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Biotic homogenization of the California flora in urban and urbanizing regions

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ABSTRACT

Biotic homogenization, driven by native species losses and invasive species gains was investigated for the flora of California. Data from a variety of available databases were aggregated at the county level to examine patterns in county population density and growth in relation to floristic change. Based on population, California was divided into three zones: high ($n = 9$; 257–1320 people/km^2), medium ($n = 25$; 28–177 people/km^2), and low ($n = 24$; 1–24 people/km^2) density counties. Examining patterns of rare plant occurrences among these counties revealed that high and medium density counties contained, on average, as many or more rare and endemic species than low density counties. The largest pool of these species, 48 percent of the 962 highly threatened taxa in California, is restricted to high and medium density counties. Thus, urban and urbanizing counties play a strategic role in maintaining a part of California's flora that is both globally significant and threatened with extinction. Examining species losses and noxious weed additions across high density counties, reveals a consistent pattern of low similarity among species that have been extirpated from high density counties and a high similarity among noxious weeds that these counties now share. The consequence is that California's urban county floras appear to be homogenizing. Examining homogenization using the entire flora for urban counties demonstrates that less similar counties become more similar. The effect of loss of rare species could outweigh the gain in exotics, under an assumption of strong extinction. Finally, a strong negative relationship between population density and the proportion of county land in public ownership suggests that high and medium density counties are in a poor position to protect rare plant populations on a localized basis.

1. Introduction

Biotic homogenization has emerged in the conservation literature as a concept that jointly describes how biodiversity loss and biological invasion combine to increase biotic similarity among communities through time and across space (McKinney and Lockwood, 1999; Simberloff, 2001; Olden and Poff, 2003). Biotic homogenization measures can be applied at different organizational, spatial or temporal scales. Here we examine biotic homogenization of the California flora, with particular attention to the flora distributed in urban and urbanizing areas. We use electronic databases that tabulate human population trends, public lands for conservation, and attributes of biological diversity at the county level. Owing to the large flora of California (8375 taxa recognized by Calflora (CalFlora, 2004)), it is difficult to get a statewide overview of biotic homogenization at a finer spatial scale.

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With the continued growth of urban environments it is increasingly apparent that successfully conserving threatened biological diversity requires significant efforts within urban and urbanizing areas (Dobson et al., 1997; Schwartz et al., 2002; Seabloom et al., 2002). Toward that end, Schwartz et al. (2002) detailed the high concentrations of federally listed endangered and threatened plants within the United States showing that roughly a quarter of all county occurrences of such species are found within the 40 metropolitan areas where 50% of Americans live. This report also detailed the plight of rare plants within northern California, where over three-fourths of all rare plant species tracked by the California Native Plant Society within urban areas are found somewhere on public land, but very few receive any monitoring or stewardship. As a consequence, plant conservation biologists find that it is nearly impossible to assess whether protected but isolated populations within urban environments are persisting or not, despite over 30 years of active protection through the Endangered Species Act, state programs and non-profit conservation activities (e.g., The Nature Conservancy).

Although poorly documented, it is reasonable to conjecture that human disturbance of natural habitats increases with population density and that invasion of exotic species similarly increases with proximity to high human population density. Marchetti et al. (2004) and Williams et al. (2005) document the role of anthropogenic disturbance, as measured by statewide developed lands (i.e., urban and agricultural landscapes) in promoting invasion of California by exotic fishes and vascular plants, respectively. It also seems probable that these invasive weeds represent a relatively homogeneous suite of species (Kuhn et al., 2004). We examine this latter assertion below.

The focus of this paper is to build upon the work of Schwartz et al. (2002) and assess four issues related to biotic homogenization of plants within California. The human population of California, currently 36 million people (CDOF, 2004), is expected to increase to over 50 million before 2050 (US Census Bureau, 1996). Continued urbanization of habitats, and the effects of urbanization on biota remains a critical conservation issue. First, we assess the demography of California to identify counties that have high population densities and/or rapid growth rates to determine if there is a spatial pattern of threat to habitat loss. Second, given that urban areas are rapidly expanding, we examine the vascular plant diversity of California to assess changes that have accompanied this increase in human domination of California ecosystems. We assess change through introductions of non-native plants, here characterized through county occurrences of noxious weeds. We use noxious weeds as an index of invasive species as these variables are highly correlated (Rejmanek and Randall, 2004). We also assess change by delineating the county-level distributions of threatened species. To the extent possible, we characterize rare species extirpations. Third, we assess whether there is evidence that particular taxonomic lineages are more dependent upon urban environments than others. Loss of entire phylogenetic lineages would increase the loss of genetic branch length of regional biodiversity and would be a metric of biotic homogenization. Fourth, the combination of this information provides an assessment of the urban and urbanizing portions of the California landscape as it relates to biotic homogenization and conservation of regional plant diversity.

