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Food Chain Restoration for Pollinators: Regional Habitat Recovery Strategies Involving Protected Areas of the Southwest

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ABSTRACT: The steep declines over the last quarter century of wild pollinators in the Southwest among native bees, monarch butterflies (*Danaus plexippus* L.), hummingbirds, and nectar-feeding bats have come during a time of accelerated climate change, and are likely due to a variety of stresses interacting with climatic shifts. Nevertheless, there is mounting evidence that declining availability and altered timing of floral resources along "nectar corridors" accessible to pollinators involves climatic shifts as a serious stressor that had been previously underestimated. Longitudinal studies from both urban heat islands and rural habitats in Southwestern North America suggest peak flowering of many wildflowers serving as floral resources for pollinators is occurring three to five weeks earlier in spring than a century ago, leaving "phenological gaps" in nectar resource availability for certain pollinators. To avoid the threat of what A. Dobson (Professor of Ecology and Evolutionary Biology, Princeton University) and others have termed "food web collapse," a range of groups have initiated ecological restoration efforts in semi-arid zones that attempt to (a) assemble more resilient plant–pollinator food chains, and (b) hydrologically restore watercourses to ensure water scarcity will be less likely to disrupt re-assembled food chains in the face of droughts, catastrophic floods, and other correlates of global climate change. We recommend "bottom-up food chain restoration" strategies for restoring nectar corridors in protected areas on or near geopolitical and land management boundaries in all regions, but particularly in the Southwest or US-Mexico desert border states. We highlight binational and multicultural workshops facilitated to communicate about, and initiate restoration of, mutualistic relationships among plants, pollinators, and people to protected area managers on both sides of the border.

Index terms: climate change, food web restoration, phenological mismatch, pollinators

INTRODUCTION

There is now widespread scientific agreement that dramatic declines and changes in the ranges of both migratory and center-foraging wild pollinators of many kinds have occurred over the last quarter century (Buchmann and Nabhan 1996; Allen-Wardell et al. 1998; Goulson et al. 2015). What is less clear is the extent to which these precipitous declines have been primarily driven by, or secondarily accelerated by, climate change over the same time period (Inouye 2009; Abrol 2012; Martin 2015). Nevertheless, one survey of 1420 species of pollinators known to visit at least 429 kinds of plants predicts that climate-driven changes in flowering times will reduce available floral resources for at least 17% and perhaps as many as 50% of all pollinators, resulting in diminished nutritional diversity within their diets (Memmot et al. 2007). While specific predictions for climate change impacts are difficult to discern, there is concern for the fate of pollinators worldwide and the potentially catastrophic implications for human well-being.

Abrol (2012) asserts that the current "pollination crisis" may be due to climatic changes aggravating "disruption of the critical balance between the two mutually-interacting organisms" in several co-evolved plant–pollinator systems. Perhaps nowhere else in North America are these disruptions already so evident as in the Southwest or US-Mexico border states, where complex topography, habitat heterogeneity, and high plant diversity all contribute to a richer suite of pollinators than is found in other regions of comparable size in North America (Nabhan 2013). Already, the changes in the climate system in this region over the last 20 to 30 years are resulting in phenological shifts that could have significant implications for wild pollinators and their food webs (Bowers 2007; Crimmins et al. 2010; Fabina et al. 2010).

For those engaged in conservation biology and protected areas management, we must consider whether we have inadvertently narrowed public concern too much by advancing conservation largely through attempts to simply avert extinction and foster recovery of single imperiled species. Today, we have the opportunity and need to build broader public support for the more complex task of managing lands for the "conservation of mutualisms" (Nabhan and Fleming 2002) and "restoration of food webs" (Dobson et al. 2009). It may well be that Vitousek et al. (1997) are correct that climate change and other environmental disruptions are unraveling the "tangled bank" of complex ecological networks first described by Darwin from an evolutionary perspective. If so, it behooves us to try to manage whichever variables we can before ecological networks become simplified through the disruption of interspecific interactions in space and time and contribute to food chain collapse.

