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Provincial and cosmopolitan: floristic composition of a dryland urban river

Juliet C. Stromberg[1] · **Elizabeth Makings**[1] · **Amy Eyden**[1] · **Robert Madera**[1] · **John Samsky III**[1] · **Francis S. Coburn**[1] · **Brenton D. Scott**[1]

Abstract High rates of intercontinental exchange of plant species have caused scientists to ask whether floristic areas with similar environments are undergoing global homogenization. We focused on riparian forests of the urban Salt River (Sonoran Desert, USA) to ask: (1) Is the forest dominated by cosmopolitan or provincial elements? (2) Which trees planted in the irrigated cityscape have established along the river? (3) Which types of restoration interventions have favored provincial species? We surveyed tree abundance, size and vigor in belt transects among five reaches that differed in degree of restoration, and obtained data on tree species composition of the urban landscape and pre-development riparian zone. Our results reveal the urban riparian forest to have many cosmopolitan elements, owing in part to spillover of trees from the cultivated cityscape (e.g., *Acacia stenophylla*, *Vitex agnus-castus)*. Global spread of some regional (Neotropical) riparian taxa (e.g., *Parkinsonia aculeata*, *Prosopis*) also has contributed to the cosmopolitan status. Yet, the forests retain a distinct regional signature. Unintentional restoration of winter floods has allowed for regeneration of *Salix gooddingii,* a vernally-adapted provincial pioneer, although its long-term survivorship is restricted to limited micro-sites (storm drain outfalls). Urbanization-related changes in stream hydrogeomorphology explain increases in some regional species (e.g., *Washingtonia* spp.) that historically were excluded from the river.

Reaches restored by planting, weeding, watering, and geocountouring had the greatest abundance of provincial species and greatest floristic similarity to historic conditions.

Keywords Arid region · Cosmopolitan · Plant community · Ecosystem restoration · Riparian forest · Urban river

✉ Juliet C. Stromberg
jstrom@asu.edu

1 School of Life Sciences, Arizona State University, Tempe, AZ 85287-4501, USA

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Introduction

High rates of intercontinental exchange of plant species have stimulated biogeographers to ask whether climatically-similar floristic areas are becoming globally similar (McKinney 2004; Garcillan et al. 2014). Urban ecosystems provide a useful arena for such studies, given their diverse mix of landscape cultivars, urban specialists, "weedy" plants, and pre-development taxa (Rebele 1994; McKinney 2002; Pickett et al. 2008; Walker et al. 2009). Several studies show urban floras to have some cosmopolitan elements, yet to retain a distinct regional floristic identity (del Tredici 2010; Kendal et al. 2012; Ricotta et al. 2012).

The river corridors that are embedded within cityscapes also provide excellent locations to examine questions related to the changing biogeographical status of floras. The rapid turnover of resources in riparian environments allows for considerable flux in species (Davis et al. 2000). The physical habitat of urban rivers may differ appreciably from their wild counterparts with respect to flood patterns, base flow rates, substrates, and nutrient concentrations (Webb and Leake 2006; Poff et al. 2007; Townsend-Small et al. 2013), and this can select for a new suite of plants (Burton et al. 2009; Pennington et al. 2010; Catford et al. 2014). Plant community composition of riparian areas is influenced by the seed pools of upstream and adjacent lands, and thus potentially by the plants growing in irrigated (and riparianized) patches of the cityscape (Turnbull et al. 2000; Mouw and Alaback 2003; Santos 2010).

The abiotic and biotic conditions of urban rivers typically varies along a longitudinal gradient, owing to differential management by multiple municipalities or jurisdictional agencies. Urban rivers and their vegetation are influenced by unintended consequences (such as discharge of water from urban hydro-infrastructure) as well as by intentional management (such as restoration plantings and plant removal to increase flood water conveyance). Assessments of urban rivers need to accommodate the variety of conditions present.

In this case study, we focus on tree species of the Salt River in the Phoenix metropolitan area (Arizona, USA) to determine the abundance of provincial elements (those restricted to the local region) versus cosmopolitan elements (those that are globally distributed within similar climatic zones), and to determine how river management has influenced this composition. Our expectations were that (1) the urban riparian forest has become cosmopolitan, owing to influx of species planted in the surrounding irrigated and forested cityscape; (2) few provincial species persist, owing to extensive hydrogeomorphic alteration of the river bed beyond their tolerance range; (3) restored sites along the River have greater abundance of provincial species (and greater similarity to the historic forest composition) than unrestored sites.

Materials and methods

Study area The Salt River is a major tributary of the Gila River within the arid Lower Colorado River watershed. Average annual maximum and minimum daily temperatures in Phoenix, Arizona are 30 °C and 16 °C (Station 026486; http://www.wrcc.dri.edu/). Annual precipitation averages 20 cm, with most rain occurring in the winter wet season (November to March) and late summer monsoon season (July–August). Historically, the Salt River in the Phoenix area experienced periodic large winter floods during years with abundant rain and snow in the mountainous watershed. The River laterally migrated within a flood plain that was ~3-km wide, and its surface and ground water flows sustained wetlands, Sonoran riparian cottonwood- willow forests (*Populus fremontii* – *Salix gooddingii*) and mesquite (*Prosopis*) forests, and shrublands of seep-willow (*Baccharis salicifolia*), arrowweed (*Pluchea sericea*) and saltbush (*Atriplex*) (Shantz and Piemeisel 1924; Haase 1972; Rea 1983) (Fig. 1). The arid uplands supported Sonoran desertscrub vegetation (Brown 1994).

The Salt River was dammed and flow regulated upstream of Phoenix in the early 1900s. Its flow is diverted at Granite Reef Diversion Dam into a series of delivery canals creating a mostly-dry reach in the Phoenix metropolitan area. Originally intended for agricultural irrigation, the diverted water increasingly is used for urban landscaping and other municipal uses (Rosenberg et al. 1987; Roberge 2002; Keys et al. 2007). Mean annual flow of the Salt River in the center of Phoenix is 5.5 cms, although median annual flow is only 0.2 cms (USGS 09512165) (compared to mean annual flow of 790 cms upstream of the diversion dam; USGS 09502000, http://nwis.waterdata.usgs.gov). Following major floods in the wet decades of the 1970s and 1980s, portions of the river were channelized to increase flood water conveyance creating a deep, narrow river bed (Graf 2000; Roberge 2002). Storage capacity of Roosevelt Lake, the main reservoir on the Salt River, was increased in the 1990s, reducing but not eliminating downstream flooding (Fig. 2).

Phoenix developed rapidly in the mid 1900s, and the *Prosopis*-dominated floodplains and terraces were converted to farmland and then urban land (Douglas 1938). Water tables near the river declined owing to the combination of surface flow diversion and intensified groundwater

