Smart Techniques for a Low-Budget, High-Performance Wildfire GIS

The Mission-Driven Wildland Fire Mapping Project
Marine Corps Base Camp Pendleton, California

This paper describes the implementation of the Mission-Driven Wildland Fire Mapping Project at Marine Corps Base Camp Pendleton, California. The project, a simple data-collection and analysis effort, is burdened by the restrictions imposed on field data collection at Camp Pendleton. These restrictions spurred the innovative use of GIS. In 2005 the project produced valuable fire data that can be used for environmental planning. This paper shows how GIS can be used to enhance a project that is limited by some decidedly low-tech methods, and attempts to uncover any implications for other small projects.

Introduction

An accurate fire history is an important asset in environmental resource management. Not only does such information provide a useful means of record-keeping, but it can be an invaluable tool for tracking fire-related environmental changes, such as hazardous fuel loading and vegetation type conversion. Researchers have reconstructed fire histories using remote-sensing data (Minnich 1983), tree-ring burn scars (Swetnam 1993), and stands of even-aged vegetation (Baker and Kipfmueller, 2001). Wildfires are now routinely mapped (via visual observation, GPS, or aerial infrared sensor) by the agencies in charge of fire suppression, and the resulting perimeter data increasingly find their way into GIS-based fire histories. The State of California's Fire and Resource Assessment Program, a database of fire perimeters from the past several decades, is an example. Researchers have used such data in a variety of ecological applications, from estimating past vegetation biodiversity (Romme 1982) to assessing forest stand structure (Wells and Getis, 1999).

At Marine Corps Base Camp Pendleton (Figure 1), the need for historical fire data is especially acute. The base is largely undeveloped (Figure 2), and wildfires spread readily through large areas of dry grass and brush, often interrupting military training. Due to the frequency of weapons-related ignitions, fire "return intervals" (the average number of years between fires at a given place) at Camp Pendleton are likely the shortest anywhere in southern California, if not the entire country (Kellogg et al., 1998). Intensified military training, the recognition of several fire-sensitive species and habitats on base, and increased residential development near the base have put a premium on effective fire management. For example, the coastal sage scrub plant community is sensitive to overly frequent fire, which is typical of some parts of the base. A fire history can directly benefit the effort to conserve this rare resource.

Camp Pendleton's Mission-Driven Wildland

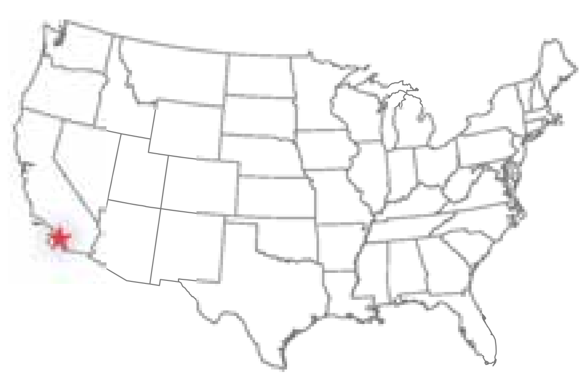

Figure 1: Marine Corps Base Camp Pendleton, California

Figure 2: Camp Pendleton detail. Developed areas are shown in purple. Most of the base is undeveloped grassland and shrubland. Adjacent coastal areas are rapidly developing.

Fire Mapping Project is a multi-year effort to map the perimeters and burn severity (an indicator of the intensity of the fire) of all fires greater than five acres in area. For the 2005 fire season, ITS Corporation took over implementation of the project. As ITS's GIS analyst, I introduced several improvements to field data collection and database design. The restrictive security environment on base imposes several challenges on collecting data, and my work addressing these limitations is relevant to other small GIS projects with limited budgets. These technical approaches, and their implications for projects of similar scope, are the focus of this paper.

