Geospatial Informatics for Management of a New Forest Disease: Sudden Oak Death

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A New Forest Disease: Sudden Oak Death

In central California coastal forests, a recently discovered, virulent pathogen (*Phytophthora ramorum*) has killed hundreds of thousands of trees, including tanoak (*Lithocarpus densiflorus*), coast live oak (*Quercus agrifolia*), and black oak (*Quercus kelloggii*). The disease complex rapidly reached epidemic levels in several coastal forests and was quickly and convincingly dubbed "Sudden Oak Death" (SOD) by both the popular press and the research community (Rizzo and Garbelotto, 2003). As of May 2004, the disease was present in 12 California counties (Figure 1), has been detected on 16.2 ha in southern Oregon (Curry County), and been found in the United Kingdom and the Netherlands. In addition, hosts for the disease are present throughout the western coastal states and the American southeast. Clearly, the disease has the potential to affect many more areas than are currently measurably impacted. In California, where SOD has been evident the longest, epidemic dieback of tanoaks, coast live oaks, and black oaks occurs in large patches along the coast, presenting serious threats to the ecology, wildlife habitat, soil erosion properties, fire regime, and aesthetic value of thousands of hectares of forest (Garbelotto et al., 2001; McPherson et al., 2000; Rizzo and Garbelotto, 2003). Monitoring the disease through time is a critical issue for natural resource management, and for further elucidating disease spread patterns (Kelly and McPherson, 2001).

Figure 1. Images of the disease: a) oak woodland affected by Sudden Oak Death, b) a coast live oak with the disease, removed shortly after photo was taken, and c) high resolution imagery of an area with the disease; the dead crowns appear as grey areas throughout the healthy forest (in red).

Quite quickly after the disease first appeared in California, a unique statewide task force – the California Oak Mortality Task Force (COMTF) – was created by a host of local, state, and federal agencies dedicated to implementing a program for managing, monitoring, and researching SOD, as well as developing outreach and educational programs. The Task Force has continued to expand, and currently includes natural resource managers, foresters, arborists, outdoor enthusiasts, nursery officials and representatives, regulators, fire personnel, and database managers, among others, all united in a desire to develop and apply strategies to alleviate the impacts of this disease. For more information, please see www.suddenoakdeath.org.

How Geospatial Informatics Have Helped

The new disease appeared suddenly on the landscape in Marin County in the late 1990s, and engendered great public and government concerns about spread, trade impacts, increased forest fire risk, and loss of cherished trees. For a geographer viewing the early days of the epidemic, there were several intriguing spatial aspects, including: 1) disease impact, particularly in advanced stages, was clearly visible at multiple spatial scales, making remote sensing useful in the monitoring process; 2) disease spread and consequent mortality were patchy at landscape scales, making spatial analysis useful; 3) the disease appeared to be spatially regulated, making accurate spatial data collected using GPS and maintained and mapped using GIS critical; and 4) public awareness and concern about the disease were high, and public participation was needed in the monitoring/tracking process, making webGIS and cartography immediately useful tools for information distribution and management assistance.

The core factor in these observations is disease location; it is the critical indexing factor, influencing all other aspects of disease research and management. And, as with any location-driven phenomena, geospatial informatics has a role to play. Indeed, research and management of the disease have been driven by the full suite of geospatial informatics tools: GPS, GIS, cartography and geovisualization, remote sensing, spatial analyses, and webGIS.

The SOD Geospatial Informatics Project

Accurate disease location information remains a key component of all management efforts. Early in the process, there was a desire to constrain mapping efforts to the county level because regulation was to take place on a county-by-county basis. However, once the disease appeared in forests bridging infested and uninfested counties, accurate location information was needed to precisely determine the county location of diseased trees, and handheld GPS units became standard for field personnel

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sampling trees with symptoms or at risk for the disease. We developed an easy-to-follow GPS protocol, explaining Position Dilution of Precision (PDOP) and good satellite position, and requesting that location information be captured in Universal Transverse Mercator (UTM) and NAD 83 datum. We have also conducted training efforts throughout the process, including information such as how to take a point under canopy cover. However, not all location data comes from GPS; we also receive disease confirmations with addresses, or photocopies of maps. Once collected in the field, samples are sent to the labs of the California Department of Food and Agriculture, University of California Davis, or UC Berkeley, and all disease presence/absence results are forwarded to our GIS lab at UC Berkeley.

