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Geographic discrepancies between global and local rarity richness patterns and the implications for conservation

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Abstract The emerging interest in the biological and conservation significance of locally rare species prompts a number of questions about their correspondence with other categories of biodiversity, especially global rarity. Here we present an analysis of the correspondence between the distributions of globally *and* locally rare plants. Using biological hotspots of rarity as our framework, we evaluate the extent to which conservation of globally rare plants will act as a surrogate for conservation of locally rare taxa. Subsequently, we aim to identify gaps between rarity hotspots and protected land to guide conservation planning. We compiled distribution data for globally and locally rare plants from botanically diverse Napa County, California into a geographic information system. We then generated richness maps highlighting hotspots of global and local rarity. Following this, we overlaid the distribution of these hotspots with the distribution of protected lands to identify conservation gaps. Based on occupancy of 1 km^2 grid cells, we found that over half of Napa County is occupied by at least one globally or locally rare plant. Hotspots of global and local rarity occurred in a substantially smaller portion of the county. Of these hotspots, less than 5% were classified as multi-scale hotspots, i.e. they were hotspots of global *and* local rarity. Although, several hotspots corresponded with the 483 km^2 of protected lands in Napa County, some of the richest areas did not. Thus, our results show

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that there are important conservation gaps in Napa County. Furthermore, if only hotspots of global rarity are preserved, only a subset of locally rare plants will be protected. Therefore, conservation of global, local, and multi-scale hotspots needs serious consideration if the goals are to protect a larger variety of biological attributes, prevent extinction, and limit extirpation in Napa County.

Keywords Biodiversity hotspots · Conservation surrogates · Local rarity · Global rarity · Napa county · Rare plant richness

Introduction

Worldwide, conservation of rare and endangered species is an increasingly pressing concern. Identification and prioritization of biological hotspots, i.e. threatened locations with high concentrations of particular organisms or other biological attributes, is a prominent method to address this issue (Myers et al. 2000; Roberts et al. 2002). Given that conservation efforts take place at global, national, sub-national, *and* local jurisdictional levels, incorporation of multiple scales of analysis is necessary to strengthen our understanding of a given area (Poiani et al. 2000; Gärdenfors 2001; Venevsky and Venevskaia 2005; Crain and White 2011). Consequently, there is substantial need for local analyses of globally prioritized regions to accomplish biodiversity conservation goals (Médail and Quézel 1997; Poiani et al. 2000; Harris et al. 2005; Brooks et al. 2006, Murray-Smith et al. 2009).

Although Myers et al. (2000, 2003) identified global hotspots of diversity based in part on global endemics, within individual biodiversity hotspots, several forms of rarity can exist (Rabinowitz 1981; Crain and White 2011). For example, globally rare species, i.e. those that are rare at the global scale, have very narrow ranges, low population numbers, and are often restricted to specific habitats (Rabinowitz 1981). In contrast, locally rare species are those that are rare at a local scale, but more common at the state, national, or global level (Leppig and White 2006; Crain and White 2011). Because of this, locally rare taxa often have a wide global distribution and large overall population numbers despite being sparse at local scales. Moreover, locally rare taxa are often found near major habitat or climate transitions and therefore they frequently occur in a variety of habitats. Consequently, locally rare species are innately different from globally rare species, and may have unique distributions as a result.

Here we conduct a unique analysis of the distribution of global rarity richness in relation to local rarity richness in a regional geographic setting. Thus far, the potential for global rarity hotspots to act as surrogates for locally rarity hotspots has never been tested. Therefore, the primary objectives of this study are to integrate the distributions of globally and locally rare plants identified by NatureServe (2006), and Crain and White (2011), to identify rarity richness hotspots. The subsequent goal is to examine the extent to which globally rare plant richness hotspots correspond with hotspots of local rarity. We specifically test the hypothesis that the distributions of global and local rarity hotspots have limited correspondence largely because of the unique biological and geographical underpinnings responsible for generating these two types of rarity (Mills and Schwartz 2005; Leppig and White 2006; Master et al. 2009). We seek to determine the extent of spatial protection locally rare plant taxa could receive under the umbrella of global rarity conservation efforts. Our final endeavor is to highlight specific locations that deserve conservation prioritization (i.e. those with high levels of globally and locally rare plants) and the gaps between these hotspots and protected areas.

