Geodatabase Application for Invasive Plant Tracking and Coordinated Habitat Restoration

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Abstract

Non-native invasive plants, such as *Lepidium latifolium* and *Arundo donax*, threaten the ecological integrity of riparian habitat throughout California. Numerous projects across the state are underway to eradicate select weeds, yet there is little or no monitoring of parameters that would be useful in evaluating ecosystem recovery over time and space. Researchers at the California Information Node of NBII at UC Davis, in cooperation with Sonoma Ecology Center (SEC) and The Nature Conservancy (TNC), have developed integrated personal geodatabases to aid in weed management and habitat restoration efforts in California's Bay-Delta. Using ESRI ArcGIS 9.0, we initiated a cross-entity effort to standardize database attributes and data collection methods, improve temporal tracking capability within a geodatabase framework, and improve integration between research and resource management. There is an outstanding need for GIS to monitor weed management and ecosystem restoration efforts; this application of geodatabase technology is a solution.

Introduction

Vegetation monitoring is a critical and common component of almost all terrestrial conservation work, yet monitoring data are often unused to promote active management or to guide adaptation in management objectives. To be useful in management – and to be effectively integrated into data warehousing / data mining activities – monitoring data must be stored in such a way that they are both accessible and well documented, as per core metadata elements.

Better information is especially critical in addressing invasive species, which are the second most important cause of species loss (after land conversion) and are estimated to cost the U.S. economy in excess of $100 billion per year. In recent years, various land management and natural resource conservation organizations have promoted a variety of techniques and elements to map weed infestations. A quick web search on "weed mapping" returns a long list of weed mapping projects and information. Local resources include the 2002 California Weed Mapping Handbook and the continuously updated online weed mapping utility CRISIS maps, a project of the California Information Node of the National Biological Information Infrastructure. These resources serve as guidance for accumulation of spatial data into GIS shapefiles, but they fail to offer a model for data management which promotes ease of evaluation within and among site-specific data sets.

Discussion among "weed mappers" frequently focuses on the difficulty of tracking weed patches over time (see CAL-IPC Weed Mapping Committee). The difficulty arises from the fact that patches can grow, shrink, merge, divide or disappear. Such changes create a major challenge if one attempts to track numbered patches as permanent entities. As initial entities merge and dissolve, formerly distinct patches lose their definition. Modeling this behavior within a relational database has proven difficult.

A Collaborative Effort

Recently, two projects were funded by the California Bay-Delta Authority (CBDA), or CALFED, which is a state and federal partnership to promote recovery of the San Francisco Bay and delta created by the confluence of the Sacramento River and San Joaquin River. CBDA is multi-programmatic; however, the projects described herein are under the auspices of the Ecological Restoration Program (ERP). The two projects, Cosumnes River Preserve Perennial Pepperweed (*Lepidium latifolium*) Control Project and the Arundo Eradication and Coordination Program, were selected for directed action and are presently implementing project directives.

At its base, these two independent projects are seeking standardized methodologies and modes of communication to promote sound research toward weed eradication and control. The two targeted plant species (*Lepidium latifolium*, or perennial pepperweed, and *Arundo donax*, or giant cane) are pernicious riparian invaders of great concern to many landowners and public agencies, making them good candidates for developing standardized geospatial frameworks of analysis and data cataloging to inform weed control efforts. The primary goals of our collaborative effort are to initiate fundamental elements of coordinated invasion response, such as early detection/rapid response, scientific experimental design, and multiscale meta-analysis.

Arundo Project

Team Arundo del Norte (TAdN) is a network of local, state, and federal organizations dedicated to the eradication of *Arundo donax*, a non-native invasive species that threatens riparian and aquatic habitat through native plant displacement, stream channel degradation, increased flood and fire risk, and increased water use. Sonoma Ecology Center is a founding member of TAdN, and in cooperation with other key partners in TAdN, such as the Information Center for the Environment (UC Davis), California Environmental Resources Evaluation System (CERES), USDA Agricultural Research Service, University of Nevada - Reno, California Department of Fish & Game, Sonoma State University, and 10 eradication efforts throughout the CBDA region.

