essential insights in collectively addressing the biodiversity crisis.

In this study, I investigate how cultivating herbaceous native plants in gardens affects species' long-term population trends and endangerment. I focus on the native and cultivated flora of Germany, using data from Rothmaler's “Herbaceous Ornamental and Crop Plants” in Germany (Jäger et al., 2016), and integrating the German Red List of 1998 and 2018 (Metzing et al., 2018). My analysis addresses three main questions. First, does cultivating native plants, especially those cultivated more frequently, reduce their likelihood of being listed as endangered? Second, do cultivated species, depending on how often they are cultivated, tend to show more often neutral or positive long-term population trends (over a time period of 50 - 150 years)? Third, can cultivation contribute to improving the Red List status of endangered species? This study provides an initial assessment of how cultivation and gardens might play a role in conserving native plant diversity.

Methods

Data and R code to reproduce the analysis and figures are available on GitHub at: https://github.com/istaude/cultivation-rltrends.

Cultivated flora. To compile a list of cultivated plants and their cultivation frequencies, I employed a semi-automatic text-mining method to digitize Rothmaler Volume 5, titled "Krautige Nutz- und Zierpflanzen" (Jäger et al., 2016). This particular volume serves as an identification guide for cultivated herbaceous plants and offers details about the frequency by which plants are cultivated in gardens. This resource, compiled over a span of 30 years (starting in 1977 and first published in 2007), presents an unique compendium to study the cultivated flora in Germany. In order to extract data, I employed a semi-automatic text-mining approach. I converted the PDF into HTML format, and text-mined genus names, species epithets, the primary and secondary use of plants (Z = ornamental , N = crop) and the frequency of cultivation (v = common, z = scattered, s = rare). Due to the diverse formatting within the volume, which hindered a completely automated process, I reviewed and revised the extracted list four times, conducting manual checks after each extraction step. Plants mentioned in smaller font sizes, under headings such as "Ähnlich" (Similar) or "Anm:"/"Bem:" (Remark), as well as subspecies, varieties, convarieties or forms listed after the main species, were excluded from the dataset. The extracted data may hold potential for further research and is available at github.com/istaude/cultivation-rltrends/blob/main/Data/rothmaler_complete_corrected.csv (see “01-data-textmining.R” for the text-mining protocol).

Red Lists/population trends. I used the 2018 German national Red List (RL) on vascular plants (Metzing et al., 2018), which not only incorporates the most current RL categories but also integrates the 1998 RL categories for species that were evaluated during that period. RL categories include: 0 = Extinct or lost, 1 = Critically endangered, 2 = Endangered, 3 = Vulnerable, G = Endangered - unknown extent, R = Rare, V = Near threatened, * = Not endangered, nb = Not assessed). Species categorized as endangered are encompassed within categories 0, 1, 2, 3, and G, but note the categories R and V also imply declines. The German RL additionally incorporates data on the long-term population trends of species, offering insights into changes relative to a historical span of 50 to 150 years ago. These changes are denoted using categorical indicators: “<” signifies a moderate decline, “<<” signifies a strong decline, “<<<” signifies a very strong decline, “=” indicates stability, and “>” indicates a significant increase. Furthermore, the RL encompasses non-native plant species in Germany, detailing species status as follows: “I” indicates indigenous, “N” indicates established non-native, “U” indicates transient, and “F” indicates doubtful. In this analysis, I focus on native species and therefore only include species with status “I”. I only included taxa at the species level, utilizing the “Arten” column to select species.

Plant growth forms. As the cultivated plant dataset focused solely on herbaceous species, I had to exclude woody plants from the RL. While I assumed the herbaceous cultivated species list was exhaustive, allowing me to deduce that any native RL species absent from Rothmaler were genuinely uncultivated, this determination was not possible for woody species. To address this, I employed categorical trait data from TRY (Kattge et al., 2020) found at https://www.try-db.org/TryWeb/Data.php#3, detailing plant growth forms. Utilizing growth form information, I omitted species categorized as “trees” and “shrubs/trees” from the

RL. I retained species in the “shrub” category in the RL, as the cultivated flora encompassed those (e.g., species within Erica L.).

Taxonomic harmonization. To harmonize all three data sources (Rothmaler, Red List and TRY), I used the rWCVP and rWCVPdata package in R (Brown et al., 2023), which assigned every species in the data to its accepted species name in the World Checklist of Vascular Plants (WCVP). I used the accepted species name to join all three data sources. The combined and taxonomically harmonized dataset is available at github.com/istaude/cultivation-rltrends/blob/main/Data/redlist_rothmaler_t.csv (see “02-taxonomic-harmonization.R” for harmonization protocol).