Research conducted at global, national, and state levels repeatedly highlights the California Floristic Province as a biodiversity hotspot based on a variety of criteria ranging from overall diversity to rarity-weighted richness (Dobson et al. 1997; Abbitt et al. 2000; Myers et al. 2000; Stein et al. 2000). In agreement with similar findings from Médail and Quézel (1997, 1999) and Murray-Smith et al. (2009), research on the California Floristic Province indicates that diversity is not evenly distributed (Parisi 2003). This is largely the result of the geographic complexity of the State of California in general. The result is a region that is rich with globally and locally rare taxa (Parisi 2003; Crain and White 2011; CNPS 2011). Therefore, analysis of biodiversity distributions within individual counties of California is invaluable for understanding patterns of global and local rarity richness and for development of conservation strategies within this global biodiversity hotspot.

The present study focuses specifically on Napa County, a highly diverse local subset of the California Floristic Province that has had much of its land converted for agriculture and other human uses (Thorne et al. 2004). Napa County's position along several major environmental transitions has likely contributed to its overall diversity (Hickman 1993). The county has high richness levels for numerous taxonomic groups and contains a disproportionate number of endangered taxa (Stein et al. 2000; Parisi 2003). Floristic studies in particular indicate that Napa is uniquely rich, and numerous globally and locally rare plants occupy the county (Stebbins and Major 1965; CNDDB 2006, 2007; Crain and White 2011), thus making it an ideal location for this analysis.

Methods

Recent assessments indicate that numerous plant taxa distributed in Napa County are considered rare at the global and/or state geographic assessment level (G-rank $\leq$ 3 and/or S-rank $\leq$ 3, hereafter referred to collectively as globally rare plants) according to criteria outlined by NatureServe's Element Ranking System. These rankings correspond to the critically imperiled, imperiled, or vulnerable categories employed by NatureServe (CNDDB 2006, 2007; Master et al. 2009). Using newly developed L-rank criteria, Crain and White (2011) also identified several locally rare plant taxa distributed within Napa County (taxa with L-ranks 1, 2 or 3). We used ArcGIS 9.1 (ESRI 2005) to map and analyze the distributions of these plants in Napa County. For the 55 globally rare plants and 89 locally rare plants with available geographic information system (GIS) distribution data, we imported vector layers from the California Department of Fish and Game Natural Diversity Database RareFind 3.0.5 computer application (CNDDB 2006, also see Bittman 2001) and raster layers from the CalJep database (Viers et al. 2006) into a new map. We then converted each vector layer to produce new 1 km $\times$ 1 km (1 km^2) raster distribution layers for each rare plant taxon. We reclassified each raster layer with spatial analyst (ESRI 2005) to create new layers with a binary code (1 or 0) indicating presence or absence of the taxa within each 1 km^2 grid cell. Finally, we isolated each plant's distribution in Napa County from its distribution in the rest of the state by applying a Napa County mask layer to each plant distribution layer.

Once completed, we joined the distribution layers of 144 ranked plants (G-, S-, and L-ranks 1, 2 or, 3) in Napa County. The resulting layer showed the distribution of cells in Napa that were occupied by at least one rare taxa of any geographic assessment level; these cells were classified as plant rarity cells. To generate new layers highlighting rare plant richness hotspots, we used the Raster Calculator in spatial analyst (ESRI 2005) to sum the presence/absence data from the individual plant distribution layers. We summed distribution layers for globally and locally rare taxa individually. In the two resulting rarity richness layers, cells were ranked according to the number of rare taxa/cell. For purposes of reporting results, we defined rarity richness cells as any cell with two or more rare taxa. Following protocols established in two previous hotspot analyses (Prendergast et al. 1993; Williams et al. 1996), we classified the top 5% of cells ranked by species richness (in this case cells with 5 or more globally rare taxa or 20 or more locally rare taxa) as rarity hotspots.