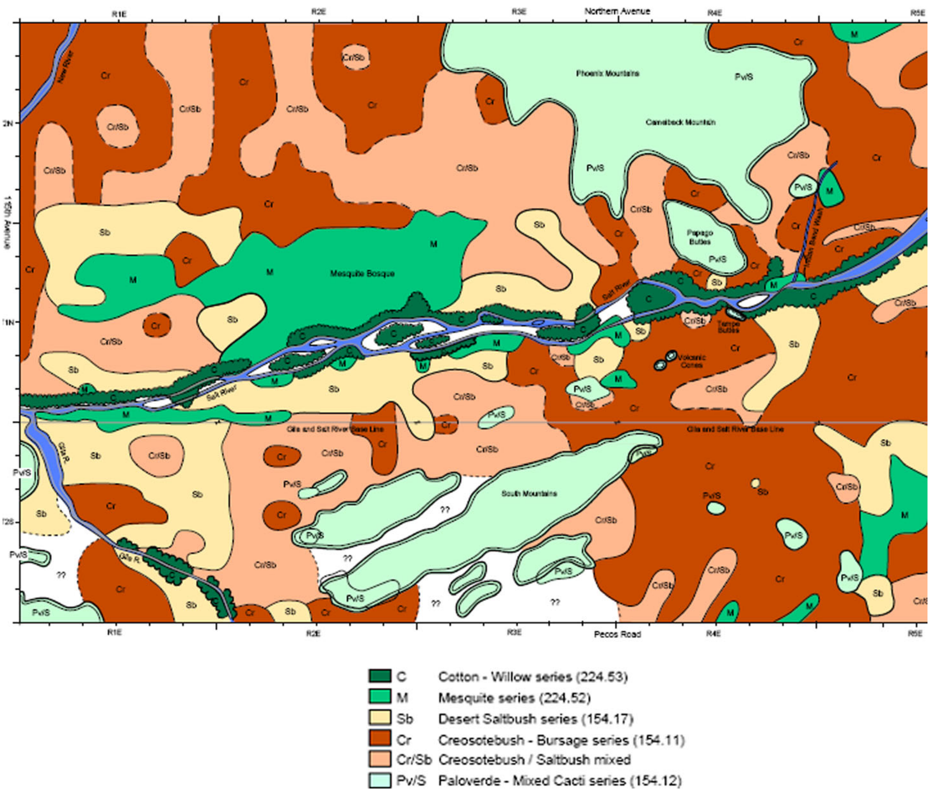

Fig. 1 Vegetation map of present-day Phoenix metropolitan area as of 1867/1868, based on Public Lands Survey Logs (http://caplter.asu.edu/docs/contributions/Vegetation_of_Phx_color.pdf). Labels for the vegetation series follow Brown et al. (1979)

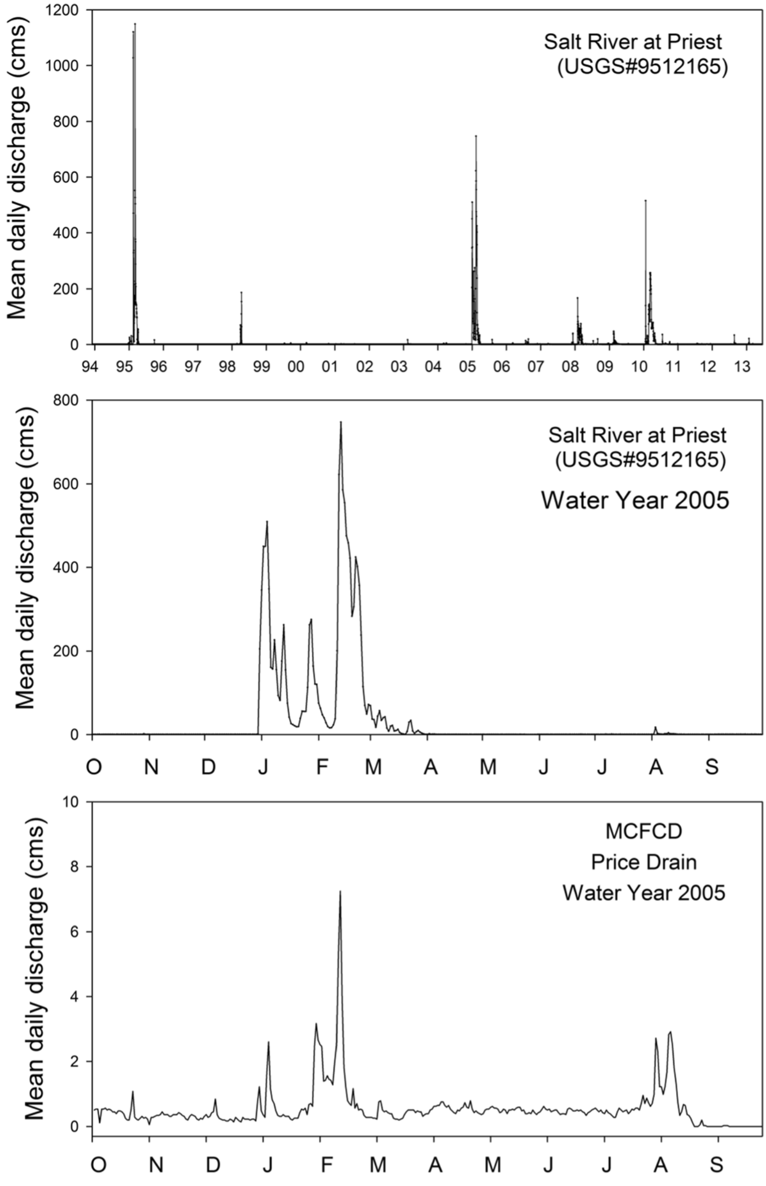

Fig. 2 Mean daily discharge of the urban Salt River from 1994 through 2013 (upper figure), and during water year 2005 (middle figure), at a location in central Phoenix The bottom panel shows discharge in water year 2005 from a large storm drain that flows into the Wet Unrestored site

withdrawals, causing replacement of *Populus-Salix* forests by the more deeply-rooted introduced *Tamarix chinensis* and ultimately causing decline of *Tamarix* itself (Graf 1982). Today, pockets of riparian vegetation grow in areas of the narrowed river bed that are wetted seasonally or perennially by outfalls of water from the more than 800 storm and effluent drains within the Phoenix metropolitan area (White and Stromberg 2009; Bateman et al. 2015). Vegetation also has been planted at restoration sites.

Study sites We delineated five sites along the Salt River in Phoenix and Tempe (309–365 m in elevation) that varied in restoration intensity and in flow regime (Fig. 3). Two sites were within the Phoenix Rio Salado Habitat area, a five-mile stretch of the Salt River between 24th Street and 19th Ave. The restoration was a partnership between the U.S. Army Corps of Engineers and the City of Phoenix, and was completed in November 2005. A goal was to restore historically present species (via planting) while excluding those considered non-native to the system (via weeding). Restoration interventions included earth recontouring, installation of drip irrigation systems, tree and shrub planting, seeding, riverbed cleanup, low flow channel stabilization, and construction of a groundwater delivery system (five supply wells) to provide water for the terrace plantings and constructed wetlands. Riparian tree species planted in the project area include *Acacia constricta, Acacia greggii, Celtis reticulata, Chilopsis linearis, Parkinsonia florida, Populus fremontii, Salix gooddingii, Prosopis velutina, Prosopis glandulosa*, and *Prosopis pubescens.* Twenty-two stormwater outfalls in the area provide intermittent to perennial flow within the low-flow channel. No trees were planted in the low-flow channel. We divided the Rio Salado area into two sites (Restored-West and Restored-East) owing to its large size.

