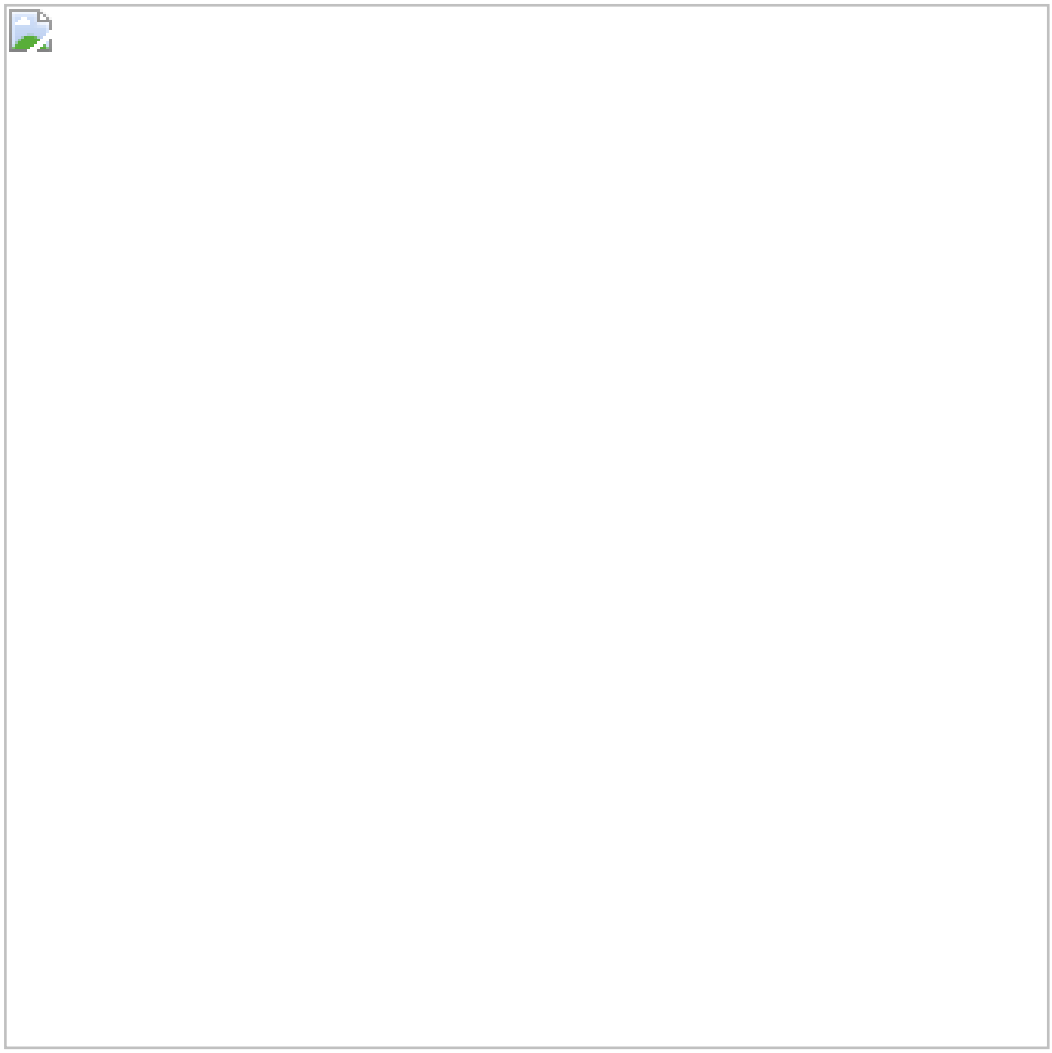

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An Approach for Creating Site-Specific Planting Palettes to Support Pollinators in the Sky Islands

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ABSTRACT: Restoration practitioners are challenged to continually modify and adapt their approaches to restoration by considering a greater diversity of restoration techniques and broader suites of plant species. Presented herein is a pollinator planting palette design approach that leverages botanical species richness to assist pollinator conservation efforts in the uniquely biodiverse Sky Island region.