We propose here that ecological restoration efforts in and beyond protected areas must focus more on "food chain restoration," not only for plants and their pollinators, but more broadly for entire food webs that offer us natural capital and ecosystem services as crop pollinators surely do. Restoring food webs includes enhancing soil moisture through the restoration of hydrologic function using constructed water harvesting features, which in turn support restoration of native plant communities along with native soil fauna. These links in the food chain then support herbivores that feed predators, parasites, and pollinators.

Food chain restoration includes conserving existing native landscapes, along with actively replanting a wide range of native plant species in cultural or cultivated landscapes (Menz et al. 2011; Wratten et al. 2012). These efforts may restore critically important nectar resources at migratory stopovers and extend nectar bridges to shape long-distance corridors (Nabhan 2004). This, in fact, is the proposed strategy for tri-national monarch butterfly (*Danaus plexippus* L.) conservation efforts, which include planting both milkweeds for larval food as well as a wide range of nectar plants that are essential for migration (Nabhan et al. 2015). We will also briefly comment on what such a paradigm shift implies for transboundary conservation management of migratory corridors (Lopez-Hoffman et al. 2009), and for our efforts to train protected area managers on both sides of the US-Mexico border in pragmatic food chain restoration techniques.

Pitfalls of Disrupted Plant–Pollinator Interactions

Numerous field studies in North America—but particularly in the Southwest—have confirmed climate change as the likely driver of significant temporal and spatial shifts in flowering times for nectar resources critically important to pollination and pollinator health (Bowers 2007; Miller-Rushing and Primack 2008; Crimmins et al. 2010; Elwood et al. 2013). Pollinator specialists (such as oligolectic bees) and even generalists (such as polylectic bees) have the potential to suffer phenological disruption, with fitness consequences both nutritionally or reproductively, because of temporal and spatial shifts in flowering times (Waser et al. 1996; Tepedino et al. 2014; Rafferty et al. 2015). The implication is that reduced floral richness of nectar plants during the foraging and breeding season of certain pollinators could affect the nutritional status and limit the fitness or reproductive success of those pollinators, which will likely have disproportionate consequences for specialists (Memmott et al. 2007; Hegland et al. 2009).

Nevertheless, other studies (Memmott et al. 2007; Fabina et al. 2010; Forrest and Thompson 2011; Inouye 2011) offer differing perspectives on how much climate change is already triggering "phenological mismatches" between flowers and pollinators and how much of an impact such mismatches will have. Such mismatches occur when species that depend on one another become so separated in time or space that they can no longer interact. Hypothetically, such mismatches may generate cascading effects that ripple throughout a biotic community or landscape. In particular, ecological models of food webs developed by Fabina et al. (2010) now suggest that climate change-induced phenological shifts can have a major impact on communities even in cases where complete phenological mismatches do not occur. This may be because the mismatching of flowering times with the timing of pollinator emergence or arrival may be only one of many ways that plant–pollinator interactions may be disrupted by climate change (Table 1). Rafferty et al. (2015) are more direct, noting that they "expect non-symbiotic mutualisms to be more susceptible to phenological disruption."

There are numerous studies documenting phenological changes in vascular plants linked to climate change (Primack et al. 2004; Miller-Rushing and Inouye 2009; Davis et al. 2015; Munson and Sher 2015). Herbarium collections data drawn from the Sonoran Desert in Arizona across the last century illustrate the trend in earlier flowering of herbaceous perennials such as *Hibiscus denudatus* Benth. (Figure 1).

This shift of flowering by more than 30 days is representative of broader trends documented by Bowers (2007) for the majority of 100 Sonoran Desert species examined more broadly in Pima County, Arizona, over roughly the same time period. There was a 20 to 41 day earlier flowering from 1894 to 2004, with the decline of floral resources in late winter and early spring, just as many native bees and butterflies emerge, and migratory bats, hummingbirds, and mourning doves (*Zenaida macroura* L.) are returning to the Sonoran Desert uplands.

Although earlier flowering by three to five weeks does not categorically determine phenological mismatches with either migratory or year-round residential pollinators, it is significant enough to warrant further monitoring and management considerations. When coupled with extensive land use conversion and habitat fragmentation associated with human development, along with the spread of nonnative species, the nectar landscapes supporting these plant–pollinator interactions appear to become increasingly fragile.

