Restoration Notes

Restoration Notes have been a distinguishing feature of *Ecological Restoration* for more than 25 years. This section is geared toward introducing innovative research, tools, technologies, programs, and ideas, as well as providing short-term research results and updates on ongoing efforts. Please direct submissions and inquiries to the editorial staff (ERjournal@aesop.rutgers.edu).

Restoration Map: A Web-based Tool for Spatial and Participatory Adaptive Management of Ecological Restoration Projects

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Managing ecological restoration projects often requires coordination and communication among diverse stakeholders such as landowner agencies, restoration contractors, volunteer groups, and partner conservation organizations (Leach et al. 2002). Web-based Geographic Information Systems (GIS) are increasingly being used for collaborative decision-making among stakeholder partnerships (Dragićević and Balram 2004). However, these systems often require licensing fees and technical expertise that are prohibitively expensive, especially to some restoration contractors, nonprofit, and volunteer organizations. To encourage collaborative management of restoration projects, there is a need to develop accessible and open GIS-based decision support tools that integrate the spatially explicit management history of ecological restoration projects with multiple sources of species monitoring data. To address these challenges in the context of ecological restoration in the Chicago, IL, USA area, we used open-source and freely available software to develop a web-based decision support tool called Restoration Map.

Restoration Map (restorationmap.org) is a web-based geospatial application to help plan, implement, and assess ecological restoration projects within Chicago Wilderness natural areas. Use of the map is completely free to any user, and the source code is freely available under the GNU General Public License (Free Software Foundation 2007). By integrating long term monitoring data to provide feedback on the effects of restoration work, the map is designed to enable the adaptive management of restoration projects. Adaptive management is an iterative, cyclical approach to management that incorporates experimental results into an evolving management plan (Walters and Green 1997, Morghan et al. 2006, Williams 2011). By overlaying monitoring data with management data, Restoration Map encourages users to follow the adaptive management cycle: the user visually explores existing management trends while planning future work, then documents the work on the map as it is implemented, and finally assesses the outcome and adapts future plans. Data from the Bird Conservation Network eBird (BCN 2012; Sullivan et al. 2009), the Calling Frog Survey (CFS 2013), region-wide vegetation surveys, site-specific vegetation monitoring, and various bird and weed inventories (Habitat Project 2013) are available as map layers that can be overlaid with spatial management history data such as prescribed burns, seed applications, or weed control. The visualization of these datasets together enables the user to explore trends previously difficult to detect, such as correlations between the frequency of prescribed burns and changes in the number of birds of conservation concern (Figure 1). Restoration Map also includes map layers representing soil data (Soil Survey Staff, NRCS, USDA 2013) and U.S. Fish and Wildlife Service wetland data (USFWS 2013). Google Earth (Google Inc. 2013) historical imagery visualizes the impact of management history through changes in the satellite imagery.

Use of Restoration Map is designed to be straightforward for non-technical users; any authorized person (staff, partner agency, contractor or volunteer steward) can simply draw new management history map layers or import GPX or KML data. These map layers are public by default, but can be set private to protect untested options or locations of rare species. Data openness and sharing are encouraged by making all data available for export in KML or shapefile formats. Reports can be generated and downloaded as spreadsheets. Furthermore, the monitoring datasets are integrated using a modular plug-in design to enable the map's administrators to easily add or remove monitoring components. This allows Restoration Map to potentially be set up for other regions that, like the Chicago area, have multiple, region-specific monitoring datasets.

Restoration Map was implemented using all open-source or free software. On the map's webserver is a standard

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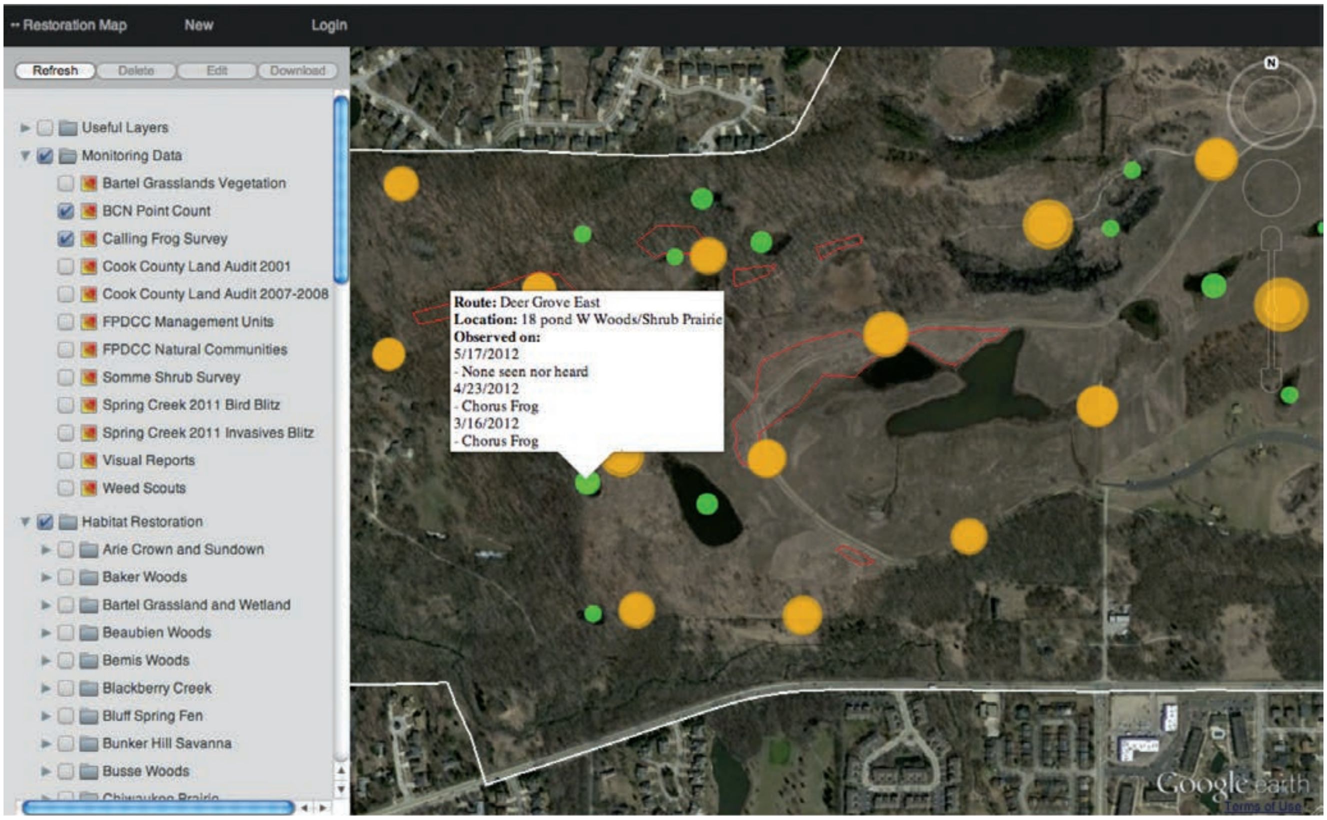