To determine if globally and locally rare plants are protected concurrently, we compared the distribution of global rarity richness with the distribution of local rarity richness to determine the extent of their correspondence. To accomplish this, we generated two new raster layers by reclassifying the richness distribution layers. As before, rarity richness cells in each layer were binary coded (1, 0) to indicate presence or absence, layers were added using the Raster Calculator (ESRI 2005), and a new layer showing the intersection of global *and* local rarity richness cells was created. Cells or clusters of cells with values of two in the new layer were thus classified as multi-scale hotspots of plant rarity richness, defined here as any cell occupied by two or more locally rare plant taxa in addition to two or more globally rare plant taxa.

Finally, we compared the results from our hotspot distribution maps to the distribution of protected lands in Napa County. Data on the distribution of protected lands was available from Napa County Land Trust (NCLT) with permission (NCLT 2006). We overlaid each hotspot layer with the protected lands layer to identify significant rare plant conservation gaps.

Results

Napa County emerged as a region rich in plant rarity, as over 58.0% of the county was occupied by at least one rare plant based on occupancy of 1 km^2 grid cells. Collectively, rare plants occupied 1,191 grid cells out of 2,052 (Fig. 1a). Globally rare plants occupied 37.7% of the county, or 775 cells, and locally rare plants as defined by the L-rank criteria occupied 31.3% of the county, or 644 cells (Fig. 1b, c).

In terms of global rarity, 321 cells, or 15.6% of Napa County, were occupied by two or more globally rare plants and were therefore classified as global rarity richness cells. Of these cells, 50 of them, or 2.4% of the county, were occupied by five or more rare plants, and classified as global rarity hotspots. These cells were distributed in 11 discrete locations that varied in overall size. The very richest cell was occupied by nine globally rare plant taxa and was located in northwest Napa County in the Mount St Helena area (Table 1; Fig. 1b).

In terms of local rarity, 331 grid cells, or 16.1% of Napa County, were occupied by two or more locally rare plants, and were therefore classified as local rarity richness cells. Of these cells, 84 of them, or 4.1% of the county, were occupied by at least 20 ranked plants, and were classified as local rarity richness hotspots. These cells were distributed in 14 different areas that also varied substantially in size. The very richest cell in the county was occupied by 26 locally rare plant taxa and was also located in northwest Napa County in the Mount St. Helena area, corresponding with the peak richness locality for globally rare plants (Table 2; Fig. 1c).

When the distribution of global rarity richness cells (1 km^2 cells) was overlaid with the distribution of local rarity richness cells, 568 grid cells (27.7% of Napa's total) met the definition of rarity richness cells for at least one geographic assessment level (global/sub-national or local). Of these grid cells, 84 (4.1% of Napa's total) met the