The central aim of TAdN is to eliminate further invasion impacts; other compelling aims include restoration of riparian and fluvial functions at infestation/eradication sites, and improvement of the coordination of habitat restoration activities across large ecoregional areas. Although much is known about how to eradicate *Arundo* and the benefits of its removal, there are still pressing needs to document long-term riparian and fluvial recovery after eradication, map *Arundo* invasions to better prioritize eradication efforts, and apply monitoring data adaptively to the ongoing management activities. The TAdN program selects high-priority sites for *Arundo* eradication and subsequent restoration through comprehensive geospatial inventory and post-treatment monitoring. TAdN monitoring uses GIS and field mapping to better prioritize eradication efforts (Figure 1) along Cache Creek, San Joaquin River, Lindo Channel, American River, and the Gray Lodge State Wildlife Area. Ongoing TAdN sites include Sonoma Creek, Walnut Creek, Napa River, Putah Creek, and San Fransicquito Creek.

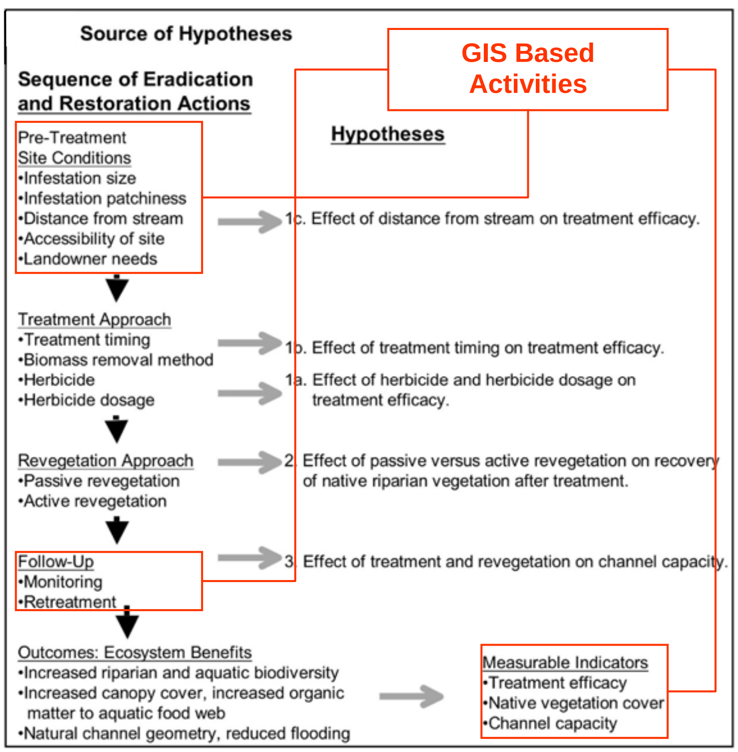

Figure 1. A conceptual model, adapted from Team Arundo del Norte, showing processes with gained advantage using geodatabase technologies.

Lepidium Project

Perennial pepperweed, *Lepidium latifolium* (hereafter referred to as *Lepidium*), is a highly invasive perennial herb that can thrive in a wide range of habitats including riparian areas, wetlands, marshes, and floodplains. This weed has already invaded many habitats throughout the San Francisco Bay-Delta area and is of particular concern in areas where active restoration is underway. Once established this plant creates large monospecific stands that displace native plants and animals and can alter soil composition by concentrating salts at the surface. It interferes with regeneration of cottonwood and willow species, as well as key herbaceous species, in riparian and wetland areas. It is on the A-list of the California Invasive Plant Council's (Cal-IPC) list of Exotic Pest plants of Greatest Ecological Concern in California, and on the California Department of Food and Agriculture's B list of noxious weeds due to its highly invasive nature. This species is considered a high-ranking threat to critical habitats within the Cosumnes River Preserve, located in southern Sacramento County, California. It is a priority for control efforts because it spreads rapidly and threatens native habitats including valley oak riparian forest, mixed riparian forest, seasonal and permanent wetlands and associated uplands, but also because the potential for controlling its spread is thought to be greater than for many other noxious weeds.

It has become increasingly clear that the biological element most likely to disrupt the desired future conditions in the Cosumnes floodplain (and generally throughout the Delta region) is invasive species. The *Lepidum* project continues the partnership between the Cosumnes River Preserve (CRP) and the Information Center for the Environment (ICE); it also complements ongoing Cosumnes research by performing an intensive study of the most rapidly expanding invasive plant in the Cosumnes study area. The approach closely follows recommendations of the recent CALFED workshop on Adaptive Management of Invasive Species, and represents a pilot-species, pilot-region application of a general framework to experimentally develop control strategies for terrestrial invasive plant species in the CALFED region.