A third site was within the Tempe Rio Salado Restoration area, between Tempe Town Lake and Priest Road. This restoration was a partnership between and the U.S. Army Corps of Engineers and the city of Tempe. We refer to this site as Minimally Restored because even though trees (including *Chilopsis linearis, Fraxinus sp*. and *Prosopis pubescens*) were planted in the low-flow channel, no restoration actions were undertaken on the bordering river terrace. This site has only recently had perennial flows, following the rerouting and combining of

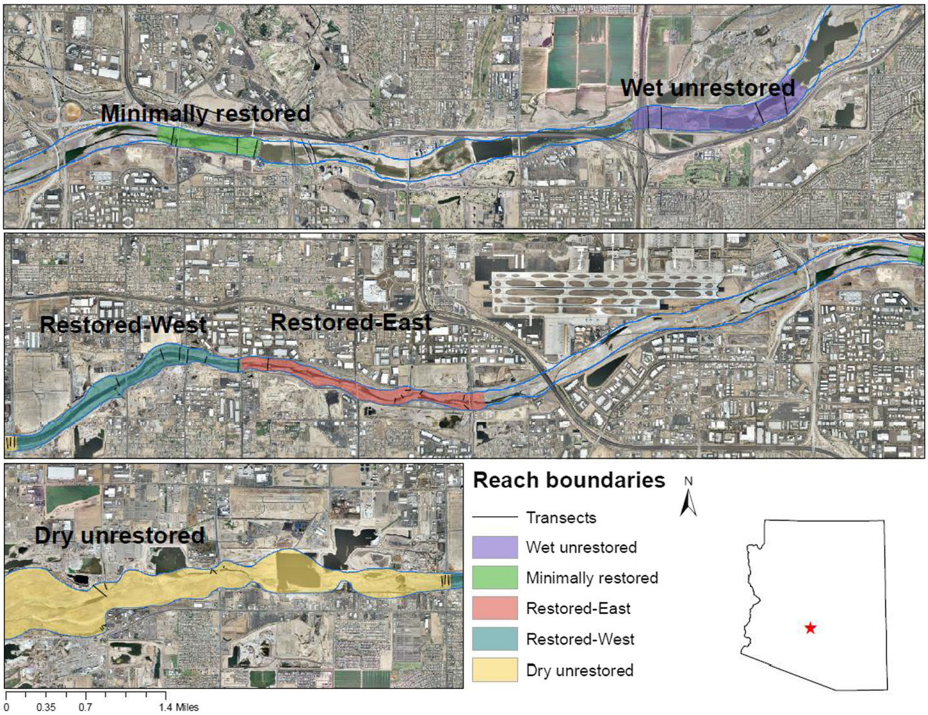

Fig. 3 Location of study sites and belt transects along the urban Salt River, Phoenix and Tempe, Arizona

storm drains just below the Tempe Town Lake west dam (Basil Boyd, 2013, City of Tempe, personal communication).

The remaining two study sites (Wet Unrestored and Dry Unrestored) have had no restoration activity but have been rewatered by urban runoff to varying degrees. The wet unrestored site, located upstream of Tempe Town Lake (an urban water feature constructed in 1999) between Dobson and Price roads, had perennial stream flow. The flows derive from a combination of sources including discharge from Price Drain (Fig. 2), other storm drains, and the City of Mesa's Northwest Water Reclamation Plant. The dry unrestored site extended from 19th Avenue to 43rd Avenue. Several storm drains and one effluent drain discharge intermittently to the main channel which flows only during major storm events. The City of Phoenix intends to restore this area via the Rio Salado Oeste Project but funding has yet to be procured (Gerlak et al. 2009). We excluded from study the dry reaches in the far east (upstream) sectors of the river, where return flows have had negligible influence and riparian forests are sparse to nonexistent.

Field data We sampled a total of 35, 10-m wide belt transects, distributed among the study sites. Each transect spanned the active channel and adjoining bank and floodplain; the river terrace, if vegetated, also was sampled. Transects were perpendicular to the channel, and were either along the main river channel or along the short channels of storm drains (Fig. 4). Transects varied in length (from 16 m to 433 m, average of 147 m) because the riparian zone varied in width. Approximately 1 ha of

Fig. 4 A restored section of the Salt River (Phoenix Rio Salado) showing landscape features within the riparian zone

riparian habitat was sampled per site. For sites with perennial to intermittent flow, transects were randomly located. At the single site with ephemeral flow (Dry Unrestored), transects were located in stratified random fashion within areas that supported riparian vegetation.

Within each belt transect we assessed tree composition, size structure, and vigor. For each tree encountered we recorded its scientific name, diameter of main stem at 1 m height (caliper or dbh tape), number and size of ramets, and vigor class (healthy, stressed as indicated by yellowing leaves or branch death, or dead). We focused on plants classified as trees according to the USDA Plants database (USDA-NRCS 2014). We did not include shrubs such as *Baccharis salicifolia* or *Pluchea sericea,* but did include plants such as *Nicotiana glauca*, *Salix exigua*, *Tamarix chinensis* and *Prosopis* spp. which have variable growth form and are classified as both shrubs and trees. We used the belt transect data to calculate density, basal area, and frequency of each species per reach, and scaled these values per hectare. We calculated a modified Importance Value (IV) for each species per reach by averaging relative density, relative basal area, and relative frequency; our scale ranges to a maximum of 100 (Curtis 1959). We examined the distribution of main stems among size classes to determine which species have ongoing recruitment.

In a few cases we could not identify individuals to species. Two species of *Eucalyptus (E. camaldulensis* and *E. microtheca)* were present but most were non-reproductive and difficult to discriminate based on vegetative characteristics. Thus, we pooled *Eucalyptus* species at the genus level. Similarly, we grouped *Washingtonia robusta* and *W. filifera* as *Washingtonia* spp. Finally, *Prosopis velutina, P. glandulosa* var. *torreyana,* and cultivated *Prosopis* from South America (known as Chilean mesquite or Argentinian mesquite in the landscape trade) all occur along the river, and hybridize. These were pooled as *Prosopis* spp. *Prosopis pubescens* was identifiable to species owing to its distinctive features.

Biogeographical classification We determined the region of evolutionary origin of the trees based on literature review (e.g., Pinkava and Lehto 1970; Turner et al. 1972; Hawkins et al. 2007). We assigned each species to one of eight global biogeographic regions following Udvardy (1975)- Antarctic, Australian, Afrotropic, Neotropic (the local region), Nearctic, Palearctic, Indomalayan, and Oceanic- and calculated the Importance Value of trees deriving from each region. We used global abundance and distribution maps of each species, based on data from the Encyclopedia of Life (EOL 2014), to determine which elements of the flora were cosmopolitan (documented occurrences in at least three biogeographic regions), which were provincial (limited to the American West or Southwest), and which were in an intermediate category (present in two biogeographic regions). We further divided the cosmopolitan category into species that originated in the local region (Nearctic) and those that originated in a different region. Potential shortcomings of this method are non-uniform collecting and vouchering of species among regions of the world, but it is the best available data. We treated *Prosopis* spp. as provincial.

To document the historical occurrence of trees along the Salt River, we examined data from General Land Office surveys of the Phoenix area undertaken in the late 1800s and also queried a regional herbarium database for the date of earliest herbarium vouchers (SEINe 2014). The General Land Office surveys reveal three dominant riparian tree genera (*Populus, Prosopis,* and *Salix*) within the study area (Fig. 1) and the herbarium search revealed historical collections of ten tree species (Table 2). To place the arboreal flora of the Salt River into regional context, we compiled tree species lists for five non-urban perennial, low-elevation rivers in Arizona using published floras or vegetation surveys.

Phoenix landscape trees To determine whether the urban landscape functioned as a potential source of the riverbed trees, we generated a list of tree species present in the Phoenix metro landscape using two sources. The City of Phoenix provided a dataset of all trees (and their abundance) planted on property maintained by the City of Phoenix, including parks and walkways. The Central Arizona Phoenix-Long Term Ecological Research program (CAP-LTER) provided results of their Survey 200 project (year 2010 sampling), in which vegetation is sampled at 200 plots randomly distributed throughout the Phoenix metropolitan area. We truncated the comprehensive City of Phoenix list to exclude species with less than 50 occurrences, and combined it with the CAP-LTER list.

River restoration and management To determine which sites had the greatest floristic similarity to the historic condition, we calculated Sorenson similarity coefficients (presence/absence) between the known historic Salt River tree community and the tree communities of each of the five study sites. The historic river data set and the current field data sets have vastly different sampling approaches, but we view the results in only a relative sense to make comparisons between reaches.

Human and animal rights No animals were harmed during this project. Field collections (of leaves and flowers) were made to identify plants to species, and were deposited in the ASU Herbarium.