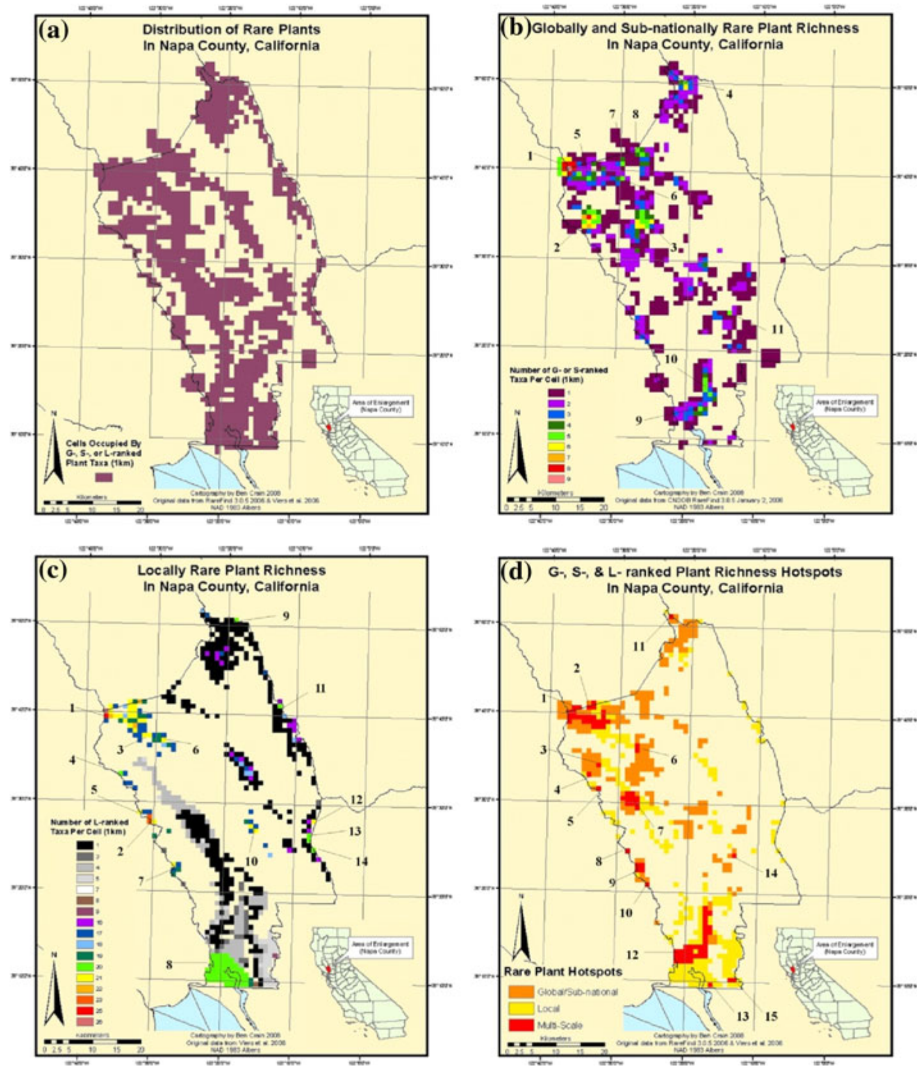

Fig. 1 **a** The distribution of rare plants in Napa County. **b** The distribution of G- and S-ranked plant richness in Napa County. Numbered locations indicate hotspots of global rarity (see Table 1). **c** The distribution of L-ranked plant richness in Napa County. Numbered locations indicate hotspots of local rarity (see Table 2). **d** Global and local rarity richness cells and multi-scale hotspots in Napa County. Numbered locations indicate multi-scale hotspots (see Table 3). All maps are based on occupancy of 1 km^2 grid cells and presented in NAD 1983 Albers projection

criteria for both global *and* local rarity richness cells, and thus, were highlighted as multi-scale hotspots of rare plant richness. Approximately 26.0% of all global rarity richness cells corresponded with local rarity richness cells while 25.0% of all local rarity richness cells corresponded with global rarity richness cells (Fig. 1d). In total, 15 localities in Napa County were classified as multi-scale hotspots (Table 3; Fig. 1d). Locations among the richest hotpots of global *and* local rarity (Tables 1, 2) only corresponded in the Mount St. Helena area.

Table 1 The 11 global rarity hotspots in Napa County, CA

Number	Hotspot location	Area (km^2)
1	Mount St. Helena/Table Mountain area	15
2	Southeast Calistoga area	13
3	Angwin area near Howell Mountain	9
4	Knoxville area near the Yolo County Border	2
5	Area near Table Rock	1
6	Area southwest of Aetna Springs	1
7	Area near James Creek northeast of Aetna Springs	1
8	Area along Butts Canyon	2
9	Area near Cutting Wharf near the Napa River	1
10	Area along the Napa River near Rocktram	4
11	Area near Foss Valley east of Atlas Peak Road	1