Project Collaboration

The University of California, Davis, Information Center for the Environment, Team Arundo del Norte, Sonoma Ecology Center, and The Nature Conservancy are active participants in both state and federal initiatives to establish early detection/rapid response (EDRR) networks, and our joint activities form a field test of emerging proposed standards from the National Invasive Species Council (through several partner agencies) on how to share EDRR information over the Internet. With USGS funding, ICE has taken a leadership role in data interoperability standards. The TNC Wildland Invasive Species Team is a leading on-line source of species identification and control method data. However these EDRR capabilities have not been combined, nor used in the context of site risk assessments to target high-risk sites for early detection activities. Use of experimental design for identifying weed occurrences and testing control methods is fundamental to each of these projects, and provides the basis for incremental experimentation over the long term; thus, when held against a standardized control, this framework methodology provides a measure of statistical certainty in examination and formal hypothesis testing. Our approach also provides the opportunity to examine invasion at nested scales, individual (blocked) control method experiments on a meter-scale, inundation frequency/duration and related soil properties at the scale of hectares to square kilometers, and control strategies at the watershed scale.

Using GIS to Monitor Weeds

Monitoring, in both the *Arundo* and *Lepidium* projects, aims to establish baseline data at an appropriate spatial and temporal scale, use standard methods, measure effort and effectiveness, be affordable, and involve quality assessment and control, peer review and cooperative data management. The *Lepidium* project seeks to address needs of adaptive management and monitoring of weed control efforts in general, and control of *Lepidium*, specifically. Current database and GIS-based systems of tracking have been identified as insufficient for maintaining complex files integrating management records with weed population change over time. Participants in the workshop “Mapping: Setting priorities and communicating scope” at the 2003 Cal-IPC conference came to the conclusion that the California weed mapping community lacks a standardized database model for successive observations that can address non-discrete units of shrinking and swelling populations (i.e., situations when patches of vegetation merge or fragment).

To more fully address the monitoring and analysis needs of *Lepidium* population patterns and trends, we have conducted annual or more frequent GPS-based pilot surveys of *Lepidium* in selected portions of the Cosumnes Preserve, notably those near the headquarters and visitor area, within oak restoration sites, and in the intensively studied experimental floodplains that are core sites for the current CALFED grant research in the Cosumnes River floodplain. Many of these were unfunded TNC volunteer or UC Davis student projects, but they have established that *Lepidium* is a growing problem on sensitive habitats within the Preserve boundaries. Present monitoring includes the restored “upper and lower floodplain” area of the Preserve, and has expanded into new adaptive management experimental areas. Monitoring at these sites currently includes recording of location (via Global Positioning System), patch size (area and perimeter), and *Lepidium* stem count within each geographically distinct patch. We also include surveys of surrounding vegetation, density estimates of *Lepidium* using visual, as well as site-specific records.

These monitoring data serve as the basis for our ArcGIS-based tracking system to assess expansion or decline of *Lepidium* populations on the preserve relative to site characteristics and management actions – described in detail below. In the end, we will analyze *Lepidium* spread using geographic information system technology to investigate relationships between population trends, physical site characteristics, and geographic location such as proximity to roads or waterways. To better inform analysis of physical site factors (e.g., digital elevation and canopy height), we will soon integrate laser altimetry into our analyses. These data will allow calculation of relative elevation (a surrogate for flooding frequency) and canopy heights throughout the project area. In addition, we are attempting to meet an ongoing need within the GIS weed tracking community by developing a standardized, geographically based database framework for this and other weed control projects. This framework, described more fully in this paper, should enable data sharing and meta-analysis of multiple CALFED projects. On the level of individual projects, this framework will help to streamline data storage, project assessment and statistical evaluation of results and provide a mechanism to make core data from multiple projects, agencies, and landowners available in a common format over the Web.

Vegetation Monitoring Using Database Technology

By combining the advantages of a geographic information system for mapping and data storage with the advantages of a relational database for data management, a geodatabase offers the potential to store monitoring data in a format which is visibly and organizationally accessible. We have developed a ESRI ArcGIS 9 versioned geodatabase designed specifically to track population dynamics of vegetation patches over time.