Results

Floristic regions and global distribution patterns The 30 tree species detected in the urban Salt River riparian transects derived from six biogeographic regions (Table 1, Fig. 5). Slightly more than half of the species (53 %) were Nearctic in origin with the remainder being Australian (17 %), Palearctic (10 %), Neotropic (10 %), Indomalay (7 %) and Afrotropic (Cape of South Africa, in particular) (3 %). In terms of abundance within the riparian community, the Nearctic species had a combined Importance Value of 64. Importance Values of species from other regions were 28 (Paleartic), 4 (Australian), 3 (Neotropic), <1 (Afrotropic) and <1 (Indomalay).

The tree species planted in the Phoenix urban area similarly derived from six biogeographic regions (Fig. 5). Of the 81 tree species that were abundant in the Phoenix metropolitan landscape, 35 % were Nearctic in origin (including many from the Sonoran Desert), 26 % were Palearctic, 19 % were Australian, 10 % were Neotropic, 10 % were Indomalay, and 1 % were Afrotropic. In terms of overlap, 27 species were common to the city and the river, three were unique to the river (*Celtis reticulata, Salix exigua,* and *Salix gooddingii*) and 54 were unique to the city (Appendix 1). All of the overlapping species had been cultivated and planted in the Phoenix landscape.

Approximately two-thirds of the species along the river, with aggregate Importance Value of 64, were cosmopolitan (Fig. 6). Five in this group- *Acacia farnesiana, Parkinsonia aculeata, Prosopis velutina, Washingtonia* spp. *(W. filifera* and *W. robusta)*- with aggregate IV of 30- originated in the Nearctic. The remaining 13 (with aggregate IV of 33) originated in

Table 1 Importance Values of tree species in five riparian sites of the urban Salt River

Species name	Family	Region of origin	Global status	Landscape plant?	Restoration planting?	Importance Value, by reach					
						R5	R4	R3	R2	R1	Avg
Tamarix chinensis	Tamaricaceae	Palearctic	CO	–	–	20	6	5	38	39	**21.4**
Salix gooddingii	Salicaceae	Nearctic	PR	–	R	14	27	19	20	20	**20.2**
Prosopis spp.	Fabaceae					10	13	19	6	5	**10.8**
-*P. velutina*	Fabaceae	Nearctic	CO	L	R						
- *P. glandulosa*	Fabaceae	Nearctic	CO	L	–						
-*P. cf . chilensis*	Fabaceae	Neotropic	CO	L	–						
Parkinsonia aculeata	Fabaceae	Nearc./Neotropic	CO	L	–	27	4	9	3	2	**9.1**
Populus fremontii	Salicaceae	Nearctic	PR	L	R	9	10	10	4	4	**7.4**
Washingtonia spp.	Arecaceae					4	9	7	7	10	**7.3**
-*W. filifera*	Arecaceae	Nearctic	CO	L	–						
-*W. robusta*	Arecaceae	Nearctic	CO	L	–						
Vitex agnus-castus	Verbenaceae	Palearctic	CO	L	–	8	6	8	3	5	**6.2**
Acacia farnesiana	Fabaceae	Nearctic	CO	L	–	3	3	3	4	3	**3.0**
Acacia stenophylla	Fabaceae	Australia	–	L	–	0	3	3	6	2	**2.7**
Leucaena leucocephala	Fabaceae	Neotropic	CO	L	–	2	4	4	1	1	**2.4**
Parkinsonia florida	Fabaceae	Nearctic	PR	L	R	2	2	4	2	1	**2.2**
Chilopsis linearis	Bignoniaceae	Nearctic	PR	L	R	0	5	5	1	0	**2.1**
Eucalyptus spp.	Myrtaceae					0	1	1	1	3	**1.1**
-*E. camaldulensis*	Myrtaceae	Australia	CO	L	–						
-*E. microtheca*	Myrtaceae	Australia	CO	L	–						
Prosopis pubescens	Fabaceae	Nearctic	PR	L	R	0	1	0	3	1	**0.9**
Rhus lancea	Anacardiaceae	Afrotropic	CO	L	–	0	0	0	1	1	**0.5**
Ulmus parvifolia	Ulmaceae	Indomalay	CO	L	–	0	1	1	1	0	**0.5**
Acacia greggii	Fabaceae	Nearctic	PR	L	R	0	1	1	0	0	**0.4**

Table 1 (continued)

Species name	Family	Region of origin	Global status	Landscape plant?	Restoration planting?	Importance Value, by reach					
						R5	R4	R3	R2	R1	Avg
Acacia salicina	Fabaceae	Australia	CO	L	–	0	0	0	1	1	**0.4**
Celtis reticulata	Ulmaceae	Nearctic	PR	–	R	0	2	0	0	0	**0.3**
Nicotiana glauca	Solanaceae	Neotropic	CO	L	–	2	0	0	0	0	**0.3**
Parkinsonia microphylla	Fabaceae	Nearctic	PR	L	R	0	1	1	0	0	**0.3**
Callistemon viminalis	Myrtaceae	Australia	CO	L		0	0	0	0	1	**0.2**
Acacia constricta	Fabaceae	Nearctic	PR	–	R	0	1	0	0	0	**0.1**
Salix exigua	Salicaceae	Nearctic	PR	–	R	0	1	0	0	0	**0.1**
Melia azedarach	Meliaceae	Indomalay	CO	L	–	0	1	0	0	0	**0.1**
Morus alba	Moraceae	Palearctic	CO	L	–	0	1	0	0	0	**0.1**

(R5 = Dry unrestored, R4 = Restored-West, R3 = Restored-East, R2 = Minimally restored, R1 = Wet unrestored). Also indicated is the family, biogeographic region of origin, current global distribution status, and planting status. Cosmopolitan (CO) species are present in three or more biogeographic regions; Provincial (PR) species are restricted to Nearctic region inclusive of American Southwest. "L" species were planted in the Phoenix metropolitan landscape; "R" species were planted in the riparian zone of the Salt River. Species are listed in descending order of Importance, as averaged across reaches other biogeographic regions. Of these 13, four were abundant in the study area (the Palearctic-origin *Tamarix chinensis* and *Vitex agnus-castus*, the Australian *Acacia stenophylla,* and the Neotropic *Leucaena leucophylla)* and nine had small populations (*Acacia salicina, Callistemon viminalis, Eucalyptus camaldulensis, E. microtheca*, *Melia azedarach, Morus alba, Nicotiana glauca, Rhus lancea,* and *Ulmus parvifolia*).

Restoration effects The two restored sites had the highest abundance of species from the local biogeographic region (IV of 78 for both) and the highest abundance of provincial species (i.e., those still restricted to the local regions (IV of 49 and 39) (Figs. 5 and 6). The Dry Unrestored site had the interesting combination of high abundance of Nearctic species (IV of 68) and high abundance of regional species that have become cosmopolitan, thus low abundance of provincial species (IV of 24). The wet unrestored site had relatively low abundance of Nearctic-origin species (IV of 47) and of provincial species (IV of 26). Sorenson similarity coefficients indicated that the two restored sites had the greatest similarity to the historic river flora (0.67 and 0.60 for Restored-East and Restored-West) Similarity coefficients for other pairwise comparisons to the historical flora were 0.48 (Minimally Restored), 0.44 (Dry Unrestored), and 0.36 (Wet Unrestored)..

Provincial species The Sonoran riparian pioneer tree *Salix gooddingii* was the dominant species at one site (Phoenix Rio Salado-West) and was the second most abundant species overall (Figs. 7 and 8). Like most species, *S. gooddingii* was more abundant at sites with perennial flows (e.g., <1000/ha at the unrestored wet site vs. 40/ha at the unrestored dry site). With respect to geomorphic surfaces, it was abundant in the low-flow channel and along storm drain channels as well as on irrigated terraces and pond edges. Individuals were present in many size classes, suggesting ongoing recruitment.