Figure 1. Some of the data available on Restoration Map for Deer Grove East Forest Preserve, Cook County, Illinois. The red polygons show areas that were burned in 2011. These appear as dark polygons in the black and white print version; please see the online version for the much clearer color version. Users can quickly visualize how the plants, birds, and frogs are responding to burning over time. The larger, yellow dots show bird monitoring locations. The smaller, green dots are frog monitoring locations, where detailed results are available with a click of the mouse. The size of each dot is proportional to the number of sightings at each location.

LAMP software stack (Ware 2002); data is kept in a MySQL database accessed using server-side PHP code. The application uses Ajax (Garrett 2005) to pass data asynchronously back and forth between the client and the server (providing a seamless user experience) using the JavaScript library jQuery (jQuery Team 2013). The kmltree navigational widget (MarineMap Consortium 2011) is used to interact with the Google Earth API (Google Inc. 2013). To use the map, users need to install the Google Earth plugin in their web browser. The source code for Restoration Map is publicly available in a Git version control repository (Hamano and Torvalds 2005) at github.com/wf8/restorationmap.

Restoration Map is successfully being used to refine Chicago-area restoration land management. By documenting management experiments and evaluating results through diverse monitoring data, some of the highest quality natural communities of the Forest Preserve District of Cook County (68,000 acres), Openlands, and other agencies are being adaptively managed. As of September 2013, stakeholders have entered over 2300 map layers representing management work and experimentation in Chicago-area restoration projects. Some sites include 13 years of detailed management history (controlled burns, invasives control, revegetation, and plant, bird, and other monitoring data).

At Audubon, we are using Restoration Map in all phases of management. For example, after an on-site meeting among partners to plan shrubland habitat restoration, we used the map to sketch the areas where shrubs will be planted, share this draft with the team, and incorporate partners' revisions into a final management plan. At a site where work has been ongoing for 12 years, we used Restoration Map to overlay data from bird monitoring and vegetation monitoring with the locations of management actions (burning, seeding, and herbiciding). The map helped us to formulate hypotheses about the effect of more frequent burning and seeding on the quality of the vegetation and the diversity of birds. The map also allowed us to detect hotspots of tall goldenrod (*Solidago altissima*) and to adjust mowing strategies accordingly. Finally, Audubon conducts regular monitoring "Blitzes" that send citizen monitors to hundreds of locations to look for birds or take vegetation data. Restoration Map allows us to easily communicate the monitoring locations to the volunteers and allows the monitors to readily communicate their