Analysis. In all analyses, considering the exclusive availability of categorical data (see above), I employed Fisher's Exact Test to discern statistical clarity (Dushoff et al., 2019) between count data. Notably, this test does not yield a test statistic, thus my reporting solely includes p-values. Addressing the first question—whether the cultivation of native plants, particularly those cultivated more frequently, reduces their likelihood of being listed as endangered—I tallied can compared the count of endangered (i.e., those classified in 2018 as 0, 1, 2, 3, and G) versus non-endangered species within cultivated and non-cultivated species, and then per cultivation frequency. For the second question—whether cultivated species, contingent on their cultivation frequency, tend to show fewer declining long-term population trends—I calculated and compared the count of species showing declines, stability, and increases in relation to their respective cultivation frequencies. For the third question—can cultivation contribute to improving the Red List status of species— I used the 1998 RL as a baseline and focused on species that experienced RL category changes in 2018. For this, I assigned numerical values from 1 to 8 to the categories 0, 1, 2, 3, G, R, V, and * in that order, so that lower numbers in 2018 indicate RL declines, and higher numbers indicate improvements. Throughout these analyses, I compared cultivation frequencies to the non-cultivated flora as a reference level.

Results

A total of 3407 vascular plant species (excluding trees) are cultivated as ornamental plants (n = 3100), crops (n=177) or both (n=126) in Germany. Among these, 21% are native (n=718), while the remaining 79% (n=2689) are non-native, with 165 (6%) successfully naturalized. Compared to the German wild native flora, encompassing 3512 vascular plant species (again excluding trees), the cultivated flora augments the plant species count in

Germany by 77%. Most often native species are cultivated in only a few places (rare, 55%, n=398). Scattered and common cultivation is only for 29% (n=211) and 12% (n=87) of species respectively, and 22 species (3%) did not have data on how frequently they were cultivated.