Methods

I mapped fire perimeters by either direct field observation with map and compass, or interpretation of aerial photos. These methods, admittedly somewhat quaint, were the best available given field restrictions and budget constraints. For example, the contract expressly forbids GPS, because it involves walking entire fire perimeters, which is not only impossible in the Central Impact Areas (Figure 3), but impractical given the sheer number of fires (and miles of perimeter) at Camp Pendleton. I tested a "mobile GIS" approach, in which I collected fire perimeters with a field computer running ESRI's ArcPad. I found this platform poorly suited to complex polygon feature creation (though effective for attribute data collection). Ultimately, pencil and paper were best (and least expensive

Figure 3: Central Impact Areas, Camp Pendleton. These areas are used for dud-producing artillery fire, and are off-limits to foot or vehicle travel.

by far) for precise and rapid sketch mapping.

The procedure for field mapping was increasingly standardized as the 2005 fire season unfolded. As soon as the base's Fire Department reported a new large fire, I would prepare a field map and take it into the field. A large-scale orthophoto, printed on a standard 8.5″ x 11″ sheet of paper, would serve as the base map (Figure 4). Usually, the map scale was on the order of 1:10,000. I typically supplemented the background orthophoto with the perimeters of earlier fires, as well as any relevant training area or Impact Area boundaries, and draped it semi-transparently over a shaded relief raster derived from 5-foot contour vectors. The orthophoto map held certain advantages over other base maps (e.g. topographic quadrangles). An orthophoto can reveal relatively fresh landscape features, such as new two-track trails. Such features are common at Camp Pendleton. Using a 2003 orthophoto as a base, I could often map fire perimeters to the precision of individual shrubs or trees.

After returning from the field, I would scan the field map at high resolution. The benefit of scanning the field map is that it could be georeferenced. This means that the image could be given a geographic reference (in this case, using the coordinates of the California State Plane Coordinate System, Zone VI, North American Datum of 1983). The procedure involves linking image features to already-georeferenced features in the GIS, and mathematically altering the scanned image with a coordinate transformation. The image, now a georeferenced raster inside the GIS, could be directly traced on the screen. Thus the mistakes associated with changing one's view from the map to the screen, and back again, were avoided. This process permitted a more accurate digitization of fire perimeter features.

Wildfires perimeters in general are increasingly captured by remote-sensing platforms. I investigated satellite imagery as a source of fire perimeters and found either the cost too high or the benefits too scant. Satellites with high temporal resolution, such as MODIS, detect fires as contiguous square-kilometer blocks, which is too coarse a result to be useful in environmental analyses. Images from higher-resolution platforms (e.g. SPOT, IKONOS) are prohibitively expensive, considering the dozens of images that would be required to map a full season of wildfires. Remote-sensing of Camp Pendleton's fires is unrealistic right now, though that may one day change as satellite imagery becomes more widespread (and presumably cheaper).

Aerial photos, taken from a single-engine plane at low altitude (generally 1000-5000 feet) proved an excellent alternative to satellite imagery. I flew several missions in a single-engine airplane in 2005, and took hundreds of high-resolution pictures. It must be noted that the term "aerial photo" should not be taken to imply rectified orthophotographs. My images were, strictly speaking, snapshots, taken at an approximation

Figure 4: Typical field map, showing previous fire perimeter in yellow, firing range in red.

Figure 5: At left, a sample rectified orthophoto, dated 2003. At right, overflight snapshot taken 9 days after a fire. While the scale distortion in the snapshot is visible, the quality of the image is sufficient for delineating the fire perimeter.

of the true vertical. Yet the quality of the data they produced was striking. Most of the photos were taken from just over 1000 feet above the ground; with a good digital camera (6.1 megapixels), one can capture a detailed fire perimeter. I was able to coarsely-georeference many of these photographs to the 2003 orthophoto using readily identifiable roads, trails, and even individual shrubs (Figure 5). If the snapshot angle was too oblique, then I could rotate the orthophoto until it was roughly oriented with the snapshot (this technique was achieved using dual monitors), and visually estimate the perimeter. Such flights saved countless hours in the field, as I was able to gather perimeter and severity data on several fires in one session.