And yet, until recently, the possible need for food web restoration in once-diverse wild landscapes has largely been overlooked in principles and practice of restoration ecology (Vander Zanden et al. 2006; Clewell and Aronson 2007; Mader et al. 2011; Menz et al. 2011). Research supporting restoration of pollinator communities in natural habitats has received much less emphasis than in agricultural settings (Menz et al. 2011), although there are examples from around the world for restoration of plant–pollinator networks (Forup and Memmott 2005; Winfree 2010; Devoto et al. 2012; Pocock et al. 2012). A search of the ISI Web of Science database for the search terms mutualis* and restor* reveals 418 papers, but when the search query is refined further to include the search term Ariz*, not a single result was returned. The term Mexico* added to the search terms yielded only two papers. While

Table 1. Examples of disruptions to plant–pollinator and plant–herbivore interactions.

Interaction	Case study	Potential impacts	Consequences	Reference
Pollinator larva feeding on specific host plant	Monarchs (*Danaus plexippus*) on milkweeds (*Asclepias* spp.)	Killing of milkweeds by glyphosate herbicides	Dramatic declines in monarch reach, reproduction & migratory success	Pleasants and Oberhauser 2012
Sequential mutualism of floral species to provide nectar and pollen to pollinator	Bear poppy (*Arctomecon humilis*) and other flowers in sequence with *Perdita meconis* and polylects	Changing competitive advantages of polylectic and oligolectic bees; bee parasites & local land use disruptions	Decline of specialized pollinators	Tepedino et al. 2014
Flowering time amplitude in relation to pollinator activity	Asynchronies between pollinating insects and various flowering shrubs & annuals	Climate change; urban heat island effect; parasites and pesticides	Lowered plant survival, reduced fertilization through pollination & lowered seed set; diminished nutritional value of foraging	Memmot et al 2007; Inouye 2009, 2011; Fabina et al. 2010; Forrest and Thompson 2011; Goulson 2015

the literature describing mutualisms and plant–pollinator interactions in this region is substantial, there are surprisingly few papers that broadly address the restoration of pollinator food chains in the Southwest in terms of management.

The following examples offer applications of the concept of food chain restoration for pollinators in both wild and developed landscapes within and adjacent to protected areas in the US-Mexico borderlands. These applications include how collaborative efforts can connect the threads of research, restoration, and adaptation into localized community based solutions, further tying protected areas to their surrounding communities, both human and more-than-human.

APPLICATIONS OF THE MANAGEMENT OF PROTECTED AREAS IN THE US-MEXICO BORDERLANDS

Bees and Migratory Pollinators in San Bernardino Valley, Arizona-Sonora

In southern Arizona along the US-Mexico border, conservation biologists and resource managers are working together across disciplines to develop a coordinated approach to "bottom up" restoration of pollinator food chains in one of the most diverse landscapes in the United States for native pollinators (Minckley and Ascher 2013; Nabhan 2013). It is a landscape where flowering times and longevity for many plants appear to be shifting due to water deficits triggered by climate change, aquifer depletion, and drought. Researchers have hypothesized that supporting nectar landscapes and facilitating species recovery must begin with hydrological restoration of critical breeding and migratory stopover habitats where plant cover has been degraded or denuded over time. The San Bernardino Valley in southern Arizona is one of these areas, where ongoing conservation efforts provide us with a glimpse of how the restoration of both hydrological and ecological processes contributes to pollinator recovery and persistence.