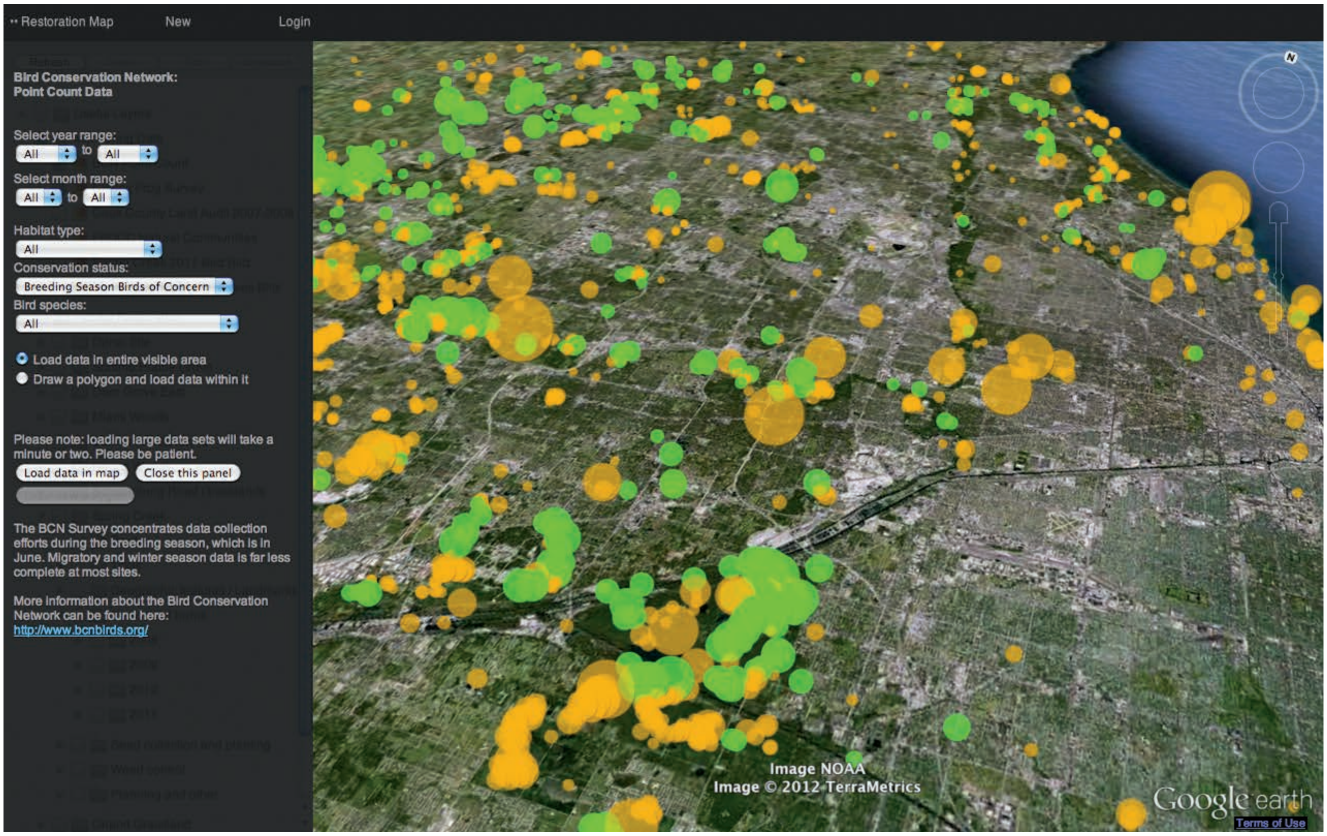

Figure 2. By providing a platform for sharing data among citizen science monitoring programs, landowner agencies, restoration contractors, and partner conservation organizations, tools like Restoration Map can contribute to a regional assessment of the work being done to restore ecosystems. The yellow and green dots (please see the online version for color) represent bird and frog monitoring locations, respectively. The size of each dot is proportional to the number of sightings at each location.

findings to us and the broader conservation community (Figure 2).

We believe Restoration Map represents a new and useful tool for transparent, collaborative and spatially explicit adaptive management of conservation projects. By enabling stakeholders to share data on a regional-level, tools like Restoration Map can contribute to a landscape-scale assessment of the work being done to restore ecosystems.

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Restoring Conservation Nodes to Enhance Biodiversity and Ecosystem Function along the Santa Clara River

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Figure 1. The Santa Clara River in Ventura County, CA, USA. Photo credit: Melinda Kelley for The Nature Conservancy.

The Santa Clara River watershed in Ventura County features southern California's last non-channelized and least ecologically disturbed major river system (Figure 1). The watershed encompasses an area of great biological richness and lies within a globally significant biodiversity hotspot (Myers et al. 2000) along the California South Coast. The resources and habitats within the Santa Clara River watershed are increasingly threatened by an array of problems related to human population growth, land-use conversion, and modifications to the river's natural hydrology. To address these threats, The Nature Conservancy (the Conservancy) has been working for the past 15 years to protect intact habitat within the watershed, and enhance riparian biodiversity through restoration projects.

The concept of protecting large landscapes to maintain biodiversity has been one of the key applications of island biogeography theory (MacArthur and Wilson 1967) to conservation practice. Larger wetland restoration projects have been shown to have faster rates of biological, hydrological, and biochemical recovery, and to be more self-sustaining over time (Moreno-Mateos et al. 2012). The Conservancy is applying these principals to the conservation on the Santa Clara River by hypothesizing that the riparian corridor and floodplain would best support native habitat through the protection of larger contiguous sections of riparian habitat, as opposed to several smaller individual parcels dotted along the river's main stem.

Within the field of restoration ecology, this approach has been referred to as the "string-of-pearls" approach, where protected sites along riparian corridors or terrestrial habitat that is surrounded by urban areas or agricultural lands are ecologically restored to produce an integrated system of discrete habitat blocks, much like a string of pearls. These habitat blocks should be close enough together to facilitate wildlife movement and support ecosystem processes. Through land acquisition, the Conservancy has managed to protect a string of habitat blocks along the Santa Clara River. Here we provide an overview of the Conservancy's strategic land protection efforts, and describe the multiple benefits to be derived from the shift that the organization is currently making in this geography—from solely acquiring lands, to planning and implementing restoration.

In 1992, the Conservancy completed a bioregional conservation analysis for the South Coast Ecoregion of California (TNC 1993) to identify large areas with generally intact natural habitats that support the biodiversity of the ecoregion. Due to the scarcity of wetland habitats in Southern California (Zedler 1996), and the fact that 38 special status species are found within the Santa Clara River watershed, the river and its tributaries were identified as a conservation priority for the Conservancy. Additional assessments of the Santa Clara River conducted in 1999 and 2001 identified four priority areas or "conservation nodes" where conservation efforts would be focused (Figure 2). These plans were further refined with completion of upper and lower river Conservation Action Plans (TNC 2006, 2008), and an additional conservation node was added in 2012 to ensure protection of a rare habitat type in an area of the river that is intermittently dry. Unlike many other rivers, the riverbed of the Santa Clara is almost entirely privately owned. Therefore, the Conservancy's initial decade of work focused on protecting the priority conservation nodes by acquiring land from willing sellers. Despite strong county growth controls, prime farmland in Ventura County can exceed $80,000 per acre, and developable land can be worth several times that amount. Only land with little or no economic value can be acquired in large blocks needed to achieve effective conservation. For

Figure 2. Map of restoration nodes along the Santa Clara River in Ventura County, CA, USA. Properties currently owned by The Nature Conservancy are outlined in white. Nodes are circled and names are provided in italicized font. Place names are shown in normal font. All boundaries are approximate.

example, land within the floodway of the river is highly regulated by state environmental agencies and is impractical to develop because of the risk of destructive flooding. Therefore, private lands in the floodplain are of little or no use to their owners, and the Conservancy is typically able to acquire these parcels of riparian habitat at $750 per acre.