All data, whether field- or photo-derived, were stored and analysed in an ESRI geodatabase. I tried to view these data through an "object-relational" lens as much as was reasonable. The basic unit of analysis was the "severity polygon," each of which represented an area of a given burn severity that burned during a single fire. There could be several severity polygons comprising a single fire (the outer fire perimeter was stored in a separate feature class). In other tables and feature classes, I stored Fire Department responses (whether they became large fires or not), firebreaks, and field compass measurements. The geodatabase structure facilitated rapid analysis (via relationship classes) and a consistent schema for export into the Marine Corps favored data format, the Spatial Data Standard for Facilities, Infrastructure and Environment (SDSFIE).

Project Results

More than 11,447 acres were mapped in 2005 at Camp Pendleton (Figure 6). Some 8381 acres (roughly 73 percent) of this total were burned in wildfires, and the remainder (3066 acres) was burned in several prescribed fires. The bulk of the burned acreage, regardless of ignition source or cause, was classified as lightly or moderately burned. These categories accounted for 96 percent of all mapped fire severity.

The distribution of the 2005 fires is similar to that of previous years, largely in the way burning activity clusters around the Impact Areas. Of the 8381 acres burned by wildfire in 2005, most (around 69 percent) had burned in the previous decade (Figure 7). Put another way, only 31 percent of fires burned over "untouched" terrain, where vegetation had been undisturbed by fire in the preceding decade. In striking contrast, 33 percent of the 2005 burned area had burned at least 3 times in the previous nine years. Such a high fire frequency precludes the buildup of heavy, woody fuels. In the field, it appeared that most fires burned over large grassy areas, where fuels were relatively light. Such fires often stopped at the interface between grassland and shrubland, especially early in the season when fuel moisture in the woody biomass was still relatively high. Much of the repeat burning occurred in such grassy areas, especially along the northern and southern margins of the Central Impact Areas.