California is generally characterized by large counties that span numerous ecosystems and biomes. This county scale analysis is not meant to imply that specific habitats or species are at risk within counties simply because density or growth is high. Many of these counties with high growth and high overall density also include a significant portion of remote lands (e.g., Riverside County). Nevertheless, counties are a significant unit for conservation planning of rare plants within the US. We place this analysis into a conservation context by examining the distribution of private versus public lands in California at the county level to identify where the challenges are for capturing natural diversity within the public domain. With the rapid increase of county land trusts, and the fact that most zoning and land use decisions are relegated to county governments, the county is a logical management unit at which to address threats to biotic diversity through homogenization.

2. Methods

2.1. *Defining urban, urbanizing and rural regions of California*

The California Department of Finance, Demographic Research Unit provides yearly population estimates for each of California's 58 counties based on 10 year US Census Bureau population figures (CDOF, 2004). These data were used to arbitrarily classify counties into three categories based on population density: high density counties (>200 people/km^2, $n = 9$); medium density counties (25–200 people/km^2, $n = 25$), and low density counties <25 people/km^2, $n = 24$). Counties were similarly assessed with respect to their history of human population growth (Fig. 1a). Note that 10 counties had a more than 200% increase since 1970; 25 others more than doubled (100% increase); and that counties with the highest population densities experienced relatively low population growth during this period (Fig. 1b).

In this study, we use human population density to assess the role of anthropogenic disturbance on the homogenization of California's flora. It is worth noting, however, that while human population density is a direct and tangible source of disturbance, other mechanisms of disturbance related to human use are pervasive in their extent and devastating in their impact on natural environments. For California, these mechanisms include agriculture (Seabloom et al., 2002) and agriculturally related development (Heaton and Merenlender, 2000), road building (Gelbard and Harrison, 2003), and dams and aqueducts (Marchetti et al., 2004), among many. We do not attempt to partition out the causal relationships between human activities and invasion processes; rather, we assert that densely populated places are inherently impacted and we seek to understand the incipient degree of biotic homogenization of this particular type of impact. This is apart from, and complementary to, other studies necessary to understand the front of invasion and the role of human disturbance in its promotion, particularly in newly urbanizing areas of the state.

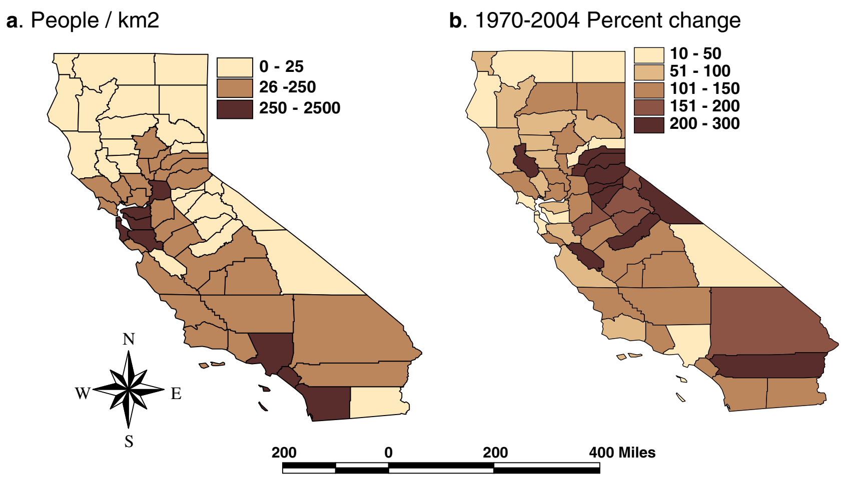

Fig. 1 – County maps of California depicting (a) human population density; and (b) increase in human population from 1970 to 2004. Data are from California Department of Finance (CDOF, 2004).

2.2. *Invasive weeds*

We present an estimate of the homogenization of California's urban flora owing to invasive species. For this assessment we used CalFlora's summary of the distribution of noxious weeds within counties (CalFlora, 2004) as tabulated by Viers et al. (2005). A total of 148 noxious weeds are designated by the California Invasive Plant Council (Cal IPC) and are reported by county through CalFlora. We used the total number of noxious weeds per county as an indicator of invasive species homogenization. Noxious weeds provide a good indicator of homogenization because these are species that are generally widespread and become dominant within natural ecosystems (Rejmanek and Randall, 2004). The composition of non-native species (1437 taxa statewide) within counties is highly correlated with the number of noxious weeds ($r^2 = 0.941$, $n = 58$, $p < 0.0001$) and includes large numbers of species that are naturalized, but do not pose threats to natural communities. Thus, both indicators appear adequate to reflect homogenization through species additions.

2.3. *Threatened taxa*

The list of threatened plant taxa used in this work come from the California Native Plant Society's list of threatened and endangered plant taxa (CNPS, 2001). This is an active web-based database (www.cnps.org) that tracks occurrences for over 2000 taxa. We focus on the 1056 taxa on List 1, those that are either presumed extinct (28 taxa) or rare throughout their distribution (1027 taxa) (CNPS, 2001). Most of these species are endemic to California. This list contains species, sub-species and varieties.