In some cases, properties within the floodway include adjacent farmland. Even if the property owner is willing to sell the entire parcel, high farm land values can cause the acquisitions to be very expensive. Furthermore, agricultural zoning laws specify large minimum lots sizes, so subdividing the land is often not an option. To address this issue, the Conservancy asked Ventura County to change the law to allow for the creation of substandard lots if they were restricted to habitat conservation in perpetuity. The county agreed and passed a conservation subdivision ordinance which has permitted the conservation of land that would have otherwise been impossible to acquire.

To date, the Conservancy has acquired over 3,300 acres along the Santa Clara River, constituting 15 river miles. Some of the priority conservation nodes now contain more than 1,000 contiguous acres of land in conservation ownership, and many of these would benefit from large scale restoration work. As such, the organization is shifting from primarily acquiring land to planning and implementing ecological restoration on the Santa Clara River. Specifically, in addition to several small weed removal projects, 250 acres of habitat restoration are planned for Conservancy property within the Hanson node over the next five years.

In 2011, a historical ecology study of the Santa Clara River and other areas of Ventura County was completed by the San Francisco Estuary Institute (SFEI) (Beller et al. 2011). This analysis was an attempt to understand the historical ecological patterns and hydrological dynamics of habitats along the river prior to the wide-spread human use and modification of the region that occurred with European settlement. Examining SFEI's maps has allowed the Conservancy an opportunity to test the suitability of our node-based conservation and restoration strategy. Each of the nodes corresponds spatially with a site along the river that was mapped as having ecologically important habitat in the past. Several of the nodes are in places that were perennially wet and supported large swaths of riparian forest. In these nodes, where adequate water resources still exist today, restoration of vegetation with the end goal of recreating riparian forest may be more feasible, and more cost effective, than a similar end-goal in locations that historically supported other forms of vegetation.

In order to restore riparian forest on the Santa Clara River, non-native invasive species must be managed. Arundo (*Arundo donax*) is an invasive non-native plant that crowds out native vegetation, alters river hydrology, reduces the natural resistance of the riparian zone to fire, and negatively impacts the suitability of habitat for a variety of special status riparian species (Giessow et al. 2011). Because of the major role that weedy species like Arundo play in altering ecosystem function and reducing habitat suitability, significant effort has been expended to plan for their removal within the Santa Clara River watershed. While a watershed-wide control effort is probably the most effective long-term strategy for elimination of these species, smaller and more targeted removal efforts can enhance the quality of habitat along the river in the short-term, providing habitat for sensitive migratory bird species such as the Least Bell's Vireo (*Vireo bellii pusillus*). The restoration nodes approach is helping the Conservancy maximize the return on investment when completing small invasive species removal projects on the Lower Santa Clara River by guiding removal efforts to lands located within the conservation nodes. This ensures that the effort expended in weed removal results in the enhancement of larger blocks of contiguous native habitat. It also allows the Conservancy to create defensible Arundo-free zones containing high quality native habitat within the restoration nodes that that can serve as propagule sources for native plants and core habitat for a broad suite of native species. For example, avian monitoring shows that along the Santa Clara River, patches of native riparian habitat have the largest populations of sensitive species.

In addition to invasive species, climate change is one of the most critical threats to biodiversity (IPCC 2007). Landscapes that contain nodes of protected habitat are more likely to be resilient to climate-induced perturbations over time, such as increased periods of drought, flood, and fire. Restoring the conservation nodes along the length of the Santa Clara River will not only provide refugia for species adapting to a changing climate but will also allow the river and floodplain to perform a number of ecosystem services. These services include soil stabilization, water filtration and retention, and the retention of flood waters. Increased development pressure combined with climate variability can place significant pressure on the services once provided by river systems. A recent economic model of floodplain development on the Santa Clara River showed that with just 80% development of the floodplain, downstream flooding would increase by over 70% and damages would rise by over one billion dollars (VCWPD 2011). Protected and restored nodes of habitat along the Santa Clara River will hold and slow flood waters, providing natural flood control. This multi-benefit approach to conservation is proving to be not only cost effective but will ultimately enhance ecological resilience of the river and floodplain.

In conclusion, the Conservancy's property acquisition efforts along the Santa Clara River have already resulted in the protection of thousands of acres of riparian lands within priority conservation nodes. The organization has now begun to selectively plan for and implement restoration of degraded habitats within the nodes by controlling invasive species. The two-step (acquisition/restoration) approach, when applied selectively to lands within priority conservation nodes, will preserve and enhance the overall biodiversity and ecological function of the river, while also providing ecosystem services to human communities nearby.

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Monitoring Michaux's Sumac Requires More Systematic Approaches

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Restoring a species requires knowledge of its population levels, geographic distribution, and long-term monitoring. This situation is especially true for Michaux's sumac (*Rhus michauxii*), a federally-listed endangered shrub and one of the rarest shrubs in the southeastern United States (Fleming and Ludwig 1996). Most of the current geographic range lies in the lower Piedmont and upper Coastal Plain of North Carolina, although the largest concentration of plants is at Fort Pickett, Virginia (Emrick and Jones 2008). Since time of discovery by Andre Michaux in 1794 in Union County, NC, Michaux's sumac has always been rare (Boynton 1901, USFWS 1993). Habitat loss and degradation from urban development and current policies of fire suppression have exacerbated the situation, allowing other woody plants to establish and making many locations too shady for Michaux's sumac to compete successfully for resources (USFWS 1993).