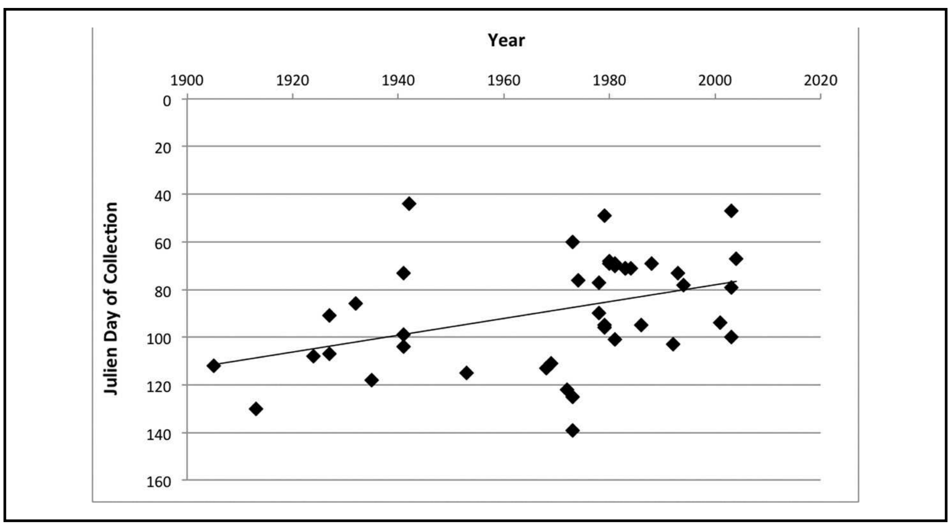

Figure 1. Flowering times of herbarium specimens of *Hibiscus denudatus* collected over a century's time in the Sonoran Desert in Arizona illustrate the trend of earlier flowering time.

Capitalizing on research to assess water harvesting through the use of both small rock structures known locally as "trincheras" and larger structures known as gabions, researchers are illustrating that bringing back water in desert landscapes can increase the availability of water and eventually increase the richness of plant species associated with these riparian habitats (Norman et al. 2014). At the San Bernardino National Wildlife Refuge, and on adjacent ranch land in Mexico, various US agencies (United States Geological Survey (USGS), Bureau of Land Management (BLM), and Fish and Wildlife Service) are working cooperatively at the watershed scale with the nonprofit, Cuenca Los Ojos Foundation (CLO), to restore large sections of the headwaters of the Rio Yaqui in the San Bernardino Valley.

The San Bernardino Valley has the highest bee diversity in the region and perhaps the nation, supporting more than 435 known species of bees, and serves as a critical linkage to nectar corridors between the United States and northwestern Mexico (Minckley and Ascher 2013). Land managers in these areas have begun a multiyear process with the end goal of restoring a range of beneficial pollinator plant species through both seeding and direct outplanting to support and enhance bee populations at sites throughout the region.

This interagency collaboration includes systematic seed collection efforts, first through the identification of those plant species that support pollinator communities, then with collection of both framework (critically important nectar species) and bridge species (resource rich species with broad application for restoration) (Dixon 2009). Seed collection ranges widely across the region to capture the genetic diversity of important species, in cooperation with national programs like the BLM's Seeds of Success (SOS). These collections are also sent to local and regional plant material production facilities, like the Madrean Archipelago Plant Propagation (MAPP) Center, where local community groups and agencies are collaborating to grow out important species for both direct planting in the protected areas and to be grown for regionally adapted seed stock.

The next step involves nonprofits like Sky Island Alliance (SIA) and Borderlands Restoration Habitat Network (BHN) to direct and guide volunteers to install the plants and reseed areas after hydrological restoration. Direct seeding has added dozens of species important to pollinator communities in the last couple years. These include numerous species of Asteraceae that have substantial importance in helping monarch butterflies build the necessary lipid reserves for their journey south, and *Asclepias,* or milkweed, to support larval food resources for when they return. These seed mixes include local species of *Salvia* and *Penstemon* to support migratory hummingbird habitat, and species of *Agave* to support many different pollinator species, but especially bats. We are learning that conserving migratory pathways for species like monarch butterflies, hummingbirds, and lesser long-nosed bats (*Leptonycteris yerbabuenae* ssp. *curasoae* Martinez and Villa) means coming to some understanding about our own essential mutualism and dependence upon them for the long-term survival of both the pollinator and human communities (Kearns et al. 1998).

Ongoing monitoring by USGS aims to characterize and quantify the recovery of vegetation at restoration sites and examine the long-term persistence of these efforts. The work hinges on public–private collaborations that involve researchers, citizen scientists, growers, agencies, and community groups working together to build the critical restoration infrastructure that will sustain long-term local efforts. Restoration work on CLO lands in Sonora, Mexico, has been ongoing for 30 years and further illustrates the possibility of restoring functioning river systems in semi-arid zones.