Populus fremontii another historically common pioneer tree, was considerably less abundant than *Salix gooddingii* with densities ranging among sites from 48/ha (wet unrestored) to 1/ha (dry unrestored). Similar to *S. gooddingii, P. fremontii* reached its highest Importance Value at restored Phoenix Rio Salado, but unlike its confamiliar, its population consisted

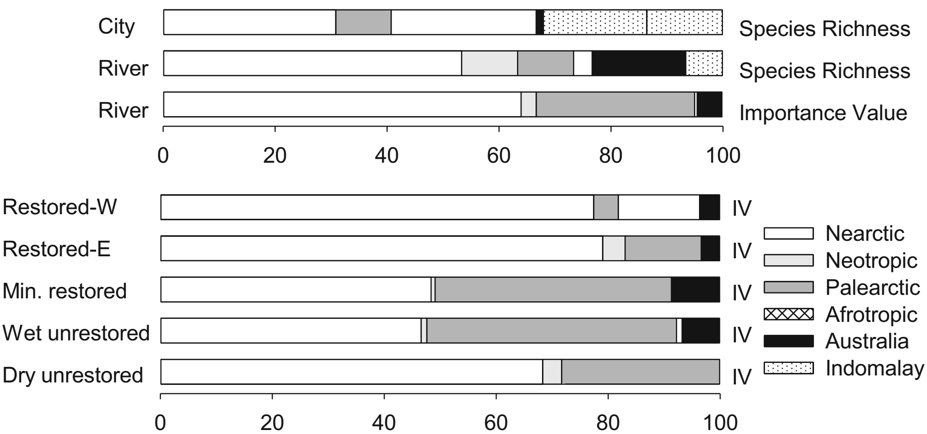

Fig. 5 Top figure: Percentage of trees originating from six different biogeographical regions, for the riparian zone of the urban Salt River and for the surrounding urban landscape. Bottom figure: Aggregate Importance Values (IV) of trees from each region, for five reaches of the River

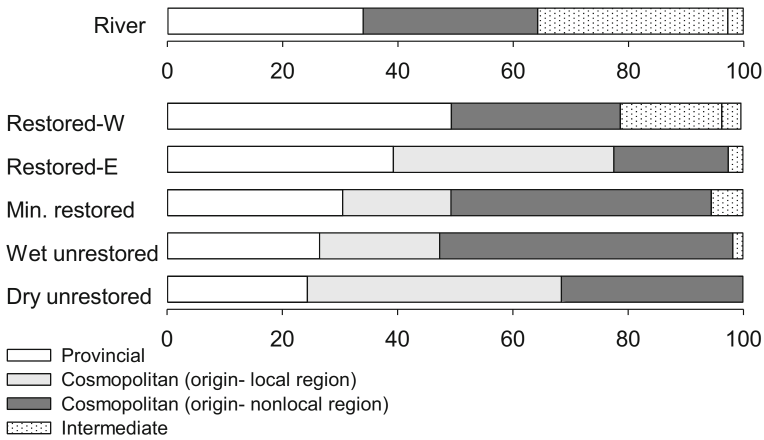

Fig. 6 Aggregate Importance Values for trees in four biogeographic categories for the urban Salt River as a whole (top figure) and by river reach (bottom figure)

mainly of planted individuals with few juveniles. *Populus fremontii* had low vigor in all sites including restored areas (e.g., 55 % percent dead in Restored-East) owing to herbivory by beaver and to insufficient water. The largest *P. fremontii* (72 cm dbh) was similar in size to the largest *S. gooddingii* (67 cm), with both reaching their maximum size on storm drain channels (Appendix 2).

Three historically present taxa were detected only at restoration sites. *Prosopis pubescens* (Salt River herbarium voucher from 1935) grew at low density at restored Phoenix Rio Salado and minimally restored Tempe Rio Salado. The planted trees were small (maximum dbh of 5 cm) but producing seed, and there were second-generation juveniles in the low-flow channel at Tempe Rio Salado. Some mature *P. pubescens* at Tempe Rio Salado had high mortality from prolonged inundation, with water levels higher than present at their time of planting. *Salix exigua* (Salt River herbarium voucher from 1912) was very sparse, with only one individual sampled. *Chilopsis linearis* (Salt River herbarium voucher from 1950) was at Phoenix Rio Salado and Tempe Rio Salado but with low density, low vigor, and high mortality. Many were on terraces and were drip-irrigated but receiving insufficient water.

Celtis reticulata also was present only at restored Phoenix Rio Salado, and only as planted individuals. The population was on an irrigated terrace and had low density (6 trees/ha), trunk diameters between 10 cm to 26 cm, varying vigor levels, and no apparent recruitment. Although there is no record of *C. reticulata* historically occurring along the Salt River in the Phoenix area, it does become common along higher elevation streams (Table 2).

Cosmopolitan species originating in the Nearctic *Prosopis* spp. was historically the most abundant riparian tree in the study area, occurring on high floodplains and terraces. Our sampling indicated *Prosopis* spp. to be the dominant species at one site (Restored-East) and to be the 3th most abundant taxon overall. Its high abundance at restored Phoenix Rio Salado was a result, in part, of terrace plantings.

Surprisingly, the four other regional taxa that are now cosmopolitan are all new to the Salt River.

Washingtonia spp. (*W. filifera* and *W. robusta)*- the 6th most abundant taxon- have been widely planted in the Phoenix landscape (with one record of a cultivated tree from 1927) and

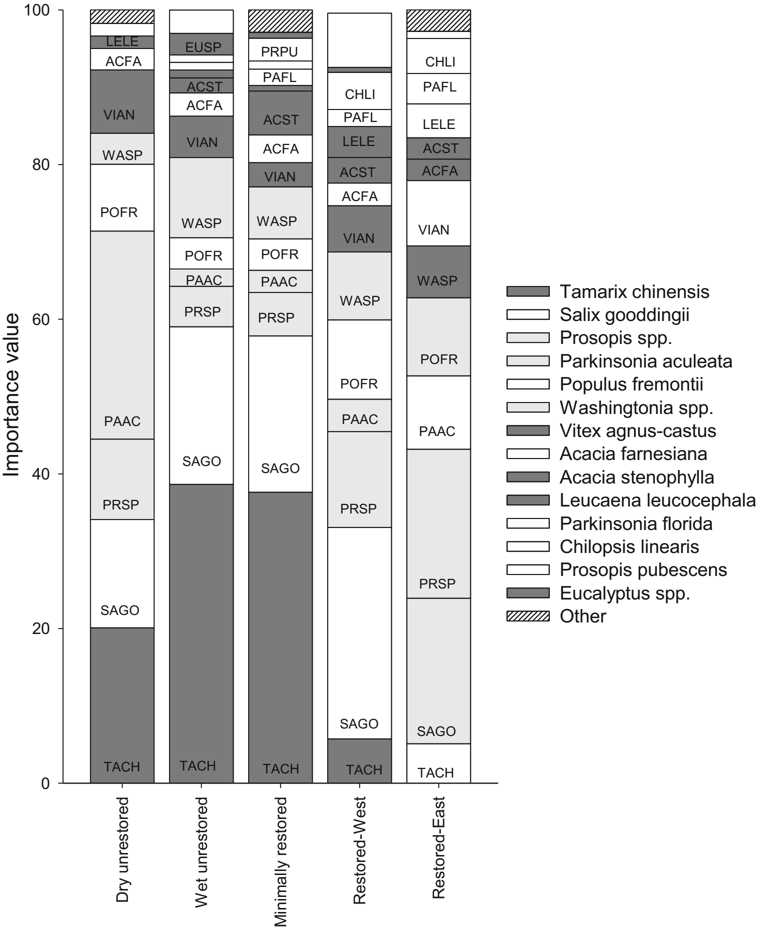

Fig. 7 Importance Values for the 14 most common trees in the riparian zone of the urban Salt River, by site. Provincial species are indicated by white fill; Cosmopolitan species that originated from the Nearctic are indicated by light grey fill; Cosmopolitan species that originated from other regions are indicated by dark grey fill

in other cities throughout the world. Both species are typically found in groundwater-fed canyons of the American Southwest, with *W. filifera* documented from a tributary of the Salt River. *Washingtonia* ssp. was present at all sites (but sparse at Dry Unrestored) and consisted mainly of young plants. The plants were recruiting in the sun as well as in shady understories of storm drain forests. Like many other species, *Washingtonia* reached its largest size (80 cm) on a storm drain channel.