Like other sumacs, Michaux's sumac is maintained by periodic disturbance (USFWS 1993, Emrick and Jones 2008). It is distinguished from other native sumacs of eastern North America by short stature (0.3–0.9 m), coarsely serrated or crenated leaves, and densely pubescent twigs and leaves. At most locations, Michaux's sumac consists of single-sex clones (USFWS 1993). Reproduction is essentially all asexual from root sprouts (Braham et al. 2006). As an endemic species with a dioecious flowering habit and geographic barriers between populations, sexual reproduction of Michaux's sumac is rare; a situation that severely limits the natural expansion of the geographic range and confounds restoration efforts.

The U.S. Fish and Wildlife Service (1993) reported that over the last 200 years Michaux's sumac had been found at 31 locations in North Carolina, but only 20 locations still contained plants in a 1993 survey. Nearly one-half of the locations in North Carolina are found in only one county (Richmond). About one-half of the known locations are along roads or rights-of-way. Because Michaux's sumac is clonal, few genotypes (one at each location) may exist in North Carolina. These situations suggest that Michaux's sumac may be vulnerable to chance disturbances and outbreeding depression (Levin et al. 1996).

The objective of this project was to determine how the number of locations with live plants and the number of plants at each location has changed over time. We wanted to determine whether the regional population of Michaux's sumac is increasing, decreasing, or stable. Because restoration of Michaux's sumac is most critical in North Carolina, we concentrated our assessment on North Carolina, but also requested information from the Natural Heritage Programs in Virginia, South Carolina, Georgia, and Florida.

To assess the number of locations and plants over time, we examined the records (elemental occurrences) kept by the Natural Heritage Program of North Carolina. With the exception of a few historical notes, record keeping began in 1980. The records indicated that regular visitation of all locations was not the norm. Some locations were visited only once, but others were visited up to eight times since 1980, a situation that made periodic comparisons impossible. We also noted several other confounding issues: the number of plants at 15 locations (almost half) was sometimes only roughly estimated, usually recorded as "over 50" or "over 100"; the records contained references to "subpopulations" within some locations; the meaning of subpopulation was not completely clear, but we suspected it referred to groups of plants somewhat separated at a particular location; the number of sumac plants at five locations had been augmented by planting; the records also included four locations where the plant was actually the hybrid (*Rhus* × *ashei*) with smooth sumac. Thus, we concluded that we could not accomplish our original objective, and instead decided to update the records by counting the number of plants at all known locations in a short time period. We hope that our update will provide a benchmark for future studies.

Between May 2005 and September 2006, we visited 36 of the 38 locations that might contain live plants as indicated by the NC Natural Heritage Program records. Two locations were not included; one Moore County location description was too vague to locate, and a Hoke County location occurred in an impact zone at Fort Bragg where access was denied. We did not recognize subpopulations, because the circumscription of each subpopulation was not clear. We included the five locations augmented by planting. Locations with hybrids were not included, because they are considered to be a different taxon. We also did not include nine experimental locations, where Michaux's sumac had been re-introduced by transplanting, because experimental locations are not counted by U. S. Fish and Wildlife Service towards restoration (Dale Suiter, USFWS, pers. comm.). At each location, we noted whether live plants were present, and, if so, we counted the number of plants (above ground shoots). We also subdivided the records into four time periods (1794–1980, 1981–1992, 1993–2004 and 2005–2006 [our study]) and counted the number of locations with live plants. We used simple descriptive statistics to analyze our results.

We counted a total of 5,726 plants, but nearly three-quarters of the plants occurred in just one county (Richmond; Table 1). We found Michaux's sumac surviving at

Table 1. Number and descriptive statistics of Michaux's sumac plants found at 33 locations in North Carolina in 2005–2006 by county.

County	# Locations	# Plants	% of Total	Avg. #/Location
Cumberland	1	17	0.3	17.0
Franklin	1	83	1.4	83.0
Hoke	3	211	3.7	70.3
Moore	2	61	1.1	30.5
Richmond	16	4251	74.2	265.7
Scotland	9	1093	19.1	121.4
Wake	1	10	0.2	10.0
Totals	33	5726	100.0	173.5

Table 2. Number of locations by county containing Michaux's sumac plants during four time periods in North Carolina. Survivorship at two locations in two counties (Hoke and Moore) could not be verified in 2005–2006, hence the range of numbers.

	Time Period			
County	1794–1980	1981–1993	1994–2004	2005–2006
Cumberland	0	0	1	1
Davie	1	1	1	0
Durham	1	0	0	0
Franklin	1	1	1	1
Hoke	2	6	3–4	3–4
Johnston	1	0	0	0
Moore	1	2	2	2–3
Richmond	0	5	15	16
Robeson	1	2	0	0
Scotland	2	6	8	9
Union	1	0	0	0
Wake	1	1	2	1
Wilson	1	0	0	0
All counties	**13**	**24**	**33–34**	**33–35**

33 of 38 possible locations in seven counties in 2005–2006 (Table 2). We could not verify survivorship at two locations in two counties (Hoke and Moore). The number of known locations with live plants increased until 1994–2004. The number of locations with live plants in 2005–2006 was about the same as in 1994–2004, but the locations were not all the same.