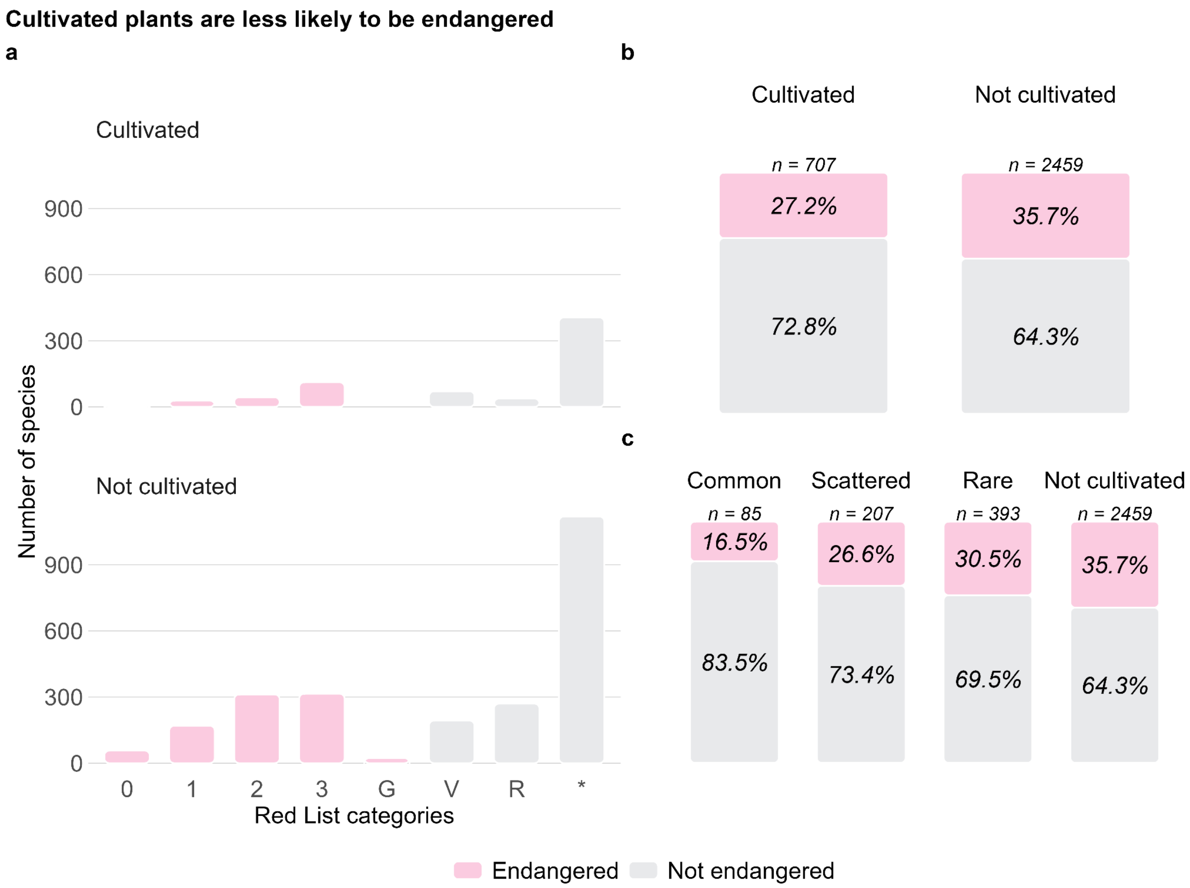

Figure 1: Cultivated plants are less likely to be endangered. a, Barplots depicting the count of species within Red List (RL) categories for cultivated (top) and not-cultivated (bottom) native plant species. RL categories include: 0 = Extinct or lost, 1 = Critically endangered, 2 = Endangered, 3 = Vulnerable, G = Endangered - unknown extent, R = Rare, V = Near threatened, * = Not endangered). Species categorized as endangered fall under the groups 0, 1, 2, 3, and G. **b,** Proportions of endangered species for both cultivated and non-cultivated species, accompanied by respective sample sizes (n). **c,** Proportion of endangered species based on cultivation frequency.

Overall, cultivated species had a 0.27 probability of being threatened on the 2018 RL, while non-cultivated species had a higher probability of 0.36 (Figure 1a and b). This difference was statistically clear (p-value < 0.001). Moreover, how frequently species were cultivated mattered. Commonly, scattered and rarely cultivated species had a 0.17, 0.27 and 0.31 probability of being threatened; species not cultivated had again a 0.36 probability of being threatened (Figure 1c). Differences were statistically clear between common and not cultivated (p-value < 0.001), and scattered and not cultivated (p-value $= 0.008$). The difference between rarely cultivated and not cultivated species was only marginally statistically clear (p-value = 0.053). Together, this indicates that common to scattered cultivation may have a positive impact on species trajectories.