KEYWORDS: pollinators, plant palette, restoration

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Introduction

The Sky Island region of southeastern Arizona and northern Sonora, also referred to as the Madrean Archipelago Ecoregion, is a unique montane complex that extends from subtropical to temperate latitudes and connects 2 major mountain systems—the Rocky Mountains and Sierra Madre.[1] The region exhibits exceptional biological diversity (species richness) and is recognized as a globally significant hotspot for many animals that serve as pollinators (eg, bats, hummingbirds, insects, etc). The region harbors the highest species richness of ants, mammals, and reptiles in North America[1] and is likely to have the most diverse bee assemblage in the world.[2]

Declines in insect species, including many groups of pollinating insects, have been widely documented and publicized. Sanchez-Bayo and Wyckhuys[3] identify the 3 most important contributing factors to be, in order of importance, habitat loss and conversion to agriculture and urbanization, pollution, and pathogens and introduced species. These factors are compounded by changing climatic conditions which can wreak havoc on the tight phenological connections between native plants and their pollinators. Changes in these phenological connections are not limited to invertebrates; in Arizona and Colorado, McKinney et al[4] documented the spring arrival of nesting broad-tailed hummingbirds in Colorado occurring earlier. The plant species they depend on for nectar is also now flowering much earlier than the bird's arrival, creating a shortened period of overlap where the blooms can provide resources for the birds, thereby jeopardizing breeding success. Similar observations have been made near Patagonia, Arizona, in the heart of the Sky Island region, where hummingbird researchers have confirmed phenological gaps in flower availability that have been implicated in the hummingbird nest failure and other potential impacts to migratory hummingbirds and ground nesting bees.[5]

Rationale for the Approach

The impact of declining insect populations and diversity ripples through many other animal taxa, and their conservation is foundational to biological conservation. A coalition of international research entomologists has recently described a roadmap for insect conservation and recovery that highlights many immediately needed actions, including the value of enhancing restoration and conservation programs and increasing landscape heterogeneity.[6] Plant materials can be used strategically to enhance this heterogeneity when diverse planting is emphasized. The "bottom-up" benefits of plant diversity on multiple tropic levels, specifically including pollinators, were demonstrated in an 8-year study in a temperate grassland ecosystem, where the authors found that "plant species richness had highly significant overall effects on the abundances of other organisms.[7]" Furthermore, Buckley and Nabhan[5] advocated for pollinator restoration in the southwestern United States, particularly in the US-Mexico desert border states. They highlighted the foundational importance of addressing issues at the base of the food chain to the overall ecological health of the region.

One of the most widely accepted best management practices for pollinator conservation is to include a diverse suite of native plant species, paying special attention to the temporal diversity of blooms, particularly in the early spring and late fall. For example, the Xerces Society recommends a minimum of 3 blooming nectar plants during each season to enhance monarch butterfly survival.[8] Buckley and Nabhan[5] emphasize the importance of considering the landscape in migration pathways and "nectar corridors." In the topographically diverse Sky Islands, these corridors may span significant elevational gradients and cross species' natural range limitations—these and other factors necessitate careful consideration of which native species are appropriate for a given site.

Various tools are available to guide restoration plant selection for pollinator conservation projects as well as for projects explicitly considering how to change which, when, and where species are being planted to respond to climate change. However, these tools are insufficient to develop site-specific plant lists for projects in the Sky Island region, with its hyperdiverse and heterogeneous flora. This is due in part to the complexity of topography, relief, and habitats[9,10] and the complicated phenological interactions between plants and wildlife due in part to a bimodal precipitation pattern that produces unique spring and summer bloom responses.

For example, the Federal Highway Administration collaborated with the US Forest Service, the Xerces Society, and others on an Ecoregional Revegetation Assistance Tool (http://www.nativerevegetation.org/era/#). Potential restoration plant species are searchable by US Environmental Protection Agency Level III Ecoregions. Although perhaps a helpful tool during initial planning stages, the output for the Madrean Archipelago Ecoregion is not detailed enough to create a site-specific plant palette; information regarding elevational range, vegetation community, and flower color is not included. However, once a site-specific palette is generated, this tool is a useful information source for pollinator benefits provided by specific species; furthermore, plant species are identified as useful as workhorse, revegetation, and/or pollinator species. Point Blue Conservation Science[11] has created tools to help practitioners consider climate-related aspects of plants when designing restoration planting palettes including tolerance to sun exposure, soil moisture conditions, "evergreeness," fire adaptation, and timing of flower and seed availability for wildlife (http://www.pointblue.org/wp-content/uploads/2018/12/CSRToolkit.pdf). However, these tools are specific to certain regions of California and not relevant to project sites in the Sky Islands.

A broad approach that uses high diversity of native plants supports a variety of pollinators. The biodiversity of the Sky Island region is what makes pollinator conservation so important and also the basis of an effective conservation strategy. The local nursery industry in southeastern Arizona is strong, vibrant, and diverse. There are several competent growers of high-quality, pesticide-free native plants that are available for conservation purposes, with nursery operators in the nonprofit sector (eg, Borderlands Restoration, Gila Watershed Partnership, and Desert Survivors Nursery), the business sector (eg, Nighthawk Natives and Spadefoot Nursery), and the government sector (eg, Bureau of Land Management [BLM] Seeds of Success, Pima County Native Plant Nursery, Natural Resources Conservation Service [NRCS] Tucson Plant Materials Center).