Parkinsonia aculeata and *A. farnesiana* derive from the American Southwest including Mexico, and are increasing in abundance in the USA owing to widespread planting of cultivars. *Parkinsonia aculeata* was the dominant species at the dry unrestored site, where it had density of 148/ha (versus 13/ha at the wet unrestored site).

Cosmopolitan species originating in other regions *Tamarix chinensis* was the most abundant species overall, with density ranging from >8000/ha in the minimally restored wet

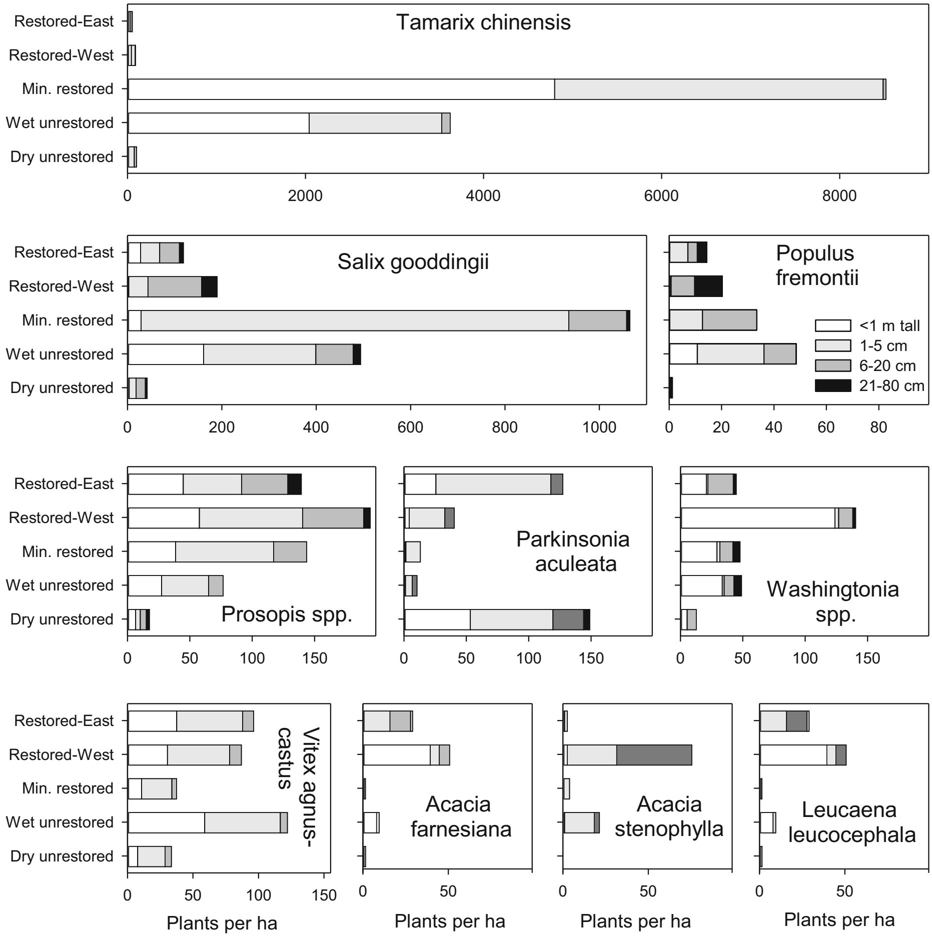

Fig. 8 Density by stem diameter class for common tree species in the riparian zone of the urban Salt River

site to 66/ha at restored Phoenix Rio Salado. It was the dominant species in two of the five sites (non-restored wet and minimally restored wet). Juveniles dominated the population, although individuals up to 20 cm were present along storm drain channels.

Vitex agnus-castus was present at all sites, in multiple size classes, occurring on main channel floodplains and terraces as well as along storm drains. *Acacia stenophylla* was present at all sites except the driest, and consisted mainly of mature individuals (the largest, 19 cm dbh, along a storm drain channel). *Leucaena leucophylla* was most abundant at restored sites, where it was represented mainly by small individuals in the understory of mature riparian forests along wet side channels.

Discussion

Cosmopolitan or provincial? Our results indicate that the urban riparian forest of an arid-region river has many cosmopolitan elements, owing, in part, to influx of species from the

Table 2 Tree species of several other perennial rivers in the Lower Colorado River Basin of Arizona including the lower Salt River (historic and present)

Species name	Family	Historic Salt River 240–400 m	Urban Salt River 300–400 m	Bill Williams and Santa Maria 150–500 m	Hassa-yampa River 590–605 m	San Pedro River 600–1300 m	Middle Verde River 915–1035 m	Upper Verde River 1035–1340 m
Acacia constricta	Fabaceae		√	√		√	√	
Acacia farnesiana	Fabaceae		√					
Acacia greggii	Fabaceae	√ (1899)	√	√	√	√	√	√
*Acacia salicina**	Fabaceae		√					
*Acacia stenophylla**	Fabaceae		√					
Acer negundo	Aceraceae					√	√	√
Ailanthus altissima	Simaroubaceae						√	√
Alnus oblongifolia	Betulaceae						√	√
Callistemon viminalis	Myrtaceae		√					
Canotia holacantha	Celastraceae						√	√
Celtis reticulata	Cannabaceae		√		√	√	√	√
Cephalanthus occidentalis	Rubiaceae	√ (1907)	√					√
Chilopsis linearis	Bignoniaceae	√ (1950)	√		√	√	√	√
*Elaeagnus angustifolia**	Elaeagnaceae						√	√
*Eucalyptus camaldulensis**	Myrtaceae		√					
*Eucalyptus microtheca**	Myrtaceae		√					
*Ficus carica**	Moraceae				√			
Fraxinus anomala var. lowellii	Oleaceae						√	√
Fraxinus velutina	Oleaceae				√	√	√	√
Juglans major	Juglandaceae					√	√	√
Juniperus coahuilensis	Cupressaceae						√	√
Juniperus deppeana	Cupressaceae					√		
Juniperus monosperma	Cupressaceae						√	√

Table 2 (continued)