2.4. *Whole flora*

Species lists of the entire county level floras are available through CalFlora, as initially distributed by Richerson and Lum (1980) and later compiled into the CalJep GIS (Viers et al., 2005). We tabulated species lists for the southern (Los Angeles, Orange, San Diego) and northern (Contra Costa, Alameda, San Francisco / San Mateo, Santa Clara) urban areas. As per initial distributional information in Richerson and Lum (1980), we have maintained San Francisco and San Mateo counties as a single analysis unit and removed the Channel Islands from Los Angeles County. The effects of this organization should be negligible in regards to the northern counties, as they are in effect the same peninsula; the southern counties organization should remove potential bias introduced from the Channel Islands flora, which contains several endemic taxa unlikely to be shared by counties adjoining Los Angeles.

2.5. *Homogenization*

Homogenization can be characterized by species losses as well as species additions (Olden and Poff, 2003). In this treatment of California urban environments we use Sorensen's similarity indices to characterize homogenization effects of species loss and species addition separately (Olden and Poff, 2003). Sorensen's similarity index is simply a metric that varies from 0 to 1 and scales to the proportion of species held in common between two samples:

$$S_{ij} = 2a/(2a + b + c) \quad (1)$$

where a is the taxa found in both sites i and j, b is the number of taxa unique to site i, and c is the number of taxa unique to site j (Krebs, 1999). Initially, we calculate Sorensen's indices among the nine high density counties in California for three groups of taxa: (1) noxious weed additions; (2) known extirpations of rare taxa; and (3) List 1B threatened taxa. The null hypothesis is that if the similarity of noxious weeds gained by urban counties is comparable to that of rare taxa that may be lost as a consequence of human habitat degradation, then we species additions and deletions would result in no net homogenization.

Alternatively, if similarity in the noxious weed pool among counties is higher than that among lost or threatened taxa, then habitat degradation through species loss and noxious weed invasion could contribute to homogenization. We further assess this issue using the whole flora. Homogenization within region was calculated as pairwise Sorensen's similarity among counties using three data subsets. The first mimics presettlement conditions by excluding all non-native taxa. The second simulates modern conditions by including all taxa. The third simulates potential future floras by including non-native taxa, but excluding those taxa that are considered highly threatened statewide presuming county extirpation of these species.

By necessity, each assessment is a caricature of homogenization. Our assessment assumes loss of all rare native species. In our assessment using the entire flora we ignore the potential for homogenization via taxa already lost to those counties, whether or not they now appear in the floral list for each county. Thus, this assessment should not be taken as a measure of absolute homogenization but as an approximation of the relative importance of rare versus non-native taxa in the homogenization process. Finally, this assessment only considers homogenization at the scale of floristic lists at the county level. This assessment does not examine homogenization among habitat types, nor does it assess the degree to which habitats may become homogenized through shifts in abundance and dominance of individual species.

2.6. Land ownership

Finally, we assess the challenges in protecting biotic diversity within urbanizing regions by examining the distribution of public lands in California. For this assessment, we use the California Spatial Information Library (CaSIL) coverage of public lands, which identifies Federal Lands by ownership agency as well as state and county parklands (CaSIL, 2003). For this treatment, we included all federal acreage as potential conservation lands. These include, in rank order of statewide acreage: National Parks, Monuments and Seashores, National Forests, Bureau of Land Management, Military, Bureau of Indian Affairs (BIA), Bureau of Reclamation (BoR), and Fish and Wildlife. We included Military, BIA, and BoR lands because they are subject to Endangered Species Act provisions, as public lands, often contribute substantially to plant conservation and comprise 8.5% of the total federal land in California (CaSIL, 2003). In this assessment, public lands comprise 44% of California with federal lands comprising over 95% of this public acreage.

3. Results

3.1. Urbanization

California, as a whole, has increased in population from an estimated 19 to 36 million people from 1970 to 2004. We classified all counties characterized by human densities of over 250 people/km^2 ($n = 9$, ave = 690.7, range = 257.4–1317.8) as high density counties (Fig. 1a). Highly urbanized counties, in general, showed relatively low population growth rates (Fig. 1b). Medium density counties were defined as those containing 25–200 people/km^2 ($n = 25$, ave = 74.9, range = 27.6–177.4; Fig. 1). Medium density counties, as a category, had the highest average growth between 1970 and 2004 (134%). Among the medium density counties, only Napa, Marin, Monterey, Santa Barbara and Yuba managed growth to less than doubling (100% increase) during this 34 year period (Fig. 1b). The remaining 80% of medium density counties averaged growth rates of 154% ($n = 20$, range = 104.9–288.8%; sd = 66.4)

Finally, the remaining counties contain fewer than 25 people/km^2 ($n = 24$, ave = 8.9 people/km^2, range = 0.7–24.3) and were considered low density counties. These low density counties varied considerably with respect to rate of growth ($n = 24$, ave = 120.6%, range = 18.8–225.9%; Fig. 1). For the remaining treatment, we categorize counties based solely on population density and consider all medium density counties as urbanizing.