Numbers in column one correspond with numbered locations in Fig. 1b

Table 2 The 14 local rarity hotspots in Napa County, CA

Number	Hotspot location	Area (km^2)
1	Mount St. Helena/Sugarloaf Mountain/Table Mountain area	21
2	Sugarloaf Ridge State Park near Bald Mountain and Heath Canyon	3
3	Rattlesnake Ridge area	2
4	South of Calistoga in the Diamond Mountain area	1
5	Area south of Sulfur Canyon	1
6	Three Peaks Area	1
7	Mount Veeder Area	1
8	Southern end of the Napa River and the adjacent sloughs and islands	46
9	Northern Long Canyon area near the Yolo/Napa border	1
10	Atlas Peak area	2
11	Along the Blue Ridge near Green Canyon	1
12	North of Bull Canyon near the Napa/Solano border	1
13	Area near the Blue Ridge Road near the Napa/Solano border	2
14	Vaca Mountains near Mix Canyon Road	1

Numbers in column one correspond with numbered locations in Fig. 1c

Lastly, spatial analyses indicated that although approximately 483 km^2 of land (23% of Napa County) is protected under some level of conservation status (Fig. 2a; NCLT 2006), in some cases, the richest hotspots did not correspond with these protected lands and conservation gaps existed (Fig. 2b). Overall, 63.0% of global rarity richness cells did not correspond with protected land in Napa County. Concerning only the hotspot cells, 78.0% did not correspond with protected land. In general, global rarity richness corresponded best with protected lands in extreme northern Napa County. The global rarity hotspot in the Knoxville area and several other smaller yet significant areas corresponded well with protected lands in this portion of the county. Other significant locations that corresponded

Table 3 The 15 multi-scale hotspots in Napa County, CA

Number	Hotspot location	Area (km^2)
1	Mount St. Helena/Sugarloaf Mountain area	22
2	Three Peaks area	3
3	East Calistoga in the north end of Napa Valley	1
4	South of Calistoga in the Diamond Mountain area	1
5	North of Spring Mountain Road near the Napa/Solano border	1
6	Area north of Angwin	2
7	St. Helena area	10
8	Area near Dry Creek Road on the Napa/Sonoma border	1
9	Mt. Veeder Area	4
10	Area near Devil's Canyon near the Napa/Sonoma border	1
11	Area on the Napa/Yolo border north of Berryessa Road	1
12	Southern end of the Napa River & adjacent sloughs and islands	33
13	Area along American Canyon Creek near the Napa/Solano border	1
14	Milliken Canyon area	1
15	American Canyon area	2

Numbers in column one correspond with numbered locations in Fig. 1d

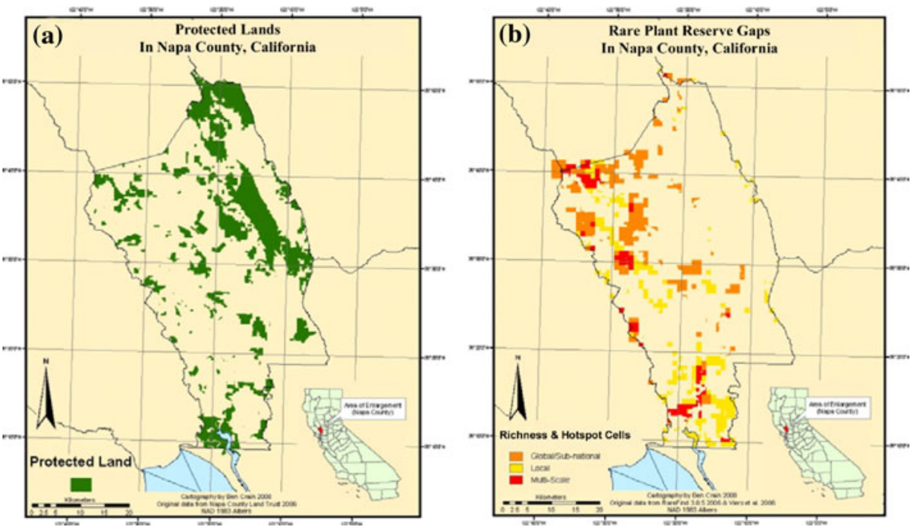

Fig. 2 **a** The distribution of protected lands in Napa County, CA. **b** Rare plant reserve gaps in Napa County. Both maps presented in NAD 1983 Albers projection