We originally attempted to design a relational database capable of storing tabular yearly field data with patchtracking capabilities (i.e., which patches merged together or dissolved apart based on assigned unique Patch ID). Two tables were added to the field survey database. Simply put, the first table preserved the data snap shot for each survey year. The second table attempted to provide a snap shot of each patch's history by serving as a registry, or archive, of changes for each patch (e.g., patch creation, patch merge, patch death). While this table broke from the established design rules, it did provide a sequencing approach to record tracking. Both tracking tables hinged upon Patch ID, a unique key assigned to each surveyed patch. The Patch ID introduced an artificial classification system into the data set. As a new Lepidium patch appeared, a new Patch ID would be assigned. This ID would carry over from year to year. In situations where patches merged, the old Patch IDs would be retired and a new Patch ID would be assigned to the new consolidated patch. In order for this classification to work, the surveyed patches needed to be consistently labeled and named year after year. In the end, this approach relied too heavily upon user input to maintain data integrity.

To remedy the tracking element and reduce user maintenance, we have developed a geodatabase which stores patch location and associated field data, and allows assessment of patch dynamics, using a spatial approach rather than a numeric patch ID to track patch behavior over time. Our approach relies on identification of patches by polygon location. We identify patches in the field using differentially corrected GPS locations and recording patch-specific information (target species cover and stem count). We inventory entire parcels, rather than subsampling, as our goal is to track and control all weed populations in our habitat restoration areas. Data are saved in feature datasets organized by year. When we return to the same parcel the following year, we complete another inventory. We can use printed maps or waypoints to navigate to the previous year's patches if desired, but we have alleviated the need to identify the patch as a former occurrence. Instead, we simply record it as a patch encountered in the current year. Analysis of patch dynamics from year to year takes place in a GIS environment, not in the field.

Our method also uses the GIS environment to define administrative categories of spatial locations in which vegetation patches are found. Other weed mapping frameworks, such as TNC's Weed Information Management System, require that the user input a description of the weed location in the form of a parcel name, USGS quad name, Weed Management Area name, etc. We have found that this information is redundant and subject to data entry error. Overlaying GIS layers of administrative boundaries to determine locations of weed occurrences within these borders reduces potential field data entry error and improves field efficiency.

We use spatial analyses in a GIS environment to analyze patch dynamics over time. We are able to track change in immigration, emigration, expansion and contraction of vegetation patches. Analyses of these tracking data are performed both within ArcGIS and through export of data to statistical programs.

Geodatabase Construction Methods

Our method of tracking weed populations over time involves four steps: (1) collection of GPS field data, (2) download of GPS data into a GIS geodatabase, (3) spatial rectification and identification, (4) analysis of weed population dynamics over time using spatial identification and geodatabase tables.

1) Collection of GPS field data

Our GPS field data collection protocol reflects our high-accuracy goals. Our minimum patch size is one individual plant of the target species, and our minimum mapping unit is 1 m^2. We systematically traverse parcels by foot to allow visual assessment of the entire parcel. We record weed patch locations using Trimble PROXRS backpack GPS units, which offer sub-meter accuracy.

Our protocol and data dictionary allow recording of point, line or polygon features in the field. Point features are recorded at patches less than 1 m^2, and at patches whose perimeters cannot be traversed (often due to location within blackberry, *Rubus spp.*, or poison oak, *Toxicodendron diversilobum*, thickets). Line features are used to record linear patches of even width located adjacent to roads. Data dictionary fields include estimated patch width (line features only), estimated area (point features only), stem count (estimated or counted), percent cover (ocular estimate), and name of person recording. Date and time are automatically recorded.

We also record our tracks using GPS, to document the extent of our survey. While surveying an area, we log our tracks using the Tracks feature of a Garmin Rino 120. We use the free software Waypoint+ to download tracks from the GPS unit.

2) Download of GPS data to a GIS geodatabase

We convert our field data into shapefiles by feature type (point, line, polygon). GPS field data are differentially corrected, exported to the appropriate shapefile format, and reprojected from WGS 1984 to the geodatabase projection (UTM NAD 1983 Zone 10N). We cumulatively add daily field data features to these three shapefiles. Data updates and corrections (e.g., attribution) are performed in these three cumulative UTM shapefiles. Original GPS files are not altered, but serve as original back-up records. At the end of the field season, these shapefiles are converted to geodatabase feature classes and added to our weed tracking geodatabase.