3.2. County level patterns in plant diversity

Plant diversity data highlight three interesting, but not unexpected patterns. First, there is a slight positive correlation between overall levels of plant diversity (species per km^2, as described by CalFlora) and human population density ($n = 58$, slope = 0.043, $r^2 = 0.074$, $p = 0.04$). Comparing the residuals of plant diversity on a species-area curve to human population density shows no pattern ($r^2 \ll 0.001$). Although these patterns are certainly not strong, the significant regression explains just 7% of the variance, we often assume that regions of high diversity are in remote areas and far from centers of human density (but see Brooks et al., 2002). Together these results suggest that overall plant diversity is neither strongly positively nor negatively distributed with respect to human density. This lack of a trend in overall plant diversity with human population is reflected in the number of List 1 rare plant taxa per county, which also shows no strong relationship ($n = 58$, $r^2 = 0.06$, $p = 0.07$). This lack of a pattern, however, serves to demonstrate that urban and urbanizing counties carry a sizeable burden in terms of providing habitat for California's most threatened taxa. In contrast to common perceptions, and perhaps reality with respect to vertebrate diversity, unique and at risk biological resources are not concentrated in remote areas.

Despite this concentration of species in urban areas, there are relatively few documented county extirpations (250) relative to the number of List 1 county occurrences (5446). Nevertheless, there are considerably more known extirpations of rare species in counties with higher human density ($n = 58$, $r^2 = 0.44$, $p < 0.0001$; Fig. 2). It is quite likely that extirpations are not independent of human density and that habitat loss and degradation are linked to these extirpations. Using our classification of California counties into high, medium and low population density, we categorized rare plant species by their occurrence in counties of differing density. We tabulated species as single county endemics, multiple county California endemics, or distributed within California and either adjoining states, or offshore islands. Offshore islands, although jurisdictionally part of California, are largely publicly owned and not inhabited. These islands are also often within the jurisdiction of urban counties (e.g., Los Angeles). Thus, they were categorized separately so as to not overstate the level of threat induced by human population. Separating counties by population density shows that 16.7% of single county

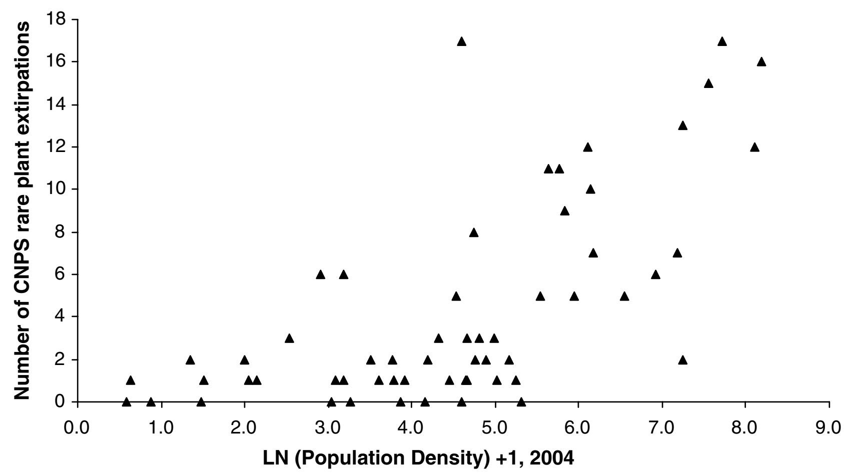

Fig. 2 – A scatterplot of the 58 California counties showing the relationship between the log of human population density (ln(people/km²)+1) for 2004 versus the number of California Native Plant Society county extirpations from their List 1 of the 1056 most threatened plant taxa (CNPS, 2001). The relationship is highly significant ($n = 58$, $r^2 = 0.437$; $p < 0.001$) showing that where there are more people, there have been more documented extirpations.

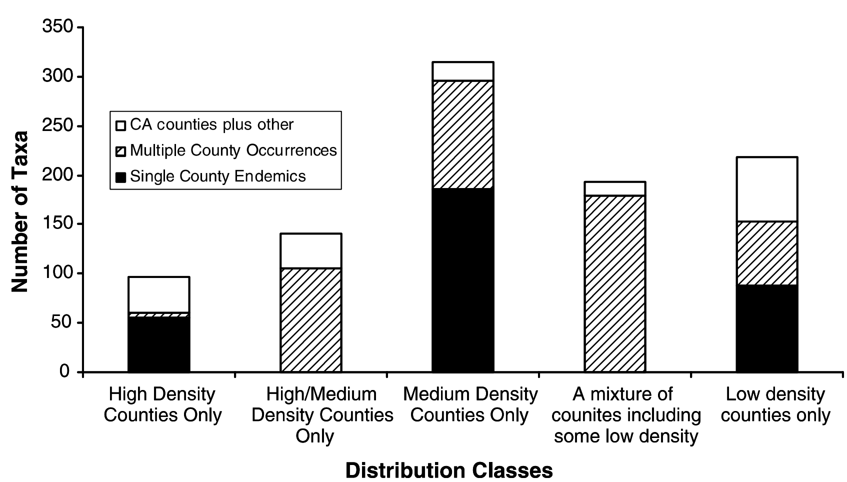

Fig. 3 – An assessment of the degree to which California rare plants are restricted to high and moderate population density counties.