to some degree were near the Napa River, the Atlas Peak area, and the Aetna Springs area. On the other hand, the Mount St. Helena and Table Rock area hotspots corresponded with protected lands only to a very limited extent, and some of the richest cells in this area did not correspond with conservation reserves at all. Furthermore, two of the richest hotspots of global rarity, the areas south of Calistoga and near Angwin, corresponded with protected areas in almost none of their ranges (Figs. 1b; 2a, b).

Local rarity richness corresponded best with protected lands in the southern portion of the county, but again, significant conservation gaps were apparent (Figs. 1c; 2a, b). In total, 50.3% of local rarity richness cells did not correspond with protected land. For example, the majority of local rarity hotspots in the central portion of the county rarely corresponded with protected areas. More surprisingly however, is the finding that 71.4% of the hotspot cells corresponded with reserves. In general, the majority of the south Napa River and adjacent sloughs and islands hotspot corresponded well with protected lands. Additionally, hotspots corresponded relatively well along the eastern border of the county; the Blue Ridge and the Bull Canyon hotspots both corresponded with protected lands to some degree. Conversely, many other hotspots of local rarity, including large portions of the richest ones, did not correspond with protected lands (Figs. 1c; 2a, b).

Finally, 59.6% of multi-scale hotspot cells did not correspond with protected land. Multi-scale hotspots in the southern part of the county corresponded with protected lands relatively well. Some portions of the Mount St. Helena/Sugarloaf Mountain multi-scale hotspot corresponded with protected land, but the richest portions did not. Likewise, the majority of multi-scale hotspots in the western portion of the county did not correspond with protected lands (Figs. 1d; 2a, b).

Discussion

Based on our analysis, globally rare taxa were distributed in approximately 38% of Napa County but global rarity richness cells were distributed in only 15.6% of the county. This is an indication that individual globally rare plant taxa frequently have distributions that are isolated from heterospecifics. As a result, conservation efforts focusing strictly on hotspots may not encompass a majority of rare plant distributions. Nevertheless, the richest global rarity hotspot cells in Napa can be protected in an area covering only 2.4% of the county. Therefore, protecting global rarity hotspots appears to be an effective strategy for preserving several globally rare plants in Napa County, particularly if other conservation strategies are employed as well.

Locally rare plants were distributed in approximately 31.0% of Napa County but local rarity richness cells were distributed in only 16.1% of the county. This suggests that like globally rare plants, the distributions of locally rare plant taxa are often isolated from each other, and again, conservation efforts focusing strictly on hotspots may not encompass a significant portion of locally rare plant distributions. Nevertheless, the richest local rarity hotspot cells in Napa can be protected in an area covering only 4.1% of the county, another realistic conservation goal. In sum, our results indicate that identification and prioritization of local rarity hotspots in Napa can focus conservation efforts and protect many significant plant populations.

Lastly, although a large proportion of Napa County is occupied by rarity richness cells, the total distribution of multi-scale hotspots is relatively limited, and equates to only 4.1% of Napa County. Our results are in agreement with those of Mills and Schwartz (2005) that show the distributions of globally rare and endemic species often differ from suffusively rare species (those which are locally rare but with wide geographic ranges). Thus, conservation programs whose primary goal is to protect multiple scales of plant rarity should emphasize these multi-scale hotspots. Current research suggests that hotspot reserves should be designed to protect species richness and to include adaptive variability (Smith et al. 2001). Conservation of global, local, and multi-scale hotspots can aid significantly in this endeavor by incorporating a larger variety of biological attributes than contained in global rarity hotspots alone. Conveniently, approximately 26.0% of global hotspots are also multi-scale hotspots, suggesting that protected global rarity hotspots could act as surrogates for locally rare plants and their unique ecological attributes. Therefore, protection of multi-scale hotspots should be considered an important conservation goal.