Hummingbirds in Harshaw Creek, Patagonia, Arizona

In similar fashion, several properties managed for wildlife conservation near Patagonia, Arizona, provide a lesson on how to restore food chains to support migratory hummingbirds, and possibly, native bees and bats. In association with participants in the international nonprofit Hummingbird Monitoring Network that she co-founded, avian ecologist Susan Wethington began to notice nest failure among hummingbirds during the hottest and driest time of the year on her own properties along Harshaw Creek. Southeastern Arizona is known to have 15 regularly occurring species of hummingbirds, and many of these are migratory (Wethington et al. 2005). At the same time, her husband, Lee Rogers, observed poor fruit set in their tree plantings in their two acre Tsintsuntsani Orchard on the same property; both noticed a lack of flowers outside of the cultivated fruit trees during early to mid-spring. Phenological monitoring through a USDA-WSARE (US Department of Agriculture-Western Sustainable Agriculture Research and Education Program) grant to the University of Arizona Southwest Center and to Borderlands Restoration confirmed phenological gaps in flower availability that potentially affected both migratory hummingbirds and native ground-nesting bees in their Tsintsuntsani Orchard (Figure 2A).

These observations were suggestive of a changing nectar landscape that might be having profound consequences for the breeding and nesting of hummingbirds, along with the availability of bee pollinators for fruit tree pollination. In response to these data, Borderlands Restoration and the University of Arizona WSARE project helped Wethington and Rogers, as well as managers of six other on-farm restoration sites nearby, to identify "pollinator-attracting perennials" that helped bridge these phenological gaps in order to maintain the supply of nectar and pollen for birds, bees, and other pollinators (Figure 2B).

In addition to managing the new WSARE-supported hedgerow plantings on the orchard's edge, Wethington and Rogers have worked with Borderlands Restoration to install water-harvesting structures throughout their property that hydrologically support additional outplanting of thousands more native plants. The hope is that these plants will fill nectar gaps and provide nectar throughout the year for hummingbirds. Continued monitoring of the restoration sites has illustrated many of the pitfalls associated with restoration projects, including poor survival of outplantings in years marked by highly variable rainfall. Even with short-term setbacks, these efforts