endemics are found in the 15.5% of counties with more than 250 people/km² (Fig. 3). Similarly, 56.5% of single county endemics are found in the 43.1% of counties with medium population density, suggesting that single county endemic species are slightly under-distributed among counties with low human density (26.7% of species in 41.4% of counties). High density counties, however, tend to be small in area. Thus, endemic plants per unit area results in a concentration of endemics in urban counties.

Examining species of concern reaffirms the notion that existing urban areas and the urbanizing environment in California are both critical to conserving plant diversity. Among the 962 List 1 species, 48% are restricted to the 34 counties with high and medium population density. Another 9% of List 1 species are not endemic to mainland California, but are found nowhere else in mainland California than in high or medium density counties. By contrast, fewer than 16% of List 1 species are restricted to low density counties, with another 6.7% of species having their sole California representation within low density counties.

The third general observation relative to biotic homogenization in the California flora is that the density of noxious weeds increases with human density ($n = 58$, $r^2 = 0.50$, $p < 0.0001$; Fig. 4). This pattern is likely to be generated by a combination of forces, including human habitat degradation along with the propensity of humans to settle and disturb habitats in the most equitable climatic regions of California.

3.3. *Biotic homogenization of the California flora*

Similarity measures of species among counties that have been lost, or gained, provide an index of homogenization. Sorensen's similarity indices for rare species among the nine high density counties in California show that rare species are very dissimilar among counties (Sorensen's Index: 0.00–0.34; ave = 0.10, Table 1). In contrast, noxious weeds are highly

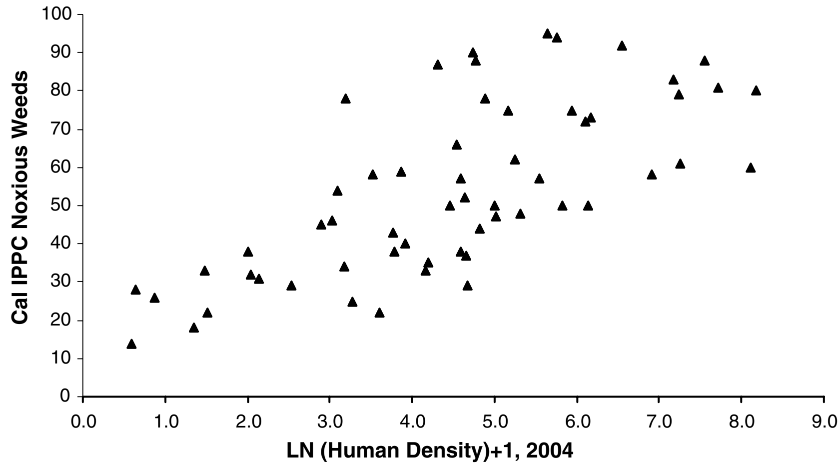

Fig. 4 – A scatterplot of the 58 California counties showing the relationship between the log of human population density (ln (people/km^2)+1) for 2004 versus the number of noxious weeds, as defined by the California Native Invasive Plant Council, and tracked in Calflora (CalFlora, 2004). The relationship is highly significant ($n = 58$, $r^2 = 0.500$, $p < 0.001$), showing that where there are more people there are more species of noxious weeds.

shared among counties (Sorensen's Index: 0.57–0.85; ave = 0.69, Table 1). A pairwise *t*-test of similarity index values is highly significant ($p \ll 0.001$). The highest similarity among rare plants, neighboring counties Santa Clara and Alameda counties, is lower than the single lowest observed similarity among noxious weeds. The pairwise similarity indices observed for extirpated species is roughly half that of rare species, with over 60% of pairwise comparisons returning a similarity of zero, and the maximum similarity of any two counties being 0.27.

Historic, current and potential future floristic similarity using entire floras shows that for both northern and southern California the addition of non-native species increases overall homogeneity within regions only slightly (Fig. 5). Pairwise similarity among exotic species, although high, is not distinctly higher than for native taxa within urban regions. A homogenization effect of non-native taxa is more obvious when comparing southern California urban counties to those from northern California. Here we find a greater increase in floristic similarity. In total, there is a correlation between floristic similarity among counties and the increase in that similarity with the addition of non-native species; the lower the initial similarity among counties, the more similar they become (Fig. 5). To put this in perspective, the average urban county considered in this analysis contains 945 native species ($n = 12$, s.d. = 200.3), and 154 exotic species (s.d. = 27.8), with an average pairwise sharing of 95 of those species. By contrast, counties could lose an average of 54.8 taxa, with an average pairwise sharing of 8.9 taxa under our assumption of loss of all highly threatened taxa. Given the relatively low sharing of these taxa among counties, the loss of taxa has the potential to cause five times as much homogenization as the addition of the exotic species thus far gained by each county (Table 2).