In Virginia, Michaux's sumac occurs in three counties (Brunswick, Dinwiddle, and Nottoway). In South Carolina, Michaux's sumac has been found in three counties (Florence, Kershaw, and Oconee), but none of these locations currently contain live plants. In Georgia, Michaux's sumac has been found in six counties (Chattahoochee, Cobb, Elbert, Fulton, Newton, and Rockdale), but currently only four counties contain live plants (Elbert, Fulton, Newton, and Rockdale). Florida had one location (Alachua County), but none of the plants survive today.

Increases in the number of locations occurred during the first three time periods, likely reflecting the increased efforts to locate and restore the species. The number of locations with live plants was similar for the most recent two time periods, suggesting that the populations stabilized or search efforts had finally identified all locations. But the number of locations was similar only because newly discovered locations equaled the number of locations where Michaux's sumac was extirpated. Reports in the literature (e.g., Emrick and Jones 2008, Willis 2008) on the number of locations with live plants differ somewhat from the estimates reported here. The reasons for these differences are only partly clear. Differences could result if locations with hybrids and experimental populations were included, and if subpopulations were counted separately. Until uniform methods are used for counting, these differences will likely persist, confounding monitoring efforts and making an accurate status report very difficult.

We suspect that the counting issues we encountered are not unique to Michaux's sumac. In the larger sense and more importantly, our results showed that monitoring rare species can occur only when systematic procedures are followed. We recommend concentrating efforts, because the financial resources needed by state and federal agencies to monitor every species each year are doubtfully forthcoming. Every known location of a limited number of species should be surveyed systematically every five to ten years, preferably in the same growing season to control variation in the number of plants related to growing conditions, especially weather.

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Sampling Intensities and Sampling Errors Associated with Pre-and Post-treatment Forest Restoration Monitoring: The Ute Valley Inventory

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Although silvicultural prescriptions may vary depending on the ecosystems treated and the objectives of the landowner, forest restoration in the southwestern United States is often designed to reduce the potential deleterious effects of grazing and other land-use practices across ranges, stands, forests and watersheds. The Collaborative Forest Restoration Program (CFRP), administered by the USDA Forest Service (USFS) Southwestern Region in Albuquerque, is a New Mexico-wide initiative to reduce the potential of catastrophic wildfire on public and tribal lands while building collaborations and partnerships among diverse stakeholders and interest groups (USFS 2001).

Among the questions associated with forest restoration monitoring is whether the inventory performed provides information consistent with both landowner objectives and the anticipated use of inventory results. On the subject of sampling intensity, current CFRP inventory protocols: suggest using land area to determine sampling intensity (USFS 2003, Savage et al. 2006, New Mexico Forest and Watershed Restoration Institute, pers. comm.); advise establishing enough plots to "make monitoring reliable," without further discussion or any indication of what is meant by reliable (Moote et al. 2010); or ignore sampling error completely, while at the same time stressing the importance of "good" baseline data to compare with future project monitoring data (Derr et al. 2005). Curiously, a CFRP-funded monitoring document asserted that "one quarter of the (CFRP) projects had ecological monitoring methods that were assessed as having low reliability," yet did not describe what was meant by "reliability" or how the assessments were made (Derr et al. 2008). Further, since the terms were not mentioned, sampling intensity and sampling error did not appear to be factors in determining monitoring or data reliability.

Table 1. Allowable errors for various forest inventory objectives.

Objective	Allowable error (percent)
Litigation	+5
Real estate with high value timber	+5
Lump sum timber sales—high value	1–5
Lump sum timber sales—low value	+10
Unit price (pay as cut) timber sale	+20
Management planning	30–40

One common CFRP project inventory protocol calls for establishing a 0.04-ha plot for every four acres of land (New Mexico Forest and Watershed Restoration Institute, pers. comm.). While this approach may work for some inventories, it is not directly sensitive to the inherent variability associated with the site and stand attributes being measured and therefore it will not be appropriate for all site conditions or inventory situations. As a result, sampling errors may be either too high or too low compared to pre-inventory, targeted allowable errors. While there is flexibility associated with the most appropriate allowable error targeted for a given inventory project, in general the decision will be based on inventory objectives, the resources available to conduct the inventory, and, in the case of timber and/or land sales, the value of the timber. For example, one set of guidelines for allowable errors for various forest inventory objectives (J. Barrett, University of New Hampshire, retired, pers. comm.) is suggested in Table 1.

In 2007, following generally accepted inventory protocols suggested by the CFRP (Derr et al. 2008), a restoration monitoring crew established 21 0.02-ha sample plots in the New Mexican Ute Valley prior to a hazardous fuels reduction treatment. In 2009, after CFRP-funded restoration treatments were applied, a crew returned to the same site, re-measuring 16 of the original 21 sample plots (five of the 2007 pre-treatment plots had not been exposed to restoration treatment, and, therefore, were not re-measured in 2009). Results indicated that the restoration treatment reduced the trees/ha from 1,808 to 148 trees/ha and the basal area from 28.7 m^2/ha to 10.3 m^2/ha (Table 2). Much of the treatment could be classified as a low thinning, that is, trees in smaller diameter classes were removed. Therefore, the mean stand diameter increased from 14.2 cm in the pre-treatment stand to 29.7 cm in the post-treatment stand, while average tree height increased from 12.7 m to 19.2 m (Table 2).

Importantly, the sampling error around the estimated mean basal area per hectare almost doubled in the post-treatment stand vs. pre-treatment, a reflection of the

Table 2. Results of the Ute Valley pre- and post-treatment inventory data analysis, focusing on the attribute basal area per hectare.