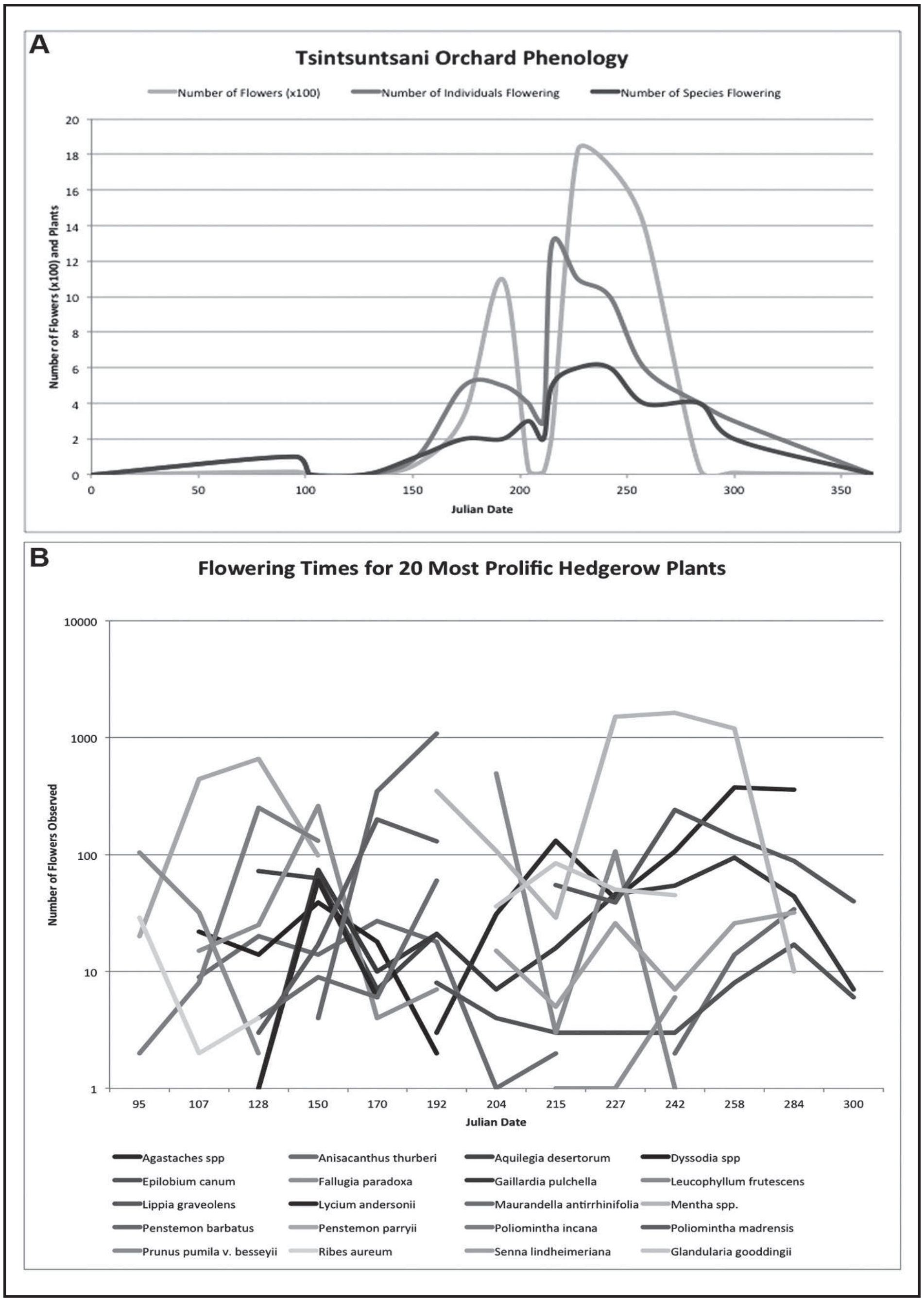

Figure 2. A (top): Pre-treatment phenology of the Tsintsuntsani Orchard in Patagonia, Arizona, illustrating the phenological gaps in the nectar landscape. B (bottom): Restoration efforts were made using 20 different pollinator-attracting perennials from the families Asteraceae, Fabaceae, Grossulariaceae, Lamiaceae, Onagraceae, Plantaginaceae, Rosaceae, and Verbenaceae that helped bridge the phenological gaps in the nectar landscape.The Figure 2B legend is included to provide species detail more than species phenology (difficult to distinguish in greyscale). (Source: G. Nabhan and C. Weaver)

have developed sufficient local capacity for doing further restoration. Increases in base flow observed in Harshaw Creek—anecdotally attributed to the water harvesting structures—mean additional planting and seeding efforts can continue to fill the gaps in the nectar landscape for years to come.

These efforts attracted the attention of the US Forest Service (USFS) who, in cooperation with the USGS, have installed stream gauges downstream to quantify the impacts of the low-tech rock structures on water quantity, quality, and persistence. Local youth are being trained in restoration techniques and have constructed water harvesting structures and planted plants at the site, along with installing bee boxes at the site, to improve the availability of bee habitat for nesting and reproduction. All these efforts are still being closely monitored by the Hummingbird Monitoring Network and by citizen scientists at Borderlands Restoration. Early results indicate that while gaps do remain in the nectar landscape, it is well worth the effort to gradually "fill in" those gaps to support the 15 species of hummingbirds known to the region (Wethington et al. 2010). The next steps are to persist in these efforts and continue to add nectar resources to the landscape over coming years.

Lesser Long-nosed Bats at Coronado National Memorial

Thirty miles east of Patagonia in Coronado National Memorial along the Arizona/Sonora, Mexico, border, park managers guided by Arizona-Sonora Desert Museum biologists are restoring habitat for lesser long-nosed bat populations. They seek to sustain the "nectar corridors" required by this endangered species by growing and restoring the *lechuguilla* agave (*Agave palmeri* Engelm.) on National Park Service lands to serve as critical food resources along known bat flyways that straddle the US-Mexico border (Nabhan and Fleming 2002; Ober and Steidl 2004).

Using mitigation money from the Department of Homeland Security to offset losses of agave due to the construction of the border fence, managers are building local capacity to grow large quantities of agaves indefinitely, working with both local and regional nurseries to increase the available supply. The challenge presented by long-lived species like agave is building a genetically appropriate and readily available supply for regional restoration efforts, which means growing plants three or more years before planting. This necessitates a commitment on the part of managers for long-term engagement with local communities and nurseries to support growing the hundreds of thousands of plants that are needed. In the case of Coronado National Memorial, it also includes the involvement of local elementary school students in the entire cycle of restoration, from learning about the lesser long-nosed bat through classroom lessons, to harvesting seed and growing plants, to eventually visiting the park and planting out the next generation of plants.