3.4. *Public lands*

Resolving the biotic homogenization issue for the California flora requires land for conservation measures. California, although rich in public lands, contains little public land

Table 1 – Sorensen's pairwise similarity indices among noxious weeds (above the diagonal) and CNPS List 1b rare plants (below the diagonal) demonstrating an increase in homogeneity among California high population density (>250 people/km^2) counties

	San Francisco	San Mateo	Contra Costa	Alameda	Santa Clara	Sacramento	Los Angeles	Orange	San Diego
San Francisco		0.75	0.73	0.75	0.71	0.57	0.71	0.62	0.70
San Mateo	*0.29*		0.64	0.69	0.63	0.58	0.65	0.61	0.67
Contra Costa	*0.12*	*0.13*		0.84	0.79	0.71	0.73	0.67	0.73
Alameda	*0.19*	*0.20*	*0.31*		0.82	0.64	0.73	0.65	0.74
Santa Clara	*0.10*	*0.20*	*0.27*	*0.34*		0.62	0.70	0.64	0.71
Sacramento	*0.00*	*0.03*	*0.16*	*0.09*	*0.09*		0.62	0.59	0.63
Los Angeles	*0.02*	*0.00*	*0.00*	*0.02*	*0.00*	*0.00*		0.80	0.85
Orange	*0.00*	*0.00*	*0.00*	*0.02*	*0.00*	*0.03*	*0.31*		0.75
San Diego	*0.00*	*0.00*	*0.01*	*0.01*	*0.00*	*0.00*	*0.23*	*0.26*	

The mean similarity among noxious weeds is 0.693 and 0.133 among list 1b species.

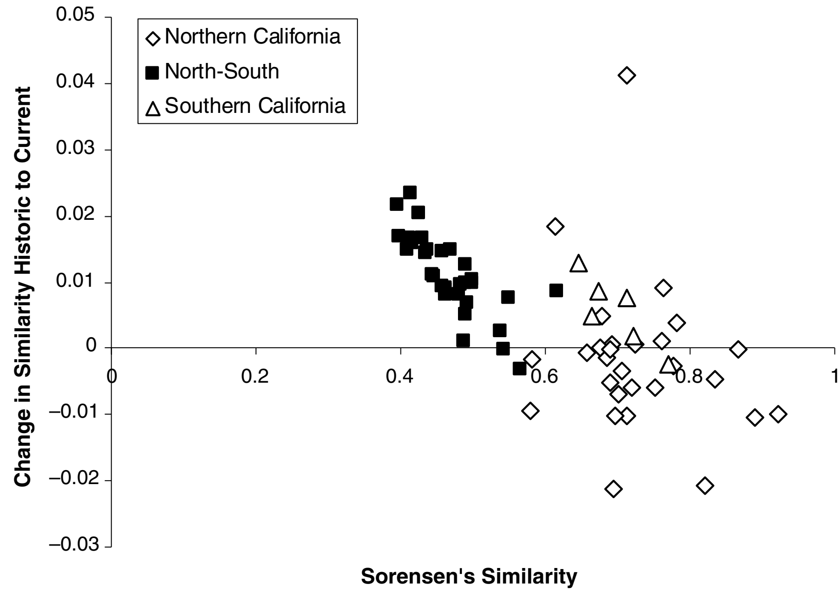

Fig. 5 – Mean pairwise Sorensen's similarity among southern (Los Angeles, Orange, San Diego Ventura) and northern (Alameda, Contra Costa, San Francisco/ San Mateo, Santa Clara) urbanized counties is used to assess homogenization potential of county level floristic composition based on presumed historic (all non-native species excluded) and current (all species included) floras.

for conservation of plant diversity where it is most needed. There is a strong negative correlation between public land acreage and human population density ($n = 58$, $r^2 = 0.51$, $p < 0.0001$; Fig. 6). Thus, urban and urbanizing environments provide habitat for a large number of rare plants but the public lands infrastructure to protect those species is lacking. A more interesting assessment is the distribution of state and county lands with respect to human population. It is well recognized that Federal lands in California are concentrated in remote montane environments with relatively low human density. State and local parklands, however, might be more likely in urban and urbanizing environments. Unfortunately, this is not the case. There is no relationship between population density and state and local public lands ($n = 58$, $r^2 = 0.02$, $p = 0.30$). What is more, the average county contains just under 2% of its lands in the state or local public domain (ave = 1.84, range = 0.001–20.1%).