Polygon, line and point geodatabase feature classes are combined as a single polygon feature class. We first convert polygon features which are less than our minimum patch size (defined a priori as 1 m^2) to points with an area of 1 m^2, transferring associated data to the new point feature and deleting the polygon feature which did not meet our minimum area requirement. We then convert all point and line features to polygon features using estimated area and estimated width fields, respectively. Using the estimated area of point features, we calculate a radius field for all points (radius = √estimated area/3.14). We then convert the point feature class to a polygon feature class by buffering the point with the calculated radius as the distance value. Line features are converted to polygons using the Trace tool in Editor mode. Overlaying the features onto high resolution photographs, estimated patch width is used to heads-up digitize the patch in the appropriate direction from the line (e.g., extending patches away from the road, not into a road, using the width indicated from the estimated field data).

We created a geodatabase designed expressly for this particular project, but with the idea of designing a model geodatabase structure which could be used for similar projects. We created separate feature datasets for each field season. All feature datasets in the geodatabase share the same *a priori* spatial reference. As such, we have customized our geodatabase parameters to meet our need for high spatial precision and accuracy while appropriately reflecting our spatial area of interest. Spatial precision determines the level of detail of spatial data storage units maintained in a geodatabase. ArcHelp recommends setting storage units “ten times smaller than the best precision of your data collection…[to] ensure that the precision of your data collection is maintained in the geodatabase regardless of how you manipulate the data with ArcGIS”, which is applicable to all forms of spatial manipulation, such as geoprocessing, topological and geometric operations. We set Min X: 425000 and Min Y: 4050000, and set our precision to 4000, which is equivalent to 0.25 mm storage units.

We also created topology rules to check for duplicate or overlapping polygons within and among feature classes. Such mistakes are common when field sites are visited by more than one field mapper or over more than one visit. We use the topology rule 'Must Not Overlap' with a cluster tolerance of 1 cm to check for overlap among polygons within the full feature class containing polygons from point, line and polygon features recorded in the field. Duplicate features are removed, and overlapping features are combined. These corrective actions are done by or in consultation with the same individuals who collected the data in the field, to inform any decisions required by discrepancies in the data of overlapping polygons.

(3) Spatial rectification and identification

Even if polygons are not directly overlapping, we define them as biologically indistinguishable if they are within an *a priori*-defined patch differentiation threshold. We define our minimum patch differentiation threshold for *Lepidium latifolium* as 3 meters based on our observations and those of others that the maximum rate of intrinsic patch radius expansion is about 3 meters per year.

Based on this threshold value, we use ArcGIS to merge field-recorded polygons whose perimeters are located 3 meters or closer to one another. This is accomplished through a process of adding and removing a 3 meter buffer around all polygons (Figure 2). We buffer all polygons by +3 meters and dissolve boundaries between resulting overlapping polygons (i.e., Buffer with Dissolve All option). We use the 'Multipart to Singlepart' command to convert non-overlapping polygons back to individual features, followed with 'Check Geometry' and 'Repair Geometry' commands as follow-up. We then implement topological rules – 'Must Not Have Gaps' and 'Must Not Overlap' - for the exploded feature class in ArcCatalog. Again, we set our cluster tolerance at 0.01 m. After fixing all topology errors, we buffer all polygons by -3 meters, again dissolving boundaries, converting multipart to singlepart, checking and repairing geometry.

Data associated with each original patch is carried into the new merged and dissolved patch. We select the option to sum appropriate quantitative data, such as stem counts, during the +3 meter buffer, merge & dissolve action. Text data (e.g. notes, comments) are not carried along with merge & dissolve actions. These attributes are saved in the geodatabase in the original feature class before dissolving, and can be linked to the resulting patches through a spatial join. Percent cover is calculated for the new, merged patches by calculating areal cover of *Lepidium latifolium* in each original patch (LELA_area = LELA_cover * Shape_Area/100), then summing these areal covers (sum_LELA_area) and dividing by the area of the new patch (100*sum_LELA_area/Shape_Area).

Because point data are frequently more convenient for both display and analysis purposes, we calculate representative points for each polygon as the centroid point of each polygon and save this as a point feature class with the same attributes as the polygon feature class with value added attribution, such as X and Y coordinate positions.