Variable	Pre-treatment	Post-treatment
No. sample plots	21	16
Mean	28.8 m^2/ha	10.4 m^2/ha
Standard deviation	15.2 m^2/ha	9.2 m^2/ha
Coefficient of variation	53%	88%
Confidence interval	28.8 m^2/ha ± 6.9 m^2/ha	10.4 m^2/ha ± 4.9 m^2/ha
Sampling error	24%	47%

increased variability in the distribution in basal area/ha after the treatment (Table 2). This is supported by differences in pre- and post-treatment coefficients of variation for basal areas (53% and 88%, respectively), as well as the smaller sample size in the post- vs. pre-treatment monitoring.

Preferred methods for determining sampling intensity include estimating the CV before the inventory from a pre-inventory, inventory data from similar stands and even, where appropriate, from the experience of a seasoned inventory specialist. Then, using the relationship: $n = t^2cv^2/E^2$, where n is the number of sample units (e.g., plots or points) required; t is an appropriate t-value for a given confidence level; cv is an estimate of the coefficient of variation (percent) for an inventory-defining attribute(s); and E is the allowable error (percent), based on inventory objectives, one may determine the number of sample units needed to derive inventory results that approximate the pre-cruise targeted allowable error. The t-value is often estimated as 2 at the 0.95 level (Wiant 1985), especially for large samples (Freese 1976) (at this confidence level t approaches 1.96 as n approaches infinity). However, iterative solutions for t are often preferred and recommended, especially when the sample size is relatively small (Freese 1976).

For example, if the estimated pre-inventory CV for the Ute Valley inventory was 53 percent (Table 2), the estimated sample size, assuming a confidence interval will be developed around the mean basal area per hectare at the 95 percent level and an allowable error of 30 percent, would be 14 plots. This relationship is discussed in more detail in most forest mensuration texts (Avery and Burkhart 2002). It is important to note that tract size is not a variable in this relationship and also to reiterate that sampling intensity is driven by the variability of the attribute(s) in question, the objective of the inventory, and the level of statistical confidence desired in the results.

Sampling errors will not directly account for errors associated with measurement or inadequate inventory design and implementation. Additional field inventory issues, such as edge effect bias, boundary overlap, and correction for slope when establishing plots (Avery and Burkhart 2002), should be addressed consistently and bias minimized.

In the end, the success of an inventory is evaluated by how well it meets the landowner's objectives and the resources available to conduct the inventory. This then drives the allowable error for the inventory, specified before the inventory at some level of statistical confidence. In turn, this information helps us to estimate the sampling intensity needed to arrive at an estimate and a sampling error around that estimate consistent with pre-inventory specifications.

For restoration monitoring, therefore, it is important to understand how the inventory results will ultimately be used before determining sampling intensity. Basing sampling intensity on the size of the land area being inventoried may provide usable results if the project planning team has a reliable pre-inventory understanding of the distribution of hazardous fuels (or some other inventory-defining attribute) in the stand being measured, is merely lucky—and luck shouldn't play a role in well-planned, systematic forest monitoring—or has little concern about sampling errors around estimates of critical stand attributes.

Unfortunately, the necessity of generating results that elucidate the effectiveness of restoration treatments from data derived from restoration project monitoring (USFS 2000) creates a tension among CFRP's stated purpose of involving all stakeholders, including youth and the general public, in restoration efforts (USFS 2000); the lack of expertise among many CFRP monitoring contractors; and the desired uses and outcomes of monitoring efforts that require reliable data collected using accepted sampling intensities and designs (Egan and Estrada 2013).

Not accounting for a stand's inherent variability may also result in inefficiencies and increased inventory costs. For example, because of the high variability and scattered distribution of trees, a recent post-restoration CFRP treatment inventory showed that there were no trees in the residual post-treatment stand when there clearly was (Natural Resources Department at Alamo Navajo, Alamo, NM, pers. comm.). The pre- and post-treatment inventories relied on the size of the inventory area instead of the stand's inherent variability to determine sampling intensity. As a result, the tract was re-visited and additional post-treatment sample plots were established in order to account for this variability—an inefficient way of conducting any inventory.

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Informing the CFLRP: Lessons Learned from New Mexico's Collaborative Forest Restoration Program

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Forest restoration in the southwest US and elsewhere has been receiving increased attention, due to climate change, changing land use practices, increasing populations in the wildland-urban interface and the historical mismanagement of some forests, as evidenced, in part, by the unusual number and severity of devastating fires in recent years. The Collaborative Forest Restoration Program (CFRP) was initiated in 2001 by the USDA Forest Service (USFS) as "a new approach to building agreement among people and organizations that care about New Mexico's forest land," by awarding grants that "restore forests on public and tribal lands and improve the use of small diameter trees thinned from those lands" (USFS 2001). Important program objectives also include reducing the threat of catastrophic wildfire on the stand or forest level and creating local employment and training opportunities.

Additionally, the Collaborative Forest Landscape Restoration Program (CFLRP), a federally-funded, nationwide, landscape-scale program, was established in 2009 "to encourage the collaborative, science-based ecosystem restoration of priority landscapes" (USFS 2009). While their purposes are articulated differently—with CFRP perhaps more explicit in its commitment to grass roots participation and equality of knowledge among all participants—ultimately, on the ground, the CFRP and CFLRP aim to accomplish similar objectives, albeit at different spatial scales. Given the experiences of the CFRP over the past twelve years, there are lessons from that program that could inform CFLRP, especially in the following critical areas: collaboration and equity of knowledge; project consistency, connectivity, and maintenance; and socio-economic monitoring.

The "Collaboration" in CFRP can be both its greatest strength and, at times, its biggest challenge. The idea of equality of knowledge among all CFRP participants, irrespective of background or experience, while perhaps laudable conceptually, can lead to the dilution of efforts to collect, analyze, and draw meaningful inferences from reliable data. Unfortunately, CFRP grantees, often more interested in completing a project and collecting grant funding than applying even the most fundamental rigor necessary to help the program answer questions related to, for example, treatment effectiveness and maintenance cycles, will sometimes take the easy way out when it comes to monitoring. The multi-party monitoring process is sometimes viewed by grantees as simply a checklist item to be signed off on and there is often little follow through by grantees in developing true multi-party monitoring plans.