The agaves used in these outplantings are propagated from seed collected at the park and from sites nearby in the Madrean Archipelago region. Park managers are now working on plans to plant at multiple park units and at hundreds of other sites throughout the region. The intention is to create a network of agave pollinator habitat that can offset losses from landscape fragmentation and development, overharvesting for mescal production, and changes in flowering resources that are available to migratory pollinators due to climate change (Nabhan 2004). This network of habitat is expanded as more agaves are grown and included as a commonly available species for planting adjacent to hydrological restoration efforts.

Building long-term restoration capacity puts people to work in local communities growing the plant material that takes years to fully mature before being put back into the wild. Being able to integrate restoration efforts from the restoration of hydrological systems in protected areas along the border, to the development of a wide range of locally supplied and adapted pollinator plant material, helps stitch the land back together to support pollinators and people.

FOOD CHAIN RESTORATION STRATEGIES FOR PROTECTED AREA LANDSCAPES IN THE SOUTHWEST

Managers in the US National Park Service (NPS) are scaling up from these localized examples in borderland areas to attempt a coordinated regional approach to restoring habitats along pollinator corridors. As one example, the Southwest Exotic Plant Management Team (SWEPMT) coordinates restoration of exotic plant-invaded areas in 55 national park units spread across six Western states. The SWEPMT cooperates with a wide range of land management agencies, and nonprofit, limited profit, and private groups to restore native biodiversity and the nectar landscape in ways that support monarch butterflies and other migratory and transboundary pollinator populations.

Beginning in 2014, the SWEPMT began systematically restoring exotic plant infested areas in the parks to increase native habitat for flowering plants that directly supports pollinator recovery and other ecological services and values. These efforts include systematically identifying both framework and bridge species of importance, collecting seed and increasing the available seed supply of critical pollinator-supporting species, and developing collaborations with researchers to inventory and monitor efforts to learn about what works, which improves the SWEPMT's ability to adaptively manage additional restoration efforts in line with other national efforts (Zavaleta et al. 2001; DOI 2015).

In this centennial year of the NPS, the restoration of food chains for pollinator recovery is a natural fit for celebrating the parks and their legacy of protecting valuable ecological places and processes in alignment with NPS policies on ecological restoration (NPS 2006). Already in six national park units in southeastern Arizona, large pollinator gardens are being designed and implemented by managers to serve specific park goals for both vegetation and pollinator restoration and to contribute to the broader goals identified in the national pollinator memorandum released by the Obama administration (Obama 2014). This stepping stone corridor approach has been identified as a first step for restoration programs connecting pollinator networks and diverse pollinator communities (Menz et al. 2011). Seed collection to support additional gardens has been initiated in four states and at over a dozen parks. Pollinator inventory efforts have been initiated at several parks, including Tumacácori National Historical Park, where a pollinator bioblitz connected local advocacy groups with taxa experts to establish baseline monitoring data for restoration efforts there using iNaturalist to connect with other citizen science efforts.

Since many protected areas are becoming island-like sanctuaries of native vegetation in the sea of anthropogenic change surrounding them, these integrated efforts focus on the point of contact between protected areas and the wildlands they inhabit. In Southwestern ecosystems, many exotic plants are wind-pollinated (i.e., buffelgrass (*Pennisetum ciliare* L.), cheatgrass (*Bromus tectorum* L.)), and while some flowering exotic plants might have limited benefits to generalist pollinators by providing additional floral resources, the decline of native biodiversity and flowering plants has subtle, and potentially more, far-reaching negative impacts on pollinator health (Aizen et al. 2008; Potts et al. 2010; Burghardt and Tallamy 2015).