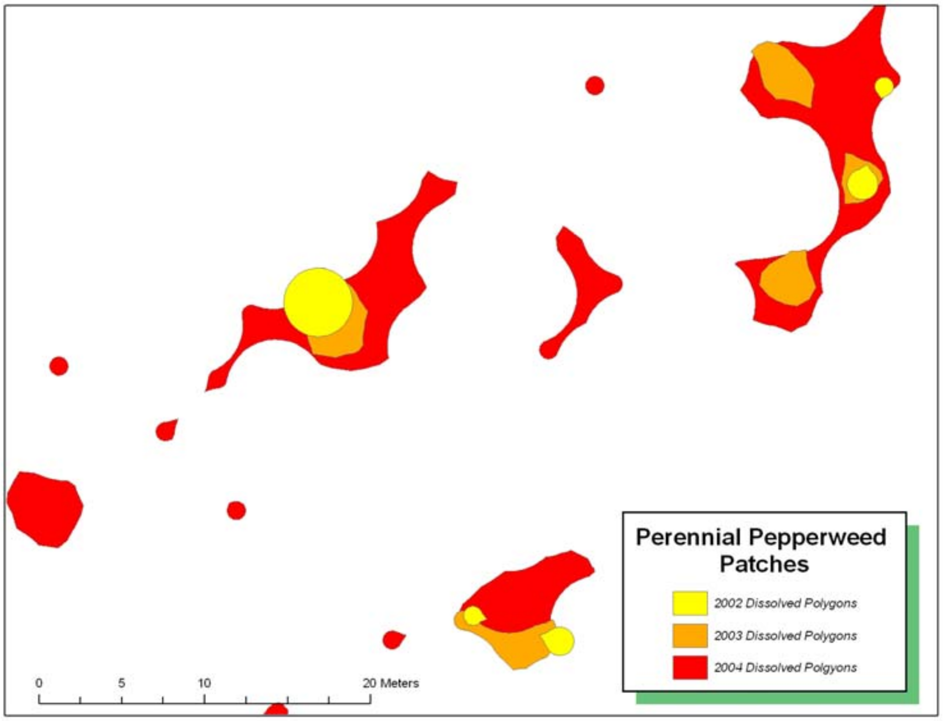

Figure 2. Dissolved polygons of perennial pepperweed patches for 3 consecutive years (2002-2004); note the 3m isthmus building through the positive/negative recursive buffering.

(4) Analysis of weed population dynamics

We use the ArcGIS spatial join capability to track changes in weed patch dynamics over time. Patch data from each year are joined with data from the same spatial location going both forward and backward in time. This forward *and* backward approach is necessary to track expansion, new invasions, and disappearance of patches.

From our pepperweed inventory data from 2002, 2003 and 2004, we use spatial joins to compare changes in patch size and pepperweed density from 2002 through 2004. In this analysis, we add a 1 meter buffer to each year's dissolved polygon layer to account for field errors. We set this threshold to 1 meter based on the accuracy of our Trimble PROXRS GPS units. We then spatially join our 2002 dissolved polygon layer to our 1 meter-buffered 2003 dissolved polygon layer (Figure 3). We chose the option to give each polygon a "summary of the numeric attributes of the polygons in the layer being joined that intersect it, and a count field showing how many polygons intersected it." We sum attributes, as measured density by stem count per patch, so that combined yearly stem counts yield the appropriate value for analysis of density changes over time.

An example of such an analysis includes renaming columns to identify the year to which they refer (Stems02, Stems 03, Area02, Area03, etc.). Blanks in 2002 data columns within the spatially joined layer indicate that a patch was newly discovered in 2003. The counts show how many 2002 polygons intersected a buffered 2003 polygon, thus providing information on how many patches merged together in 2003. We then repeat the steps to join 2004 dissolved polygons with 1 meter-buffered 2003 dissolved polygon data and, finally, we perform a spatial join from the 2002-2003 layer to the 2003-2004 layer to complete the data tracking of all 2004 patches. This information allows us to calculate the rate of patch expansion. It also allows us to test for statistical correlations between differing rates of expansion among patches and differences in spatial parameters such as soil type, elevation, degree of shading, and distance to water, contained in other GIS layers.