Pollinator Planting Palette Design Approach

The pollinator planting palette design approach described below can be used to choose an appropriate suite of native plants for installation in pollinator-focused restoration projects in urban or wildland settings. Emphasis lies in leveraging the region's diverse native flora to provide hyperdiverse, site-appropriate habitat patches that provide as many floral resources (pollen and nectar) as possible at any given time and ensuring maximum overlapping bloom periods. This is accomplished through the use of a bloom calendar, a common tool garden designers use to predict and describe when different species will bloom in their gardens. This concept is applied with the added lens of providing native floral resources for pollinators that are customizable to specific sites in the Sky Island region using 4 steps:

1. Inventory existing floral resources
2. Develop baseline bloom calendar
3. Select native plant species
4. Monitor and adaptively manage

The result is a tool that can be used to visualize a plant palette by its collective bloom phenologies and can be used to predict and evaluate whether there are periods during the year when a site could be augmented with additional species to provide better floral resources to support pollinators. This approach can be used to ensure a wider diversity of food resources are available during a particular time period and to extend the time period during which food resources are available. Maximizing diversity and overlapping bloom periods will be a benefit to many pollinator species in general; the approach can also be focused to ensure the inclusion of larval food plants for particular pollinator specialists as well.

Step 1: inventory

The first step is to inventory the plant species present onsite to create a baseline plant list. Annual species may germinate after either winter or monsoon precipitation. At many sites, there can be seasonally different suites of annual species as a result of this bimodal precipitation pattern. Best practice is to conduct multiple vegetation surveys to capture as many species as possible in the inventory. Appropriate timing for baseline inventories will vary depending on the elevation of the project area and precipitation patterns that year; for the low desert near Tucson, AZ (2400 feet), a spring survey (March-April) and a monsoon survey (August-September) are recommended. Inventories may be informal species lists or formal vegetation surveys depending on project scale, goals, and objectives. For instance, if this approach is being used to develop a large-scale restoration project that covers large acreage, a more thorough vegetation survey may be warranted than if it is being used to develop a community pollinator garden. Conditions and potential pollinator resources and/or ecological context at adjacent properties should also be noted, ideally through ground reconnaissance and with aerial imagery. Important contextual information includes location of riparian areas and other water resources;

land use type; management practices; and fragmentation and/or connection to natural areas.

Step 2: baseline bloom calendar

The species from the baseline inventory are entered into a spreadsheet that includes columns for each month of the year along with other information of interest such as elevation range, habitat, plant habit, flower shape, known benefits for pollinators, etc. Using the most current species descriptions available in the botanical literature, the spreadsheet is then populated with appropriate information. An example spreadsheet is shown in Figure 1, where species are ordered by flower color and first month of bloom. Flower color is noted across the months of bloom according to the species descriptions. For example, the listing for desert honeysuckle (*Anisacanthus thurberi*) shows entries for blooms from March to June and again in October and November. Because it has orange/red flowers, the cells of the appropriate months are filled red.

The best, most recent, and local information available should be used to develop the bloom calendar. For example, Bertelsen[12] provides updated floristic data, including elevation and phenology, for all species observed along a trail in a canyon on the south face of the Santa Catalina Mountains outside of Tucson, and Verrier[13] has also completed a very useful annotated flora of the Santa Catalina Mountains. Many projects will not have such accurate, updated, and local sources of information available. In that case, the best resource for information for the Sky Island region is the Arizona-New Mexico Chapter of the Southwest Environmental Information Network (SEINet; http://swbiodiversity.org/seinet/index.php), an online database of herbarium specimens and species descriptions. There are 10 regional networks of North American herbaria included in the SEINet database (http://symbiota.org/docs/seinet/).

Non-native species should be identified in the spreadsheet, and their contribution to floral resources of the site considered prior to plans for removal or treatment. For example, if a species is invasive and if it is the only plant blooming during a certain time period, its removal should be phased with establishment of native species that replace its bloom period. In some cases, non-natives, including ornamentals, may be providing valuable resources and considerations should be made for retaining them on site. For example, Rollings and Goulson[14] conducted field trials with more than 100 species of native and non-native ornamentals to measure pollinator visitation at a site in the United Kingdom. They found no difference in the number of insects visiting native versus non-native species; however, those native plants were visited by a more diverse suite of insect species.