Species name	Family	Historic Salt River 240–400 m	Urban Salt River 300–400 m	Bill Williams and Santa Maria 150–500 m	Hassa-yampa River 590–605 m	San Pedro River 600–1300 m	Middle Verde River 915–1035 m	Upper Verde River 1035–1340 m
Juniperus osteosperma	Cupressaceae						√	√
*Leucaena leucocephala**	Fabaceae		√					
*Maclura pomifera**	Moraceae						√	
*Malus pumila**	Rosaceae	√ (1935C)					√	
*Melia azedarach**	Meliaceae		√				√	
*Morus alba**	Moraceae		√		√		√	
Morus micropylla	Moraceae					√	√	√
Nicotiana glauca	Solanaceae		√		√			
Parkinsonia aculeata	Fabaceae		√					
Parkinsonia florida	Fabaceae	√ (1948)	√		√			
Parkinsonia microphylla	Fabaceae	√ (1896)	√					
*Pistacia integerrima**	Anacardiaceae		√					
Platanus wrightii	Platanaceae					√	√	√
Populus fremontii	Salicaceae		√	√	√	√	√	√
*Prosopis cultivar**	Fabaceae		√					
Prosopis glandulosa var. torreyana	Fabaceae		√		√		√	
Prosopis pubescens	Fabaceae	√ (1935)	√		√			
Prosopis velutina	Fabaceae	√ (1901)	√	√	√	√	√	√
Prunus sp.	Rosaceae							√
Punica granatum	Lythraceae							√
Pyrus communis	Rosaceae						√	
Quercus gambelii	Fagaceae							√
Quercus palmeri	Fagaceae						√	√

Table 2 (continued)

Species name	Family	Historic Salt River 240–400 m	Urban Salt River 300–400 m	Bill Williams and Santa Maria 150–500 m	Hassa-yampa River 590–605 m	San Pedro River 600–1300 m	Middle Verde River 915–1035 m	Upper Verde River 1035–1340 m
Quercus turbinella	Fagaceae						√	√
*Rhus lancea**	Anacardiaceae		√					
*Ricinus communis**	Euphorbiaceae		√					
Robinia neomexicana	Fabaceae							√
Salix exigua	Salicaceae	√ (1912)	√	√		√	√	√
Salix gooddingii	Salicaceae	√ (1914)	√	√	√	√	√	√
Salix laevigata							√	√
Sambucus canadensis	Adoxaceae	√ (1920)	√		√	√		√
Sapindus saponaria var. drummondii	Sapindaceae				√	√	√	√
*Tamarix aphylla**	Tamaricaceae				√			
*Tamarix chinensis or ramosissima**	Tamaricaceae	√ (1935)	√	√	√	√	√	√
*Ulmus parvifolia**	Ulmaceae		√					√
*Vitex agnus-castus**	Verbenaceae		√					
Washingtonia filifera	Arecaceae		√		√			
Washingtonia robusta	Arecaceae		√					

"√" indicates species presence; * indicates a species introduced to the American Southwest; C = Cultivated. For the historic Salt River, the year of the earliest vouchered specimen is given. Rivers are listed in order of increasing elevation. Data are from Wolden et al. (1994), Makings (2006), Jenke (2011), and unpublished data of the authors surrounding irrigated and forested cityscape. A desert city with extensive irrigated landscapes, the Phoenix metro area has a diverse assemblage of trees from a variety of floristic regions, reflecting a hundred years of landscaping trends and a cosmopolitan landscaping trade. Many of these cultivars have been repeatedly introduced in cities or villages throughout the world, facilitating a “spillover effect” and spread beyond their planting zones (Reichard and White 2001). As is often the case where managed and natural landscapes abut, several of the landscape plants have become naturalized within the urban riparian forest (Richardson et al. 2000; Vidra and Shear 2008; Blitzer et al. 2012; Litteral and Wu 2012). Genetic studies would be useful to confirm that the Phoenix urban plantings were indeed the source of the naturalized riparian populations along the Salt River (Vardien et al. 2013).

The bidirectional flow of taxa between floristic regions also has contributed to the cosmopolitan status. In addition to the “foreign” landscape plants that are thriving along the urban Salt River, several regional trees have now become established throughout the world. Some have become pan-global owing to widespread introductions not just for ornamental value or shade but also for soil stabilization, fodder, or medicinal value (Lawes and Grice 2007; Stromberg et al. 2009; Tererai et al. 2013). The relatively high number of cosmopolitan species compared to some other studies (e.g., Aronson et al. 2014) reflects, in part, our exclusive focus on trees. Herbaceous plants as a group differ from trees in their patterns of introduction and in their turnover rate among sites (Mack and Erneberg 2002; Viers et al. 2012).

Although the urban riparian forest has cosmopolitan elements, it retains a distinct regional signature. We expected few historically present tree species to persist owing to the extensive hydrogeomorphic alteration of the river bed that accompany urbanization (Everard and Moggridge 2012) and were surprised to find that trees of regional-origin comprise half of the species present and two-thirds of the abundance. Although the riparian forests are sparse overall, pre-development species co-exist with the new arrivals along the urban riparian corridor, as has been found on other urban rivers (Richardson et al. 2007; Pennington et al. 2010). The mix depends, in part, on extent of habitat alteration and on proximity to planted landscapes.

Stream hydrology and geomorphology Restoring appropriate water flows is an essential element of stream restoration. One explanation for the high relative abundance of regional taxa, and of *S. gooddingii* in particular, is the surprising presence of a “semi-natural” flood regime. *Salix gooddingii* is a vernal flood specialist with seed dispersal and seedling establishment tightly coupled with timing and rate of winter flood run-off (Stella et al. 2006; Kehr et al. 2014). Vernal floods have been suppressed on many dammed and flow-regulated rivers of the American Southwest, contributing to the decline of *S. gooddingii* and to increase of species such as *T. chinensis* that are reproductive generalists (Fenner et al. 1985; Stromberg et al. 2007; Merritt and Poff 2010). In the urban setting, however, the storm drains that feed the River have a temporal hydrograph that resembles that of wild (unregulated) rivers (Fig. 2). Further, although the Salt River is managed to supply water to urban and agricultural irrigation users (with elevated summer flows and reduced winter flows), the periodic winter flood pulses that define wild desert rivers have been accidentally restored in the Phoenix area owing to past management choices. The Verde River, a dammed tributary of the Salt, retains a small reservoir capacity owing to a decision in the 1980s to *not* construct an additional dam (the proposed Orme Dam). Thus, when the reservoirs of the Verde River exceed storage capacity (Beauchamp and Stromberg 2007), water is released into the Salt River. These occasional winter flood pulses, coupled with base flows sustained by storm runoff, are allowing *S. gooddingii* to recruit in the urban environment.

A perplexing question is why *P. fremontii*, a species in the same functional type as *S. gooddingii*, is less common along the river. Urbanization of the Salt is differentially affecting these two pioneer tree species for reasons that remain unclear. The two differ slightly in seed dispersal phenology, with *P. fremontii* beginning its dispersal in March and *S. gooddingii in* April, and this pattern may confer survival advantage to *Salix* if the urban floods are skewed towards late-spring (Stromberg et al. 1993). Seedlings of *S. gooddingii* and *P. fremontii* both require low salinity and high moisture levels, but *Salix* in some studies is slightly more tolerant of drought and fluctuating water levels and thus perhaps better adapted to urban settings (Stella and Battles 2010). Field monitoring of seedling establishment and survivorship in a winter flood year would help to clarify reasons for the differential response of these pioneer trees.

The compositional changes along the Salt River are a product of changing seed abundance in concert with creation of new types of riparian habitats (Johnson 2002). Like some other arid region urban rivers, the urban Salt River has become a surface water fed system with the water table well beyond plant rooting depth (Townsend et al. 2013). *Tamarix chinensis,* a deeply and widely rooted species that is abundant on Southwestern rivers that have undergone water table decline (Stromberg et al. 2007; Stromberg 2013) was abundant in wet reaches of the rivers but surprisingly did not have the competitive advantage in the drier, intermittently surface-fed reaches of the Salt River. Rather, the dominant species in the dry unrestored reaches was *Parkinsonia aculeata,* a regional-origin species that was not a component of the historic river flora. Its combination of drought and salinity tolerance, high phenotypic plasticity, water-dispersed seeds and apparently shallow rooting depth make it well-adapted for periodic storm drain discharge in an otherwise dry river bed (van Klinken et al. 2009; Pichancourt and van Klinken 2012; Bezerra et al. 2013).