We are also able to track disappearance of patches through use of a forward spatial join. We join 2002 dissolved polygons with 1 meter-buffered 2003 polygon data following the steps outlined above. Those polygons without 2003 data have either disappeared, or were missed in the 2003 inventory. It is instructive to also perform a join between 2002 dissolved polygons and 1-meter buffered 2004 polygons, to check if these patches re-appeared, or were found, in 2004.

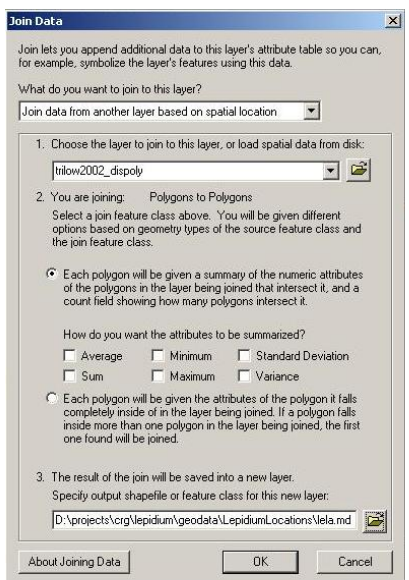

Figure 3. Spatial joins are used to track patch dynamics by location over time.

Discussion & Conclusion

Feature datasets not only allow use of topology rules for data quality control and patch reclassification, but also serve as useful organizational containers within the geodatabase. The implementation of this GIS framework also aids spatial modeling. For example, since our geolocated *Lepidium* patches are already entered into the standardized GIS framework, we can model relationships to other established geodata collected on the Cosumnes floodplain. CAIN, the California Information Node of the National Biological Information Infrastructure and other partners, including the USGS National Institute for Invasive Species Science, is constructing statistical models that use regression-like methods to predict probabilistic distributions of species from their recorded point occurrences and mapped predictors (elevation, soil, vegetation type, inundation time, distance from road, and distance from levee breach). We intend to apply the contents of our *Lepidium Project* geodatabase to at least 4 models of this kind using, for example, decision trees, logistic regression, Genetic Algorithm for Rule-set Prediction, and co-Kriging.

Spatial entities for which a high probability of occurrence is calculated should represent optimal habitat for the invader. Those with high probabilities in which ground studies show the species is absent should represent the locations with the highest risk – on which both early detection/rapid response efforts should be concentrated. Once the risk-prediction framework is in place, it can be used both to target on-the-ground management controls, and to experimentally test efficacy. (For example, it is likely that hectare-plus infestations in pepperweed-friendly habitats have escaped economically feasible control. As a result, managers may need to adopt a triage approach in which a combination of habitat value and lower pepperweed suitability make control efforts attractive.) Such capabilities are a long-term goal of this research program.

Weed Information Management System (WIMS)

Researchers from ICE, CAIN, SEC, TAdN, and TNC are collaborating on next-generation weed tracking databases. As such, the geodatabase advances described above for *Lepidium* will ultimately be integrated into the Weed Information Management System (WIMS), first developed by Oregon Bureau of Land Management and improved by TNC. Subsequent versioning of WIMS (presently 3.0 beta) will be tested against *Arundo* infestations in Summer 2005. The latest version of WIMS is focusing on improving elements designed for generic element cataloging, and amendable to next generation semantic web technologies. At present, WIMS allows for hand-held type data entry (PDA combined with GPS) or desktop data entry. There are also export to shapefile routines embedded in the database as stored procedures. However, it is not a geodatabase, and sites are not identified spatial but rather by identification number, thus limiting its ultimate ease of field application and usefulness within a GIS. Improvements will be made to improve WIMS through collaborative efforts.

The current schema (Figure 4) has the following core elements: observation session, observer, weed occurrence, and weed treatment. Within each core element type, several attribution modifiers are related to the core element itself. For example, an observation session consists of an observer, a weed occurrence, and possibly a treatment. The treatment can be mechanical, biocidal, biological control, or other, with each treatment type having a chain of modifiers appropriate for the type. At present, the spatial component of WIMS consists of a defined Weed Area, defined by the user for accounting purposes, and a delineated weed occurrence, often by GPS entry.