Once these data are entered for all the species, the spreadsheet can be sorted by flower color (or some other attribute of interest) to develop a visual representation of floral resources on the site. It is important to take note of months with very few species blooming, as well as underrepresented flower colors. This information will guide species choice for augmentation.

Step 3: choosing species for augmentation

Additions to the baseline suite of species can be guided by referencing floral inventory lists of nearby locations or by creating a custom list. The SEINet contains the resources for either of these approaches. Lists for particular agencies and land management units are available for the National Park Service (NPS), US Forest Service, and BLM (http://swbiodiversity.org/seinet/projects/index.php). Other options include using the dynamic checklist feature (http://swbiodiversity.org/seinet/checklists/dynamicmap.php?interface=checklist) to generate a list of species documented within a given radius from a point on a map, or the dynamic mapping feature (http://swbiodiversity.org/seinet/collections/map/index.php) to build a list of species documented from within a polygon—or even an entire watershed. It is important to understand that species lists generated by the SEINet include only species documented from herbarium specimens, not all potential species that could occur on the site. Using a larger surface area or greater elevational gradient will yield more plant choices; general reconnaissance in the surrounding watershed can also be helpful to identify other potential species for consideration. Species considered for augmentation need to be vetted to ensure they are native and appropriate for the elevation and habitat type, as verified by the species description or personal knowledge.

It is likely that many more potential species will be identified through this approach than can be feasibly incorporated into the project. Below are some points to consider during prioritization for plants to include. Select species that:

- Address temporal gaps in flowering periods, as identified in the baseline bloom calendar with particular emphasis on spring, arid foresummer, and late summer/fall bloomers to address periods of critical pollinator need
- Increase structural complexity (when appropriate) by selecting underrepresented plant growth habits, eg, increasing the midcanopy shrub layer in a degraded riparian system to provide additional floral resources as well as cover and breeding habitat
- Are known host plants for larvae of insect pollinators, particularly species that have very specific host plants (eg, milkweed [*Asclepias* spp.] for monarch butterfly larvae)
- Are tolerant of climate stressors such as drought and fire
- Are available for use through propagation or seeding

The "symbiota key" feature can be used to filter lists in the SEINet by plant habit, longevity, flower color, and other attributes. It is the little golden key icon that appears adjacent to the list name. See Figure 1 for an example of a "full" palette of species that were already onsite (baseline) and augmented species selected for pollinator restoration.

Bloom Calendar for the Desert Research Learning Center Pollinator Garden (Tucson, AZ)
Newly added species indicated in bold font

Latin name	Elevation range	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fouquieria splendens	<5000 ft												
Justicia californica	<2500 ft												
Justicia candicans	<2500 ft												
Anisacanthus thurberi	**2000-5000 ft**												
Epilobium canum	4000-7000 ft												
Calliandra eriophylla	2000-5000 ft												
Penstemon parryi	**1500-5000 ft**												
Echinocereus fendleri	3000-8000 ft												
Chilopsis linearis	<5500 ft												
Mammillaria grahamii	2000-5000 ft												
Maurandya antirrhiniflora	**1500-6000 ft**												
Salvia greggii	5000-9000 ft												
Gossypium thurberi	**2500-8000 ft**												
Hyptis emoryi	600-3800 ft												
Glandularia gooddingii	**<5000 ft**												
Lycium fremontii	<4500 ft												
Asclepias albicans	<2500 ft												
Asclepias subulata	**<3000 ft**												
Asclepias linaria	**2600-5800 ft**												
Pectocarya recurvata	<5000 ft												
Stephanomeria pauciflora	<7000 ft												
Datura wrightii	**1000-6500 ft**												
Eysenhardtia orthocarpa	**<5500 ft**												
Oenothera casepitosa	**3000-7500 ft**												
Dasylirion wheeleri	3000-6000 ft												
Yucca elata	1500-6000 ft												
Asclepias angustifolia	**3500-5700 ft**												
Carnegiea gigantea	500-3500 ft												
Zinnia acerosa	**3000-7500 ft**												
Baccharis sarothroides	1000-5500 ft												
Berlandieri lyrata	**4000-7000 ft**												
Lagascea decipiens	**3000-4000 ft**												
Encelia farinosa	<3000 ft												
Tecoma stans	2900-5200 ft												
Cylindropuntia leptocaulis	<5000 ft												
Cylindropuntia bigelovii	1000-3000 ft												
Amsinckia intermedia	4000 ft												
Bahia absinthifolia	2500-5500 ft												
Baileya multiradiata	1000-3000 ft												
Ericameria laricifolia	3000-6000 ft												
Isocoma tenuisecta	2000-5500 ft												
Sphaeralcea ambigua	**<3500 ft**												
Ferocactus wislizeni	1000-4500 ft												
Atriplex canescens	**300-6500 ft**												
Bouteloua curtipendula	**2500-7000 ft**												
Leptochloa dubia	**2500-6000 ft**												
total number of species blooming per month		**9**	**13**	**21**	**30**	**32**	**29**	**25**	**27**	**26**	**22**	**13**	**10**