In sum, the establishment of a variety of protected areas is likely the best solution for conserving rare plants in Napa County. This accomplishment will help protect globally rare plants from extinction while also preventing extirpation of locally rare plants. In the past, protected lands in Napa County have been designated and managed for reasons other than conservation of local rarity. For instance, the Knoxville recreation area corresponds with important rare plant habitats (e.g. serpentine soils), yet the main activities in the area are off road all terrain vehicle driving and hunting (see BLM 2011). In the Napa/Sonoma Marsh, a number of important plants and habitats are distributed; however, most research and management plans focus on bird conservation (see CDFG 2011). Even the protected land encompassing much of the Mt. St. Helena hotspot (i.e. Robert Lewis Stevenson State Park) is more renowned as a California Historical Landmark then as a plant reserve as it functions to protect the site of the famous author's honeymoon cabin (see CSP 2011). Other organizations have worked hard to protect the unique flora of Napa County; the recent creation of the Dunn-Wildlake Ranch preserve is an excellent example of these efforts (NCLT 2011). Nevertheless, conservation of local rarity is rarely a driving force behind most conservation efforts, and hence we argue it should be. As is often the case in conservation planning, globally and locally rare plants will require of a variety of different strategies suited to individual taxa and unique locations for effective protection (Schemske et al. 1994; Wu and Smeins 2000; Draper et al. 2003). Numerous studies have shown that the variable and incongruent distributions of diversity and richness hotspots among biological groups often lead to conflicting conservation priorities (Prendergast et al. 1993; Curnutt et al. 1994). Therefore, hotspots should be prioritized in a manor that best represents richness and diversity of global, sub-national, and local rarity wherever possible.

Finally, we provide some speculation about both the high levels rarity richness found in Napa county, and the partial overlap between the distributions of globally and locally rare plants. To begin, Napa County has very rich set of soil substrates that are heterogeneously distributed in the region (Lambert and Kashiwagi 1978). This contributes to overall plant richness, and thus rarity richness, as the two are substantially correlated (Mills and Schwartz 2005). Of special significance are the serpentine soil endemics that although uncommon globally, are somewhat common in the region. Indeed, over 15% of all endangered plants in California are associated with serpentine substrates and 12.5% are restricted to them (Safford et al. 2005).

In terms of local rarity, we see a different picture. Napa County is geophysically at an important junction of a number of major bioregions in the state (Hickman 1993). Here, the Sacramento Valley, the Coast Ranges, and the San Francisco Bay are either within the County or in very close proximity, and each acts as a significant barrier to north–south or east–west plant migrations. Furthermore, the San Joaquin delta system acts as a partial barrier to some north–south plant migrations creating partial isolation. The degree of isolation is however, very conditioned by climate and no doubt that over the eons, plant distributions have shifted greatly. Thus, we can reason that many locally rare plants are present due to these fluctuating biogeographical conditions. When combined with the high degree of heterogeneity of substrates, these conditions lead to higher rates of local rarity compared to global rarity. Continued work that focuses on species specific habitat requirements, as well as analyses of phylogenetic relations among rare plants will illuminate the details about the differences, and ultimately to the biological underpinnings of rare plants and their distributions, including hotspots (White 1999, 2004; Mills and Schwartz 2005).

To conclude, this research is intended to facilitate more focused analyses of individual hotspots in Napa County, as well as to promote similar research on globally and locally rare plants in different areas of the California Floristic Province and in other global diversity hotspots. Improved understanding of the distribution of biodiversity is one of the most significant objectives for ecologists and biogeographers alike (Gaston 2000). Both the distribution of organisms and the biological basis for their interactions and range dynamics are crucial for understanding and managing the Earth's biodiversity.

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