Other new habitats are the channel bank and slopes of urban storm drains (aka urban tributaries) which have intermittent to continuous low flows and infrequent flood disturbance. The historic river was characterized by large flood pulses, channel avulsion, and high rates of sediment flow: risk of flood mortality was high but aggraded 'safe sites' distal from the main channel provided juveniles with a refuge from flood scour. The river today is confined to a narrow channelized bed, and storm drains provide the major topographical relief and flood refugia in those parts of the river in which high floodplains and terraces have not been intentionally restored via earth re-contouring. *Washingtonia filifera*, widely planted along city streets in many parts of the world, is one species that has capitalized on these novel habitats (Cornett 2008). This once regionally uncommon species likely was historically excluded from large rivers by floods, but now is thriving along the urban tributaries situated above the actively flooded low-flow channel. Another species that has benefited is *Vitex agnus-castus*, a small tree of riparian zones and upland shrublands of Europe (Adrover et al. 2008).

Another intriguing question is why some of the riparian-affiliated species widely planted in the Phoenix area, such as *Nerium oleander*, a tree of Mediterranean streambeds (Salinas and Guirado 2002; Magdaleno 2013) and *Nicotiana glauca*, a bird-pollinated species now common in dry parts of the world (Ollerton et al. 2012), remain sparse along the urban Salt River. Comparisons of regeneration niches, dispersal modes, and other life-history traits will be necessary to determine why certain landscape species are thriving in the river bed while others are not (Silverstein 2005; Osawa et al. 2013). Analysis of the changing spatio-temporal patterns of abundance of trees in the Phoenix landscape, with replacement of "old-school" landscape plants (such as *Eucalyptus* spp.) by newly cultivated species (such as *Dahlbergia* *sissoo*) would complement these studies, although residence time does not necessarily relate to naturalization frequency (Loeb 2012).

Conclusions People increasingly are valuing urban rivers for their beauty, recreational opportunities, and diversity, irrespective of the geographic origin of the component species (Everard and Moggridge 2012; Standish et al. 2013). Our study reveals the Salt River to have a diverse tree flora that includes cosmopolitan elements that derived from multiple biogeographic regions, cosmopolitan species that derive from the local biogrographic region, as well as the regional iconic species that remain provincial in distribution. Placing plants into multiple biogeographic categories can provide a viewpoint for river managers that expands beyond the simple dichotomy of 'native' and 'exotic'.

The landscape context of the river- adjacent to irrigated and landscaped urban and industrial areas- has shaped the riparian forests via spillover effects and establishment of naturalized cultivars. The riparian forests also have been shaped by restoration efforts including intentional planting (and weeding) of trees, increase in water availability, and geoshaping of the riparian corridor to create side channels, ponds, and terraces. The accidental wetting of the river channel via storm drain discharge, coupled with periodic winter flood releases, have further influenced the forests and created a diverse and novel riparian forest even at sites beyond the restoration project boundaries. While some urban-related changes in stream hydrology (including shifts from a groundwater to a surface water system) have favored a new suite of plant species, the presence of a semi-natural flood regime has maintained populations of several historical species.

The restoration efforts have influenced the community dominants and restored historic (as well as non-historic) tree species to the river. Although restoration plantings seemingly have restored locally extirpated species such as *P. pubescens,* continued monitoring will be needed to determine if second-generation individuals survive to reproductive maturity. And, given the high rates of stress and mortality of certain restoration-planted taxa (such as *P. fremontii*) from insufficient water and beaver activity, future studies are needed to determine the capacity for persistence of this and other species along this coupled natural and social system.

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Conflict of Interest The authors declare that they have no conflict of interest.

Appendix

Table 3 List of tree species, by floristic region, detected only along the river (left column), in both the river and the adjacent cityscape (middle column), and only in the cityscape (right column)

River only	River & City	City only
Celtis reticulata	Acacia constricta	Caesalpinia cacalaco
Salix exigua	Acacia farnesiana	Calia secundiflora
Salix gooddingii	Acacia greggii	Carya illinoinensis

Table 3 (continued)

River only	River & City	City only
	Chilopsis linearis	Ebenopsis ebano
	Parkinsonia aculeata	Fraxinus uhdei
	Parkinsonia florida	Fraxinus velutina
	Parkinsonia microphylla	Gleditsia triacanthos
	Populus fremontii	Lysiloma watsonii
	Prosopis glandulosa	Mariosousa willardiana
	Prosopis pubescens	Olneya tesota
	Prosopis velutina	Parkinsonia praecox
	Washingtonia filifera	Platanus wrightii
	Washingtonia robusta	Quercus virginiana
		Taxodium mucronatum
Nearctic		Vauquelinia californica
	Leucaena leucocephala	Jacaranda mimosifolia
	Nicotiana glauca	Schinus molle
	Prosopis chilensis	Schinus terebenthifolius
		Syagrus romanzoffianum
Neotropic		Tipuana tipu
	Melia azedarach	Bauhinia variegata
	Ulmus parvifolia	Casuarina equisetifolia
		Citrus
		Dalbergia sissoo
		Ficus microcarpa nitida
Indomalay		Pyrus calleryana
	Morus alba	Ceratonia siliqua
	Tamarix chinensis	Chamaerops humilis
	Vitex agnus-castus	Cupressus sempervirens
		Fraxinus oxycarpa
		Nerium oleander
		Olea europaea
		Phoenix canariensis
		Phoenix roebelenii
		Pinus canariensis
		Pinus eldarica
		Pinus halepensis
		Pistacia chinensis
		Platycladus orientalis
		Prunus persica
		Pyrus kawakamii
		Tamarix aphylla
		Trachycarpus furtunei
Palearctic		Ulmus pumila
	Acacia salicina	Acacia aneura
	Acacia stenophylla	Acacia pendula
	Callistemon viminalis	Brachychiton populneus

Table 3 (continued)

River only	River & City	City only
	Eucalyptus camaldulensis	Corymbia dallachiana
	Eucalyptus microtheca	Eucalyptus eryhrocorys
		Eucalyptus polyanthemos
		Eucalyptus sideroxylon
		Eucalyptus spathulata
		Eucalyptus torquata
Australian		Grevillea robusta
Afrotropic	Rhus lancea	

Table 4 Maximum recorded trunk diameter (at one meter above ground surface) for trees sampled along the urban Salt River. Also indicated is the geomorphic surface on which the tree was growing. Species are listed in order of decreasing maximum size

Species name	Diameter (cm)	Geomorphic surface
Washingtonia spp.	80	Storm drain channel
Populus fremontii	72	Storm drain channel
Salix gooddingii	67	Storm drain slope
Prosopis spp.	43	Terrace
Eucalyptus spp.	33	Storm drain channel
Parkinsonia aculeata	31	Storm drain channel
Celtis reticulata	26	Terrace (planted)
Leucaena leucocephala	25	Storm drain terrace
Tamarix chinensis	20	Storm drain slope
Acacia stenophylla	19	Storm drain channel
Chilopsis linearis	18	Terrace (planted)
Acacia farnesiana	16	Storm drain terrace
Acacia salicina	16	Storm drain channel
Parkinsonia microphylla	16	Terrace (planted)
Vitex agnus-castus	16	Storm drain, channel
Morus alba	14	Storm drain, channel
Parkinsonia florida	12	Storm drain, slope
Rhus lancea	10	Storm drain channel
Acacia greggii	6	Terrace (planted)
Ulmus parvifolia	6	Storm drain slope
Prosopis pubescens	5	Main channel margin (planted)
Salix exigua	4	Main channel
Acacia constricta	3	Terrace (planted)
Callistemon viminalis	3	Storm drain channel
Melia azedarach	2	Storm drain channel
Nicotiana glauca	1	Storm drain channel

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