Consistent with assertions by Force and Machlis (1997), implementing a system of social indicators, for example, often requires specific skills and knowledge. Complicating the issue is the "paradox of public involvement" discussed by Walker and Daniels (2001) and referenced by Egan and Estrada (2013) as it relates to forest restoration, which posits that, while citizens may want the best available science to inform management decisions, they also want to have input into decision-making processes. However, as resource management and landscape restoration decisions and processes become more complex, few citizens have the scientific background and expertise to contribute or provide relevant criticism (Walker and Daniels 2001).

Unfortunately, the assumption of equity of knowledge among stakeholders can have devastating outcomes. Among the lessons learned from the 2010 Track Fire near Raton, NM, for example, was that pre-fire thinning was likely not aggressive enough, in part because there were those at the table who wanted to thin in a way that is consistent with the science, and those who didn't want any trees cut. As a result, a process of compromise among diverse stakeholders led to fuel reduction practices that were outside of the range of residual stand stocking for effective fuels reduction (S. Berry, City of Raton Engineer, pers. comm.), with devastating results, including the temporary loss of the city's main reservoir, Lake Maloya, due to excessive sedimentation from post-fire rains. When the city of Raton engineer was later asked what, in retrospect, he might have done differently, he responded "cut more trees."

Virtually all efforts to restore forests and reduce hazardous fuels will require a long-term plan of successive interventions that accounts for treatment maintenance cycles, evolving science, and changing public values and land uses, including an expanding wildland-urban interface. This is likely to occur sustainably only with the development of a healthy forestry sector that will enable these treatments to occur in the long-term and in the face of contracting public subsidies for forest restoration and hazardous fuel reduction (Egan 2012). Mechanical fuel reduction treatments, conducted on a rhythm consistent with a treatment's maintenance cycle, can also result in certain desired conditions, with the added benefit of providing a more sustainable supply of wood products to local forest products businesses. In addition, since CFRP provides funding at the project, rather than landscape, level, hazardous fuels reduction treatments are sometimes isolated, calling into question their potential effectiveness in reducing the impacts of large-scale wildfires. But all of this requires a plan, and funding, that looks beyond the duration of the initial treatments—not necessarily strengths of programs such as CFRP and CFLRP that rely on a relatively high level of year to year funding uncertainty.

Given the diverse goals and objectives of forest restoration programs and projects, monitoring the socio-economic outcomes of these efforts can be complex to understand and measure. Past work has been conducted to develop socio-economic indicators for forest restoration efforts (Estrada et al. 2009; Egan and Estrada 2013). The process of indicator development will continue to evolve as the forest restoration community develops keener interest and expertise in this important dimension of restoration. However, among the challenges associated with understanding the socio-economic outcomes of forest restoration have been a lack of consistency in identifying core socio-economic indicators across projects and how they may be measured; a paucity of systematic and objective approaches to indicator development; the challenge of achieving consensus among diverse stakeholders; and uneven efforts to solicit the opinions of forest restoration stakeholders on the most appropriate indicators and protocols.

In order to avoid tensions that may arise over the degree of scientific rigor required to achieve monitoring objectives, it is important for program administrators and grantees to understand that an effective evaluation of socio-economic project outcomes often requires specific expertise in social science methods, while also recognizing that there may be some indicators that demand less sophistication and rigor than others. This has been generally lacking for CFRP projects. Surveys, focus groups and key informant interviews are specific social science methods that require background, training, and preparation to be implemented well. Unfortunately, it is too often assumed that social science is easy science and that *interest* in the socio-economic dimensions of forest restoration necessarily equates to *expertise*. Perhaps the important question to resolve is whether the methods and the level of expertise of the monitoring team match the objectives.

Monitoring practitioners are encouraged to consider important regional, cultural and other project-specific characteristics before deciding on which socio-economic indicators to measure for a given forest restoration project, irrespective of the rating derived for those indicators. As with any attempt to understand something as potentially complex as socio-economic indicators for the vast array of forest restoration projects and project objectives, this should be a continuing and inclusive process.

Finally, given the potential sensitivity of information that could be derived from some socio-economic assessments, including that related to restoration business costs, revenues, and markets, for example, it is critical that the information and those who provide it are afforded adequate protections—another challenge plaguing community-based multi-party monitoring associated with some programs (Egan and Estrada 2013) that could compromise restoration businesses and raise potential program liability issues. Based on an inspection of CFRP project proposals, virtually no CFRP-funded project accounts for this; setting up the CFRP and its grantees for potential acrimony, even lawsuits, when information that may compromise the competitiveness of a restoration business is treated without sufficient care.

Much funding—and hope—is being invested in the CFLRP. It is not just about restoring healthy forested landscapes, but also about reinvigorating local, rural economies and reducing the threat of catastrophic wildfire and its ecological, economic, and social consequences. Experiences with New Mexico's CFRP have shown us that, for the ultimate success of the program, it is critical that CFLRP account for issues such as the paradox of public involvement and equity of knowledge; consistency among methodologies; and exercising care with socio-economic monitoring. Ignoring the lessons learned from New Mexico's CFRP, and perhaps other restoration programs, would appear to be a missed opportunity for CFLRP, with one likely result being a repeat of the challenges faced by these programs. But given the significant increases in CFLRP projects' spatial scales, funding, and public expectations, ignorance of these issues is likely on a much grander scale and with potentially more far reaching consequences.

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