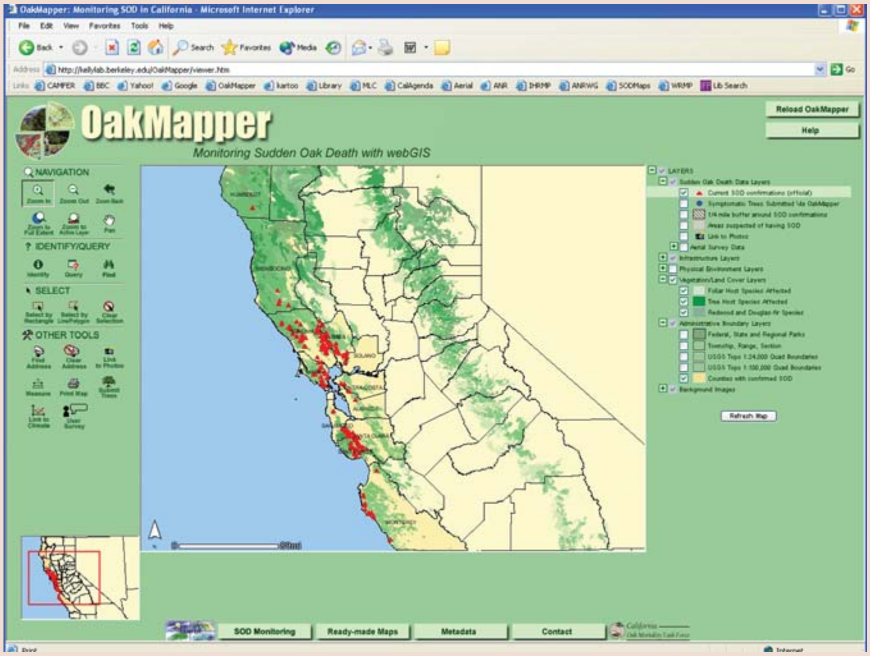

Figure 2. The OakMapper webGIS site, showing GIS database of disease distribution. The site allows customizable map production, user interaction with the database, and public submission of monitoring data.

The location information for positive SOD confirmations are entered in a relational database in UTM Zone 10, NAD 83 format; if addresses or coordinates from other projections are provided, they are geo-coded or re-projected. We require UTM as the initial projection because it prevents rounding errors common with the latitude/longitude (geographic) projection, and produces accurate, easily understood, and consistent area and distance measurements in the field. Data are then re-projected from UTM to a common projection used by the State of California, termed "California Albers," created by the Teale Data Center GIS Lab. California Albers has a Albers Equal Area source projection that has been adjusted so that it can be used for the entire state. (UTM and Stateplane, both commonly used projections, have multiple zones that fall within the state borders.) In addition, numerous ancillary geospatial datasets, including political and jurisdictional boundaries and forest and land cover data were downloaded from various public Internet sources. These data were used, in part, to develop risk analyses of potential and imminent SOD infestation, performed by research partners at the Kelly Lab and Sonoma State University. Furthermore, the COMTF funded annual aerial surveys of tree mortality to assess SOD distribution at a large scale. To do this, palm pilots and portable computers were used for on-screen digitizing and real-time GPS tracking in airplanes. All polygons of mortality as seen by aerial survey crews are also maintained in the spatial database.

Maps are powerful and beautiful tools that can be used to easily communicate complex information. We have developed both static and dynamic tools for cartographic product creation and distribution. The Sudden Oak Death monitoring website offers downloadable, "ready-made" static maps that depict SOD distribution for state, county, and vicinity areas, available in JPEG, PDF, and TIFF formats. These are updated as the SOD database is updated. In addition, we accept requests from users for custom maps, e.g., the area around a specific address or local park. There have been over 250 map or data requests in the past three years from citizens (55%), academics (23%), and regulators (21%). Maps are used for a wide range of purposes, including state legislature briefings and public meetings, and have appeared in many research publications, newspaper articles, and informational websites. In addition to static paper and digital maps, we have used webGIS to create a dynamic, customizable, and user-driven cartographic environment. The webGIS application, called OakMapper, allows user-specific interactions – including scale-dependent zooming, customized map creation, hyperlinked photography, and querying functions – with the spatial database. The webGIS site also allows users to report trees that might have the disease so that follow-up sampling can take place. [Figure 2.]