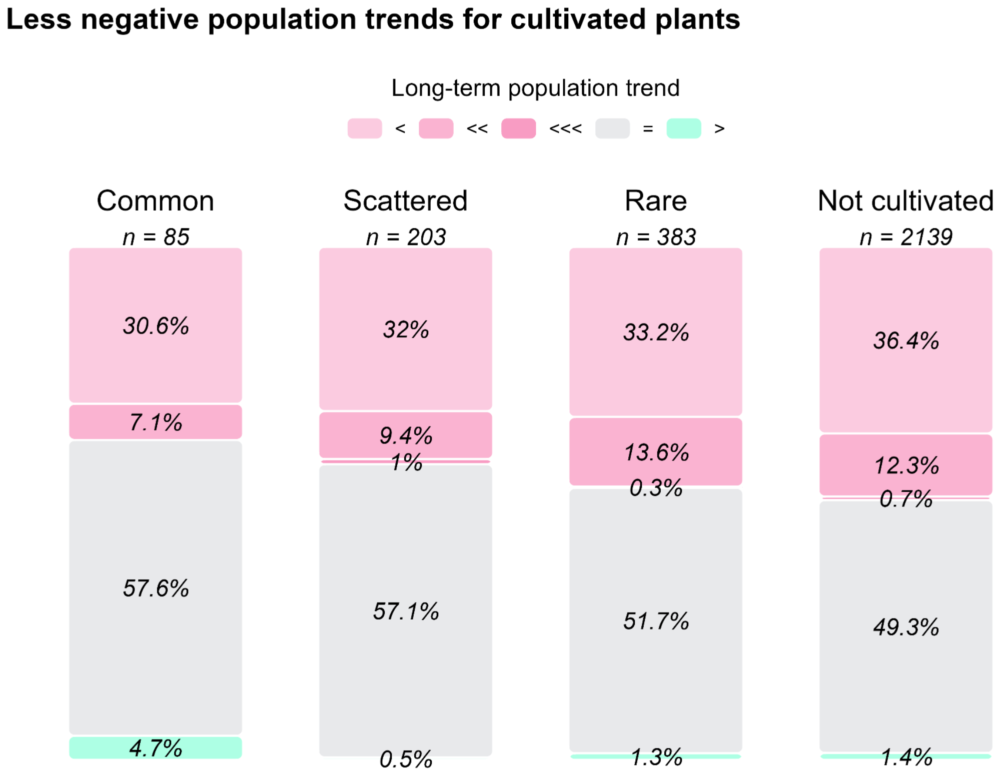

Figure 2: Positive effects of cultivation on long-term population trends. Proportions of long-term population trends (50 - 150 years) per cultivation frequency, accompanied by respective sample sizes (n) Population trends are as follows: "<" indicates moderate decline, "<<" indicates strong decline, "<<<" indicates very strong declines, "=" indicates stability, ">" indicates significant increase.

To test this hypothesis, I examined if cultivation frequency affects species' long-term population trends. Cultivated species tended to show lower instances of declines when all decline categories (moderate, strong, very strong) were combined than not cultivated species (common = 0.376; scattered = 0.424; rare = 0.47 vs. 0.494 for not cultivated species; Figure 2). This trend was statistically clear for commonly cultivated species (p = 0.036). The differences in decline probability between scattered and rarely cultivated species compared to not cultivated species were statistically marginally clear (p-value = 0.067) and uncertain (p-value = 0.406), respectively. Commonly cultivated species displayed the highest probability of stable (0.576) and positive (0.047) long-term population trends, compared to 0.493 and 0.014 probability for non-cultivated species, respectively. This difference was statistically clear for positive population trends (p-value = 0.035), but not for stable population trends (p-value = 0.153). Together, there is a trend for cultivated species to have more optimistic population trends, but this may only be truly the case for commonly cultivated species.