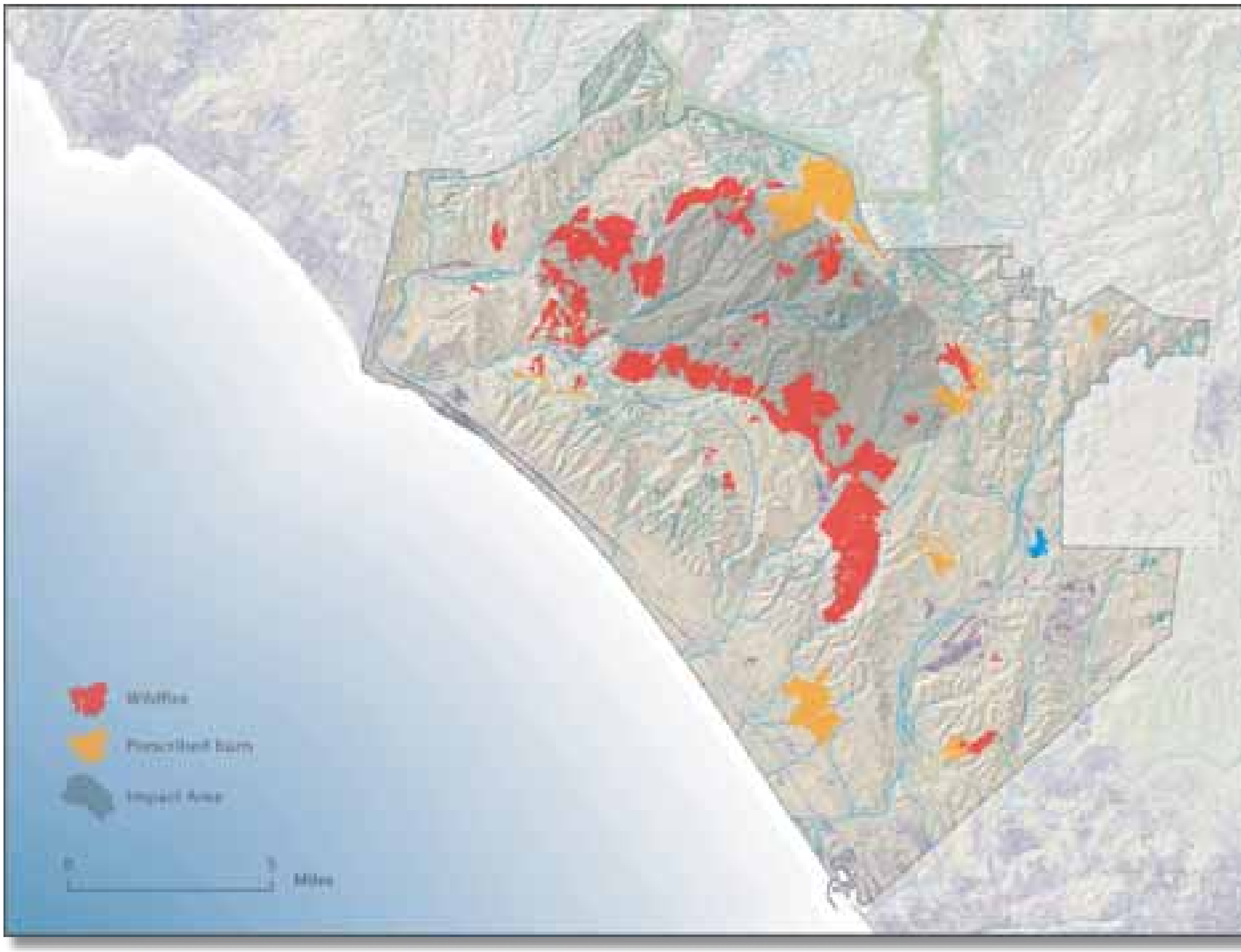

Figure 6: The final perimeters of the 11,447 acres that burned at Camp Pendleton in 2005. Many of the prescribed burns are situated so as to provide buffers of reduced fuel against actual wildfires later in the season.

Wildfire ignitions at Camp Pendleton are directly tied to training activities, as most ignitions result from live fire training of some kind. Training is restricted by the specific Fire Danger Rating of the day, which is based on meteorological observations and predictions from nearby weather stations. Despite the constraints imposed by the FDR, accidental ignitions leading to large fires do happen, more frequently in times of high fire danger (Figure 8). Not surprisingly, ignitions were most frequent during the dry summer months. The graph also depicts the relative infrequency of ignitions during periods of extreme fire danger. This class imposes the most stringent restrictions on training activities involving heat- or flame-producing devices. The relative scarcity of ignitions during these "red" periods might indicate that these restrictions were effectively enforced.

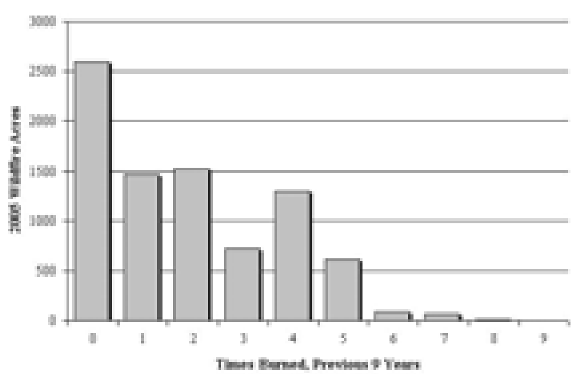

Figure 7: 2005 wildfire acreage by number of times burned since 1996. 69 percent of the area burned in 2005 had burned at least once before in that period.