The development of web-based efforts continues to prove effective in communicating SOD information to researchers, regulators, and the general public by providing a readily available avenue for viewing, searching, querying, and exporting data and maps. The ultimate goal of the OakMapper webGIS is to empower stakeholders to participate in disease monitoring. To this end, the application is designed with non-GIS experts in mind. An online form is used to gather reports of potential SOD sightings by allowing users to: 1) select a host and visible SOD symptoms (chosen from pictures and explanations that aid in identification), 2) enter information about their familiarity with forest and forest diseases, and 3) submit the location of the tree (i.e., GPS coordinates, addresses, or location on map). The numerous submissions to date have demonstrated the success of citizen-generated data in widening the sampling effort for this disease (Kelly & Tuxen, 2003). The OakMapper webGIS took more than a year to develop, and is continual work in progress as improvements are made and data is updated. We found that while a team was needed for the overall webGIS development, we needed a single champion dedicated to customizing a webGIS application for our specific project.

The OakMapper webGIS application is our comprehensive database and cartographic portal, containing all SOD data available for public viewing. As a last resort for those with very low bandwidths (i.e., dial-up modems) an online list of current positive confirmations around California, organized by county, is available. The SOD Monitoring website also catalogs data availability (in ArcView shapefile format) that can be distributed to interested parties. Currently, we do not offer anonymous access to download data; as an intermediate step, we require an email address be provided until we know more about who wants the data and how it is being used. Other similar, password-protected webGIS sites that we have developed aid researchers and regulators in determining the location of ongoing research efforts, and contain data and information not yet publishable to the greater community.

Indeed, the spatial data gathered have been analyzed by multiple groups for many purposes. Because the disease has such dramatic overstory canopy effects (more readily seen in mixed hardwood forests than redwood forests), multispectral and hyperspectral imagery have been used to map its various features. For example, high resolution imagery [primarily ADAR (Airborne Data Acquisition and Registration) imagery at 1-m spatial resolution] has been successfully used to map overstory mortality at a scale larger than is possible using plot-based methods, and to accuracies over 90 percent, but there are still considerable problems distinguishing bare forest gaps from dead trees (Kelly et al., Forthcoming). Pixel-based and object-based classifiers are being tested for this purpose. Hyperspectral data collected using field spectrometers, and from imagers such as CASI (Compact Airborne Spectrographic Imager), is also being used to detect stressed trees and map host distribution (Pu et al., 2003). Mapping host distribution is critical, as it is the California Bay tree (*Umbellularia californica*) that has the greatest potential to build up *P. ramorum inoculum* and spread it to susceptible neighboring trees in wind and rain events (Rizzo and Garbelotto, 2003). In addition, there are several ongoing research projects involving disease risk modeling for the state and country, exploring possible links between fire and the disease, and modeling potential controls on disease distribution and spread at multiple scales (Guo et al., 2003; Meentemeyer et al., 2002). All such efforts require accurate and timely spatial data as an input to the models. [Figure 3.]

Software and Hardware

The University of California at Berkeley has a site license for ESRI, Inc. products, so all SOD GIS data and maps are created and maintained using ESRI's GIS suite, including ArcGIS 8.3, ARC/INFO 8.3, ArcView 3.3, and specialized extensions (ESRI, 2004a; ESRI, 2004b). The OakMapper webGIS application uses ESRI's ArcIMS (version 4), an internet mapping service software package that uses languages like HTML and Java to provide users access to geospatial data residing on a server using any Internet browser. Alternative webGIS software options (e.g., University of Minnesota's MapServer) are also being investigated. All remote sensing work is performed using ERDAS Imagine 8.7 (Leica, 2004).

The online submission form that allows users to enter symptomatic SOD sightings uses PHP and Java programming languages to connect with our Microsoft Access 2000 database. Reports submitted with a specific address are geocoded into a shapefile using ArcGIS and TIGER 2000 street data.

Currently, all GIS data is stored in static vector (e.g., shapefiles, coverages) and raster (e.g., GRID) formats; however, migration of all data to Arc Spatial Database Engine (ArcSDE) is planned in the near future to allow real-time updates, while also retaining the data integrity and security offered by a spatial relational database management system. Future plans also include the integration of portable handhelds using ESRI's ArcPad software to enable GIS data to be created and edited in the field.