Restoration of these exotic plant infested areas offers a unique window of opportunity to turn protected areas into focal points for food web restoration for pollinators. Actively tending disturbed areas near the core of visitation also takes advantage of the unique interpretive skills of the NPS to communicate to the public the necessity of food web restoration for pollinators. From a land management perspective, using park infrastructure as a focal point addresses what is often a core problem in exotic plant management in terms of vectors for both new introductions and for managing the vegetation in disturbed public areas (Welch et al. 2014). Concerted restoration operations to deal with exotic plants and restore the nectar landscape in these high traffic zones can have immediate and multiple benefits for supporting the pollinator food chain (Wratten et al. 2012; Morandin and Kremen 2013; Dicks et al. 2015).

To accomplish larger scale restoration efforts, here are several strategies being considered or implemented:

(1) designing and building pollinator gardens, or way-stations, augmenting existing flowering plants in all parks and protected areas along major known nectar corridors (the I-35 milkweed corridor effort, which follows this north–south interstate running through the Midwest, is one such example, as are the nascent efforts to connect hummingbird and bat flyways and parks across the Southwest).

(2) working with researchers to develop and to make available the best bilingual information for park and protected area managers about incorporating nectar plants

into resource management decisions, to provide publications and interpretive material for diverse audiences, and to conduct monitoring that will feed critical information back to protected area managers to adaptively manage restoration efforts

(3) developing wide ranging partnerships and collaborations to integrate efforts into regional, national, and international efforts

(4) expanding the capacity to grow and increase availability of a wide range of locally adapted and sourced pollinator plants in the form of both seed and as nursery material, in ways that provide unique restorative economic opportunities while simultaneously supporting pollinator health.

Expanding Binational and Cross-cultural Training

One implication of our work with migratory pollinators is that conservation actions need to focus on weak links across entire "nectar corridors," not just in protected areas that may offer "stepping stone" refuges for stopover along the way. Because careful management of a single site along a migratory corridor is obviously insufficient to sustain the entire migratory phenomenon, regional efforts have emphasized cross-cultural training to achieve more harmonious land uses, restored habitats, and comparable monitoring among protected areas on both sides of the U.S.-Mexico border. This includes working with agencies, agricultural interests, NGOs, and communities on both sides of the border.

In 2015 alone, the authors organized, facilitated, or instructed protected area managers from Arizona, New Mexico, Texas, Sonora, Chihuahua, Coahuila, Nuevo Leon, Tamaulipas, Queretaro, and Guanajuato in milkweed seed collection, propagation, outplanting, monarch egg and larval host plant monitoring, and adult tagging. These workshops have addressed the need to look beyond milkweed alone and devise restoration efforts that support the whole lifecycle of not only monarch butterflies, but of all migratory pollinators. Other efforts have also fostered phenological data sharing through the Nature's Notebook social media platform of the National Phenology Network, through iNaturalist, and through Naturalista, the Spanish language platform of iNaturalist.

Training workshops have occurred in the Monte Mojonos Biosphere Reserve near Alamos, Sonora, Big Bend National Park, the Coronado National Forest, and at the Natural Resources Conservation Service's Los Lunas Plant Materials Center in New Mexico. Such trainings are now being extended to indigenous areas of binational borderlands, with certificate courses and workshops planned for communities where Seri, Yaqui, Mayo, O'odham, and Kickapoo families live along nectar corridors for migratory pollinators. In the United States, horticulturalists are working with the Intertribal Nursery Council and learning from successful tribal nurseries all across the western United States. The hope is to develop a coordinated response through open information sharing and by providing training opportunities that link us all into an inclusive community of practice.

CONCLUSIONS

Prior to 2015, the conservation of pollinators in or between protected areas had focused more on the population biology of individual species, rather than on managing ecological interactions or "keystone relationships" (see Nabhan and Fleming 2002). We believe there is an emerging paradigm shift toward restoration of ecological interactions, away from single species approaches and toward the restoration of mutualisms that occur along binational "nectar corridors." Collectively, we need not limit this to mutualistic interactions among plants and pollinators alone, but by necessity should include people and pollinators, and people and landscapes as emerging mutualisms to restore. Bridging the gaps that exist between current extractive human economic structures and restoration has the potential for bringing wholly new economic systems into existence. Restorative economic structures can benefit local communities and reinforce their relationship with protected areas by strengthening the role that protected areas play in promoting the connectivity of pollinator food chains and nectar landscapes all across the continent.

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