3.5. *Taxonomic homogenization*

A significant concern with respect to homogenization is the identification of lineages that are vulnerable to loss. If a high fraction of species within some particular lineage is threatened, then species loss within that lineage, on average, would represent a greater loss to net biodiversity of a region than loss of species drawn at random. We examined the taxonomic distribution of List 1B species and compared this to group diversity from CalFlora in order to assess the potential threat to phylogenetic branch length loss as a consequence of urbanization in California. Establishing a criterion to describe vulnerable lineages, here summarized by genera and families, is arbitrary. To illustrate the potential magnitude of the problem, however, we tabulated all genera and family where greater than half of their constituent species are both threatened and restricted to high and medium density counties (Table 3). Despite the fact that most species-poor groups

Table 2 – Comparison of homogenization effects of presumed historic (native taxa only), current (all taxa), and potential future (List 1 rare taxa removed) pairwise Sorensen's similarity measure for counties within the northern and southern California urban regions

	Average Number of Species			Pairwise Sorensen Similarity measure		
	Native	Non-native	rare	Historic	Current	Potential future
Northern California	876.25	154.4	46.0	0.730	0.727	0.750
Southern California	1087	153.5	72.5	0.692	0.698	0.721
Cross-region comparison				0.459	0.471	0.494
Overall				0.595	0.600	0.623

Northern California includes Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano and Sonoma counties, where the floras of San Francisco and San Mateo are combined to form one unit. The southern California urban region includes Los Angeles, Orange, San Diego and Ventura counties.

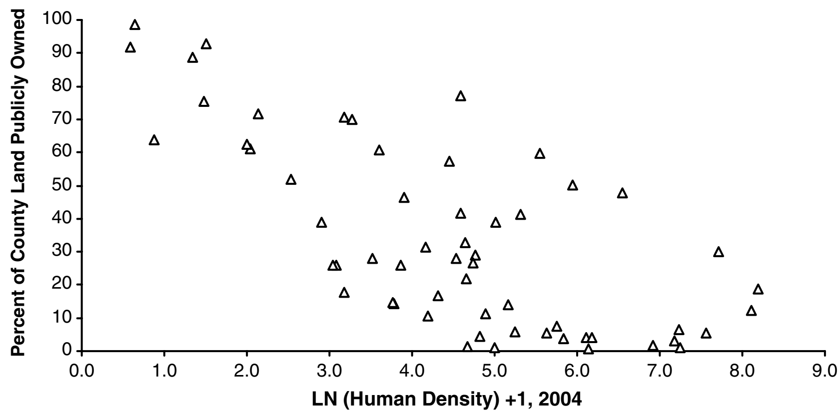

Fig. 6 – A scatterplot of the 58 California counties showing the relationship between the log of human population density (ln (people/km^2)+1) for 2004 versus the percent of county land that is in under public ownership, according to CaSIL (2003). The relationship is highly significant (n = 58, r^2 = 0.509, p < 0.001), showing that where there are more people there is less public land.

(small clades) tend to have few rare species (Schwartz and Simberloff, 2001), certain particularly vulnerable groups emerge. In addition, we include a list of larger genera (>10 species) with the highest fraction of threatened species and estimate what proportion of these constituent species depend on high and medium density counties for habitat (Table 3).

From this result we see that there are several lineages (e.g., *Sphaerocarpaceae*, *Thymelaceae*) that are prone to complete extirpation from the state of California if they were to be lost from the suite of rare species within medium and high population density counties. Similarly, there are moderate sized genera (*Cupressus, Dudleya*) that would be seriously depleted in diversity under high urban extinction rates. The data suggest that these lineages should, by virtue of having a high phylogenetic value to the biodiversity of the California flora and being restricted to areas under high threat, be a high conservation priority.

4. Discussion

This analysis points to several patterns of concern for conservation. First, primarily through extirpations, urban counties within California could experience homogenization of floras at the county level. The list of noxious weeds shared among urbanized counties is quite large; whereas, the list of extirpated species shared across those same counties is very small. Nevertheless, homogenization effects of introduced species may not be very large because of the high similarity among the floras of nearby counties within urban centers. In this sense, our data support the results of McKinney (2004), who noted that invasions can push homogenization in either direction. This analysis, of course, does not include the potential for homogenization through local population extirpations, shifts in dominance or abundance, or increasing similarity across habitat types. The strongest potential effects of homogenization assessed here would be from future extirpations of extant populations within counties. At present, however, little is known about fine scale distributions of rare taxa within counties. A better understanding of the spatial and temporal dynamics displayed by populations of rare taxa would help inform future analyses. Furthermore, a better understanding of the global status of these taxa is necessary to improve our understanding of floristic homogenization.

The second observation is that the homogenization threat may be of more concern when examining the potential loss of biodiversity through the loss of entire lineages. The California Floristic Province is well known to harbor continentally high numbers of species and globally high numbers of endemic taxa. There are several small taxonomic groups where nearly all constituent species are both rare and restricted to high and medium density counties. These species deserve particular conservation concern.