We are running the OakMapper on a Quad-Pentium3 PC with two gigabytes of system RAM and 300 gigabytes of hard disk storage. The server infrastructure is set up as a cross-platform system of Microsoft Windows 2000 and Linux Slackware 9, with a security firewall that prevents frequent computer hacking attempts from succeeding.

Global Positioning Systems (GPS) hardware includes a Trimble GeoXT with a Beacon-on-a-Belt (which offers on-the-fly differentially GPS (DGPS) correction) and various models of the Garmin eTrex unit line.

Challenges

We faced several challenges in the development and implementation of this comprehensive geospatial informatics program. These included institutional impediments, such as early lack of support for and skepticism about the high precision and accuracy provided by GPS systems; data management and software challenges, including database and GIS software coordination, and whether or not to go with a complete suite of ESRI products; security challenges – our webGIS component necessarily faced attacks from hackers as it initially relied on Windows IIS software; and issues of individual and contributor privacy, as we often catalog information using individual addresses. These and other challenges have been met in a variety of ways, as discussed below.

As household income is the strongest correlate with home computer use (USDOC, 2002), we performed an economic analysis of our target audience, namely those in or adjacent to infested counties, to address differential Internet access. In this way, we were able to focus our outreach efforts regarding alterative methods of submitting SOD sightings (i.e., by email, fax, or phone to their County Agricultural Commissioner's Office) on lower income counties. In addition, as with any volunteer generated data, the quality of submissions might be in question, and many researchers are skeptical of citizen-generated data. To date, one solution to this problem has been to encourage submitters to provide an email address, so that we can cross-check addresses in hopes of preventing multiple submissions. We have also compared the citizen submission locations to those

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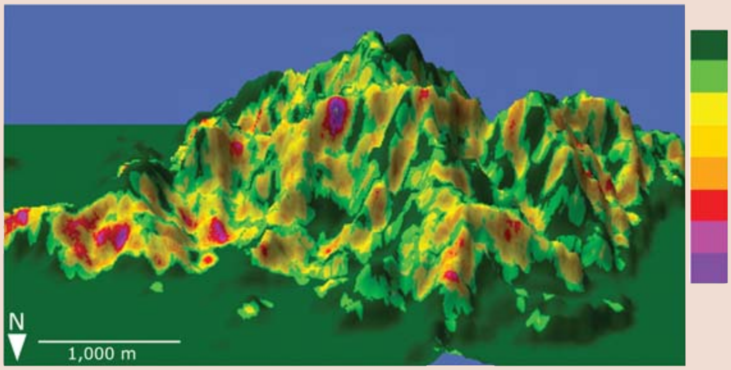

Figure 3. A spatial model of disease distribution based on classified remotely-sensed data, and density models. This data was used to determine various environmental controls on disease distribution and spread.

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of official positive SOD confirmations, and encourage County Agricultural Commissioner's Offices to view reported SOD online to help guide field sampling efforts. Furthermore, we have addressed privacy issues, namely the possible reluctance to contribute one's address or other personal information, by adding an element of error up to one-half mile from the submitted location so as to not publish the exact address of other sensitive information. In addition, we included a message on the online data input form informing the submitter that their approximate location will be published on the OakMapper. Of course, these are not sure-fire answers to the societal and institutional disadvantages that our and other webGIS projects face. As part of our ongoing outreach, research, and development, a user survey is now underway to get feedback about how the OakMapper is being used, and to find out what does and does not work, in order to better focus development towards the needs of the webGIS users.

Conclusions

Key to natural resource sustainability is collection of and access to environmental data (Kearns et al., 2003). Geospatial informatics provide a promising collection of tools and techniques for collecting, storing, and maintaining various types of data related to a location and making them widely available in a highly intuitive, visual format. An important component of the success of our project has been the ability to use these techniques to facilitate two-way communication with the general public. Although geospatial informatics has the potential to increase public participation in natural resource management issues, there are technical, institutional, and social challenges to webGIS implementation and usage that need to be addressed, such as differential Internet and computing access, training, and privacy (Kearns et al., 2003). We hope that this model of data acquisition, storage, analysis, and dissemination will be used more widely in forest health management in particular and natural resource management in general, while proponents of such a system will remain cognizant of the potential challenges. We would happily entertain communications with others developing or who have developed similar comprehensive geospatial informatics programs for natural recourse problem solving.

A project of this caliber requires diverse skills