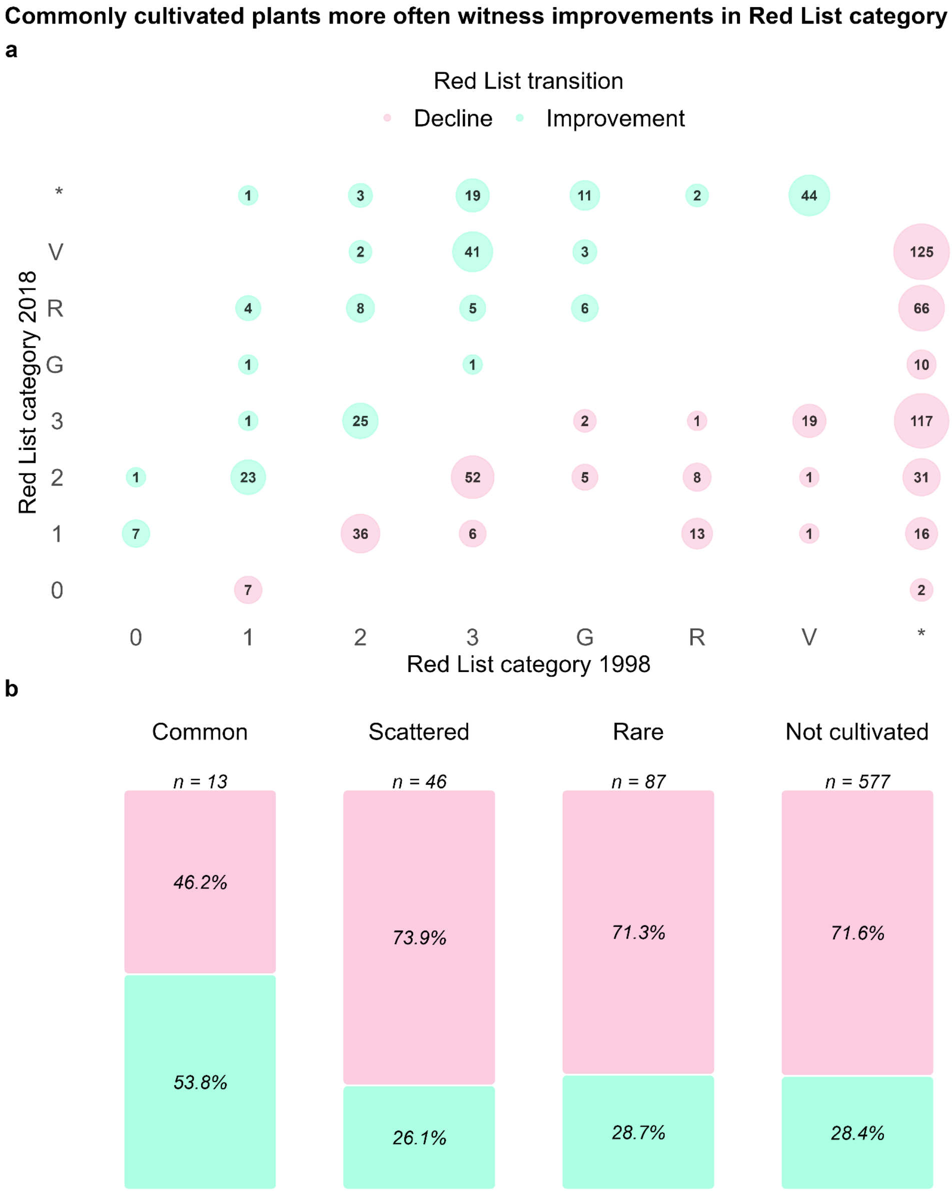

Figure 3: **Commonly cultivated plants more frequently witness improvements than declines in their 1998 Red List (RL) category. a,** RL transitions from 1998 to 2018 (red: declines in RL category, green: improvements in RL category, circle size: number of species). Red List categories are: 0 = Extinct or lost, 1 = Critically endangered, 2 = Endangered, 3 = Vulnerable, G = Endangered - unknown extent, R = Rare, V = Near threatened, * = Not endangered). **b,** Proportion of species with improvements or declines in RL category per cultivation frequency, accompanied by respective sample sizes (n).

Given these apparent positive impacts of cultivation, particularly among commonly cultivated plants, I proceeded to investigate whether cultivation might have contributed to species transitioning between endangerment categories. Among commonly cultivated species, the majority that shifted categories from 1998 to 2018 experienced an improvement in threat status (54%; Figure 3). On the other hand, for scatteredly and rarely cultivated species, the likelihood of an improvement in threat status was broadly comparable to that of non-cultivated species (26% and 29%, respectively, versus 28%). Notably, only the difference between commonly cultivated and non-cultivated species exhibited marginal statistical clarity (p-value = 0.06). However, it's crucial to note that the sample size for commonly cultivated species is quite limited, thus rendering this inference rather weak. Examples of commonly cultivated species that transitioned Red List categories include *Sagittaria sagittifolia* L., *Silene flos-cuculi* L., and *Achillea ptarmica* L., shifting their status from Near Threatened (V) to Not Threatened (*).

Discussion

Here, I present findings on the potential interaction between the cultivated flora in German gardens and the population trends and endangerment trajectories of native plants in the broader landscape. The results indicate that: 1) cultivated species exhibit lower levels of endangerment, particularly when they are common in gardens (Figure 1); 2) commonly cultivated species tend to display more favorable population trends compared to non-cultivated plants; however, scattered or rarely cultivated species show no distinct difference in population trends from those not cultivated (Figure 2); and 3) there is some evidence, albeit with a limited sample size, suggesting that commonly cultivated plants red-listed in 1998 have a higher likelihood of improving their Red List (RL) status than declining, as compared to non-cultivated plants (Figure 3). These findings collectively suggest that the widespread cultivation of native (and declining) plants in gardens may, in some instances, have a positive impact on species conservation outcomes.

While the recognition of gardens as refuges contributing to species conservation is growing, exemplified by iconic cases like the survival of *Franklinia alatamaha* Marshall in cultivation after extinction in the wild (Maunder et al., 1998), scant research has tested the potential of gardens to disperse species of conservation concern. A few instances hint at their significance, as seen with the extinct *Lysimachia minoricensis* J.J.Rodr., a Menorca endemic, that persisted in gardens and self-seeds in Menorca’s barrancos (Maunder et al., 1998). Similarly, declining species like *Gentiana verna* L. and *Pulsatilla vulgaris* Mill. have been observed escaping cultivation. A previous study, using entirely different data, identified more positive 60-year occupancy trends in frequently cultivated plants in Germany, echoing the findings of this study (Segar et al., 2022). However, due to limited data, the role of cultivation frequency and its association with national RL statuses remained unclear. By aggregating a comprehensive dataset delving into cultivation frequency and its correlation with RL trends, the present study provides a deeper understanding of this association.