Finally, we observe that the counties that currently have the highest population density also contain relatively little public land. This is a pattern of concern because it leaves the very large list of currently threatened plants particularly dependent on county governments to create habitat conservation opportunities for the protection of this large component of floristic biodiversity. California state policies leave much of the jurisdiction for open space decisions in the hands of county governments and private non-profit groups such as Trust for Public Lands (Press, 2002). In addition, California's tax code strongly promotes growth, making it difficult for counties to choose slow growth alternatives (Press, 2002). Just five counties with population densities greater than 25 people/km^2 managed to grow less than 100% between 1970 and 2004. Schwartz et al. (2002) observed that approximately 75% of rare plant species in the San Francisco Bay Area were found somewhere on public land. Most of this public land derives from acquisitions and set asides that long predate our monitoring of rare species (Press, 2002). Much of the remaining public land is a consequence of systematic conservation efforts (e.g., The Nature Conservancy programs), which includes specific targeting of threatened taxa. Although limited in number, there exist a number of regional conservation assessments that provide land use planners with the necessary information to make floristic conservation decisions that transcend county boundaries. These assessments are augmented by regional councils of governance, which were formed to specifically address trans-boundary issues, such

Table 3 – A list of taxa that are most highly threatened to be lost in their entirety from the California flora under high rates of random extinction owing to the high fraction of species in genera that are threatened by California Native Plant Society on their list of most endangered species (List 1B)

Family (*n*)	Genus (*n*)	% on List 1b
(A) Small genera 50% or greater threatened		
Thymelaeaceae (1)	*Dirca* (1)	100
Sphaerocarpaceae (2)	*Geothallus* (1)	100
Sphaerocarpaceae (2)	*Sphaerocarpos* (1)	100
Sterculiaceae (5)	*Fremontodendron* (4)	50
Bryaceae (5)	*Schizymenium* (1)	100
Pottiaceae (6)	*Pterygoneurum* (1)	100
Lamiaceae (146)	*Lepechinia* (4)	50
Apiaceae (166)	*Oreonana* (3)	67
	Lilaeopsis (2)	50
Liliaceae (311)	*Nolina* (4)	50
Poaceae (334)	*Dichanthelium* (1)	100
Polygonaceae (345)	*Aristocapsa* (1)	100
	Dodecahema (1)	100
Brassicaceae (346)	*Sibaropsis* (1)	100
	Twisselmannia (1)	100
Asteraceae (1056)	*Stebbinsoseris* (2)	50
	Taraxacum (1)	100
	Verbesina (1)	100

Family	Genus	Taxa in genus	Percent of taxa on List 1B	% of list 1 taxa restricted to high and medium density counties
(B) Large genera				
Asteraceae (1056)	*Cirsium* (34)	34	32.4	100
Polygonaceae (345)	*Chorizanthe* (58)	58	27.6	87.5
Cupressaceae (23)	*Cupressus* (15)	15	46.7	85.6
Ericaceae (164)	*Arctostaphylos* (112)	112	42.9	81.3
Onagraceae (226)	*Dudleya* (49)	49	53.1	69.2
Brassicaceae (346)	*Streptanthus* (50)	50	44.0	68.2
Liliaceae (311)	*Calochortus* (58)	58	36.2	66.7
Malvaceae (89)	*Malacothamnus* (23)	23	52.2	66.7

Criteria for inclusion in this table are: (a) genera where 50% or more of the state taxa appear on List 1B and whose distributions are wholly or mostly restricted to high and moderate density counties of California; (b) larger genera where more than 25% of taxa are threatened but where two-thirds or more of their rare taxa are restricted to high and medium density counties.

as conservation planning, transportation and infrastructural development, and revenue sharing. These regional councils include several of California's metropolitan areas (e.g., SANDAG (San Diego Association of Governments), SACOG (Sacramento Area Council of Governments), and ABAG (Association of Bay Area Governments)).

Thus, the best occurrence information we have suggests that large numbers of urban rare plant occurrences remain. Further, most species have at least one occurrence on public lands (Schwartz et al., 2002). It appears plausible that California's most vulnerable plant species can be preserved in natural environments even within the urban context of California. The public lands infrastructure for capturing and protecting rare plant occurrences within the urbanizing portion of California remains weak (Press, 2002), but the potential to minimize homogenization of the California flora remains within grasp.

With declining public resources for large-scale public lands acquisitions, privately funded conservation now significantly shares in the protection of existing biotic diversity (Press, 2002). The challenge with respect to plant diversity is that modern conservation programs have shifted their emphasis from species protection toward ecosystem protection (Noss and Cooperrider, 1994). Thus, plant conservationists must take the lead to inform county level conservation efforts (e.g., Public Land Trusts). Specifically, high priority conservation projects to minimize county level floristic homogenization should exist even within moderate and high density counties.

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