Conclusion

The 2005 project year was successful by many standards. The project was implemented "on-budget," and to a standard exceeding that specified in

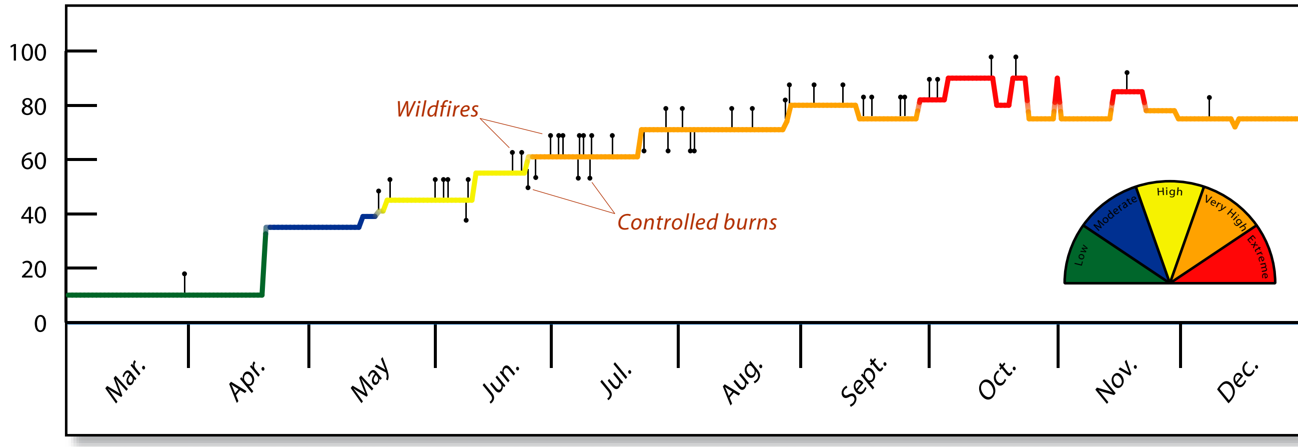

Figure 8: Timeline of fire ignitions, 2005. The y-axis of the graph shows the daily Fire Danger Rating and how it changed over the fire season. The pattern of ignitions reflects the competing interests of live-fire training and wildfire prevention.

the Statement of Work. I improved and standardized existing field and GIS methods. Subsequent mapping will likely benefit from these developments, and more accurate and comprehensive fire data will result. I have also found that GIS software provides superb tools for ensuring a certain consistency in this project's more procedural tasks.

As an example, for the 2006 season I have decided to digitize all compass readings. Very often, a feature I am attempting to map is inaccessible. It may be inside an Impact Area, or within a steep ravine. If I take a magnetic bearing from a known point, I can later digitize that bearing as a line in ArcGIS, using the standard angle-editing tools. Then, I can "snap" the fire perimeter to that line. and be assured that the perimeter at that point is at least based on a field measurement. Moreover, this bearing line is stored in the geodatabase, and serves as a record of how that particular fire was mapped (through a relationship class to the Fires feature class).

The flexibility of the software lends itself to such innovations. A common feature of small-scale GIS projects is their tendency toward entropy. When the contract or project does not explicitly mandate it, there is less incentive to establish procedures for data collection and import, a relational database design, adequate documentation, or any of the other industry "best practices." But these practices are effective for large and small projects alike. A relational database design was not contractually required for the Fire Mapping Project. I found, however, that once I became comfortable with the technology, it really did make analysis easier. As an incentive to innovate, it helps to remember that whether or not one uses the more advanced features of the software, someone has paid for those features anyway. Learning them is almost always worth the investment in time.

Acknowledgements

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ITS Corporation has served the Federal IT Marketplace for over 30 years - Department of Defense, Intelligence, Homeland Security, and other Federal Agencies. Core competencies include systems development and integration, acquisition management, program management, business information management, environmental studies and analyses, and enterprise management and security for a broad spectrum of government customers.