By capturing core data/metadata elements, later versions of WIMS will have the capacity for real-time harvesting of EDRR records of novel occurrences when expressed as either a *pushed* RDF document or a *pulled* RSS feed. Future integration with geodatabase technology will allow for actual GIS manipulation and reduce geolocational errors, among many benefits. The collaboration of Team Arundo del Norte, through Sonoma Ecology Center, with the UC Davis Information Center for the Environment and the affiliated California Information Node of the National Biological Information Infrastructure has allowed for real-world testing of geodatabase applications, as it pertains to invasive plant tracking and coordinated habitat restoration efforts within the California Bay-Delta region. We look forward to the future integration of GIS technology into standardized data capture frameworks used for natural resource assessment and monitoring.

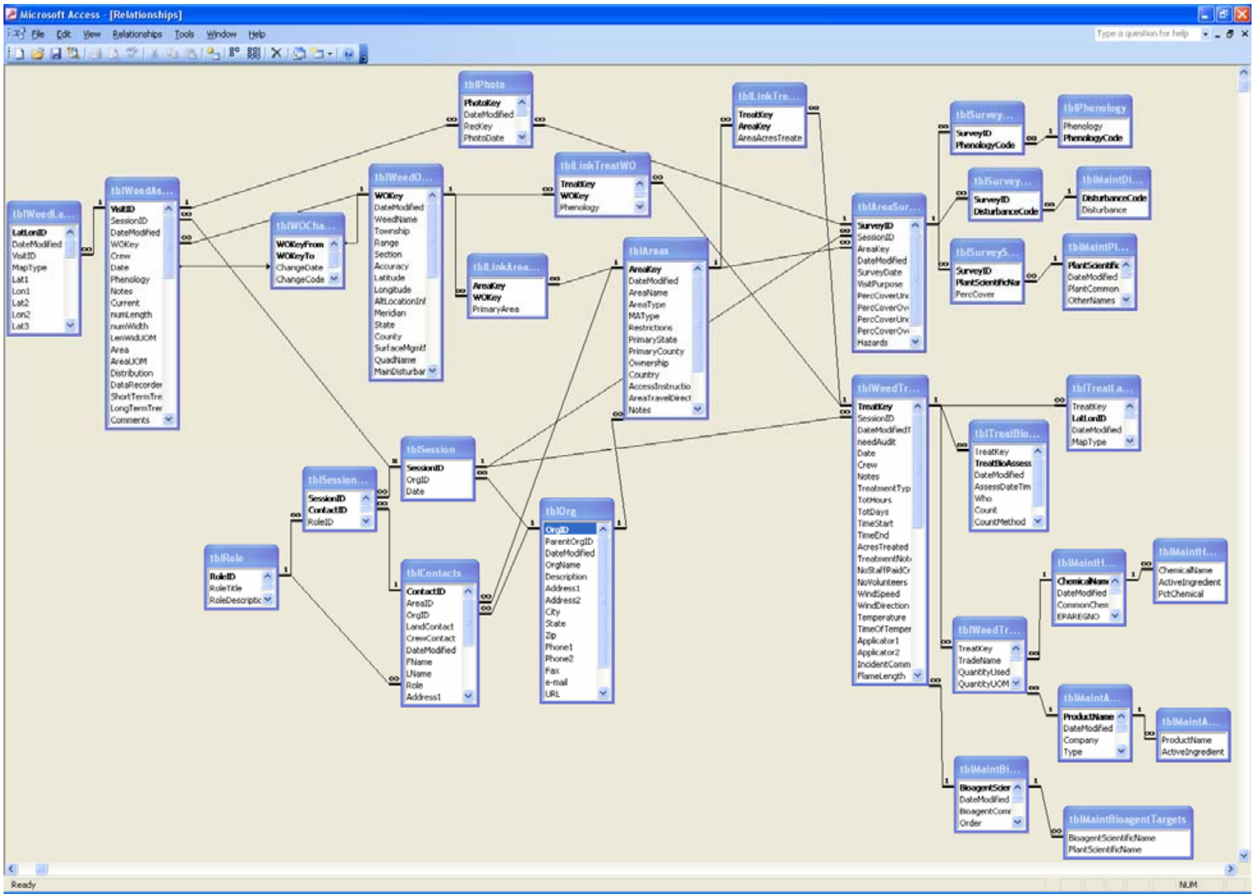

Figure 4. Schematic of WIMS v. 3.0 beta, a work in progress.