Figure 1. Example bloom calendar spreadsheet from the Desert Research Learning Center Project in Tucson, Arizona. Special emphasis is placed on early spring (February-March) and fall (September-October) blooming plants.

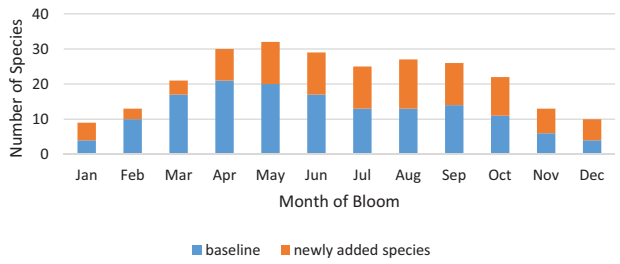

Figure 2. Potential number of species blooming by month in the Desert Research Learning Center Pollinator Garden, Tucson, Arizona.

Step 4: monitoring and adaptive management

Once native plants have been installed according to the developed palette, the spreadsheet can be used to monitor and manage the project for maximum diversity and overlapping bloom periods. A simple comparison of the installed palette to the baseline bloom calendar can produce assessments of site improvement through metrics such as the number of families and/or species; number of species blooming in each month (gross number and by flower color), with particular attention to improvement in the early spring and late fall; species known to be host plants for insects of concern, etc.

Information regarding elevation ranges and bloom periods used to construct bloom calendars, taken from historic species descriptions, may have shifted since those resources were published. In addition, the actual timing of flowering can vary annually and between sites. The accuracy of the spreadsheet can be improved for a specific project area by updating it with local phenological observations. Weekly or monthly observations of blooming species can be used to increase the accuracy and granularity of floral resources provided by the site, and also to guide subsequent species augmentation efforts.

At the Desert Research Learning Center (DRLC), an NPS facility in Tucson, AZ, this approach was implemented during a workshop in the spring 2019. The NPS personnel wanted to assess the pollinator garden that had been previously installed to see if there were additional plant species that could be added to increase the resources available for pollinators at any given time during the year. After the local flora was evaluated, 17 species were selected for augmentation that collectively increased the bloom potential during all 12 months of the year (Figure 2). In addition, 3 native milkweeds (*Asclepias* spp.) were included to increase the potential to support monarch butterfly larvae in the garden. The DRLC is both a research and teaching facility, making it the perfect location to observe and monitor patterns of blooming compared with the bloom calendar developed for the project.

Scalability of Approach

Although this approach was developed to address a technical gap in projects in the Sky Island region, it is adaptable to any location by using the appropriate regional floral data. Other North American regional herbaria networks included in the SEINet are as follows:

- Consortium of Midwest Herbaria
- Consortium of Southern Rocky Mountain Herbaria
- Intermountain Regional Herbarium Network
- Madrean Discovery Expeditions
- Mid-Atlantic Herbaria Consortium
- North American Network of Small Herbaria
- North Great Plains Herbaria
- Red de Herbarios del Noroeste de Mexico (northern Mexico)
- SouthEast Regional Network of Expertise and Collections (Southeast USA)
- Texas Oklahoma Regional Consortium of Herbaria

The plant palette design approach described here is compatible with all these other regional networks. This approach provides a tool for land managers, researchers, and scientific-minded gardeners who seek to provide pollinators with the floral resources that they need, at the time when they need them.

As climate change affects the annual cycles of plants and the wildlife that depend on them, restoration projects must become more sophisticated. Careful consideration of the plant species diversity and phenologies can facilitate restoration of degraded ecosystems and ensure food and shelter for as many species of pollinators as possible well into the future. The Sky Island region's diverse habitats, elevations, and species provide ample opportunities to implement and monitor this approach in restoration projects. Although this approach addresses specific issues and traits in the Sky Island region, the concept and steps outlined to design a plant palette are applicable to any restoration project that seeks to provide phenological diversity as resilience to climate change.

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Author Contributions

CC developed the approach described and oversaw its implementation in field and workshop settings.

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