This study demonstrates a positive impact of cultivation on species' RL status (if it is simply that cultivated plants decline less frequently). And further suggests that widespread, but not rare or scattered cultivation of species is likely to yield conservation benefits. But it is also evident that cultivation alone is not a universal solution for bolstering native species populations. Notably, in 2018, 16.5% of widely cultivated species were still categorized as endangered, including examples like *Helleborus niger* L., *Petrosedum forsterianum* (Sm.) Grulich, and *Iris sibirica* L. Similarly, a significant proportion of cultivated species experienced declining long-term population trends, and while more commonly cultivated species improved in RL status than declined, a substantial fraction still faced decline (46%; e.g., *Geranium sanguineum* L. and *Centaurea cyanus* L.). Hence, it becomes essential to discern the species that benefit through gardening. Furthermore, investigating the extent to which endangered species differ in their dispersal and germination traits compared to non-endangered native or non-native species—for which, to my knowledge, no synthesis study exists yet (but see Ozinga et al., 2009)—could provide essential insights. Understanding this facet could provide insights into the extent to which declining native plant species are diminishing due to inherently low germination rates and limited dispersal capabilities. This understanding is instrumental in determining how much endangered plant species may benefit from gardening initiatives, such as conservation gardening.

Studying the dispersal pathways from gardens, and how plants can make use of them, is further at core of this research avenue. While mechanisms like wind, water, and gravity play a role in abiotic dispersal, biotic dispersal pathways may be particularly strong in gardens. Gardens are prevalent in urban and suburban areas with high human population densities, enhancing the potential for human-mediated plant dispersal (Hodkinson & Thompson, 1997; Bullock et al., 2018). Humans may disperse plant material inadvertently or deliberately. Seeds can adhere to clothing, facilitating their transport to other areas (Auffret, 2011). For instance, visitors to natural habitats may unknowingly carry seeds or plant fragments from gardens, leading to their inadvertent dispersal to wild habitats (Pickering et al., 2011). Human-mediated dispersal can further synergize with abiotic dispersal mechanisms, expanding the dispersal kernel of plants (Rogers et al., 2019). For instance, increased traffic around urban areas can lead to secondary seed dispersal by wind (Von der Lippe & Kowarik, 2008; Bullock et al., 2018). Intentional actions by gardeners, like sharing plants, seeds, or propagules, can further lead to the dispersal of plants to other gardens or natural habitats. Likewise, gardens, designed with intentional wildlife habitats and abundant flowers, seeds and fruits, can attract a diverse array of animals, serving as an additional significant biotic dispersal agent (Cabral et al., 2017; Callaghan et al., 2019; Van Helden et al., 2020). Applied ecology could offer valuable guidance to practitioners in identifying plants that stand to gain the most from these dispersal pathways.

Finally, the present analysis does come with limitations. While commonly cultivated species are less likely to be currently endangered than non-cultivated species, this observation may not solely reflect the impact of cultivation. It's plausible that species selected for cultivation inherently possess greater vigor, reducing their endangerment risk. While such confounding factors might exert a weaker influence in the analysis investigating changes in native plant populations over time, a deeper understanding of dispersal dynamics requires observational studies and experiments. For instance, similar to studies exploring non-native plant linkages between gardens and their surroundings (Marco et al., 2010), investigations could focus on native species. Experimental designs could involve varying plot sizes of native plants within surroundings subjected to varying treatments (disturbance, sparse or dense vegetation) to dissect the role of habitat quality and proximity in native plant dispersal and establishment. Moreover, the relatively limited number of commonly cultivated native plant species restricts the breadth of possible inferences. Yet if the practice of conservation gardening gains momentum, it could offer a natural laboratory to study how native plant species disperse beyond garden confines. AI-powered plant identification tools, combined with citizen science initiatives, offer promising avenues for comprehensive short-term monitoring of such cultivated plants.

With this study, I hope to motivate the scientific investigation into the potential of gardens for native plant dispersal and biodiversity conservation—a realm that has garnered considerably less attention compared to the role of gardens in facilitating non-native species spread. Many questions remain unanswered, encouraging avenues for future research, such as unraveling the dispersal ecology of declining native plants, its interaction with garden-based dispersal pathways, and how habitat proximity and quality modulate dispersal and establishment success across urban and rural garden settings. The present study suggests cultivation could help bolster populations of native plants, hinting at their promising role in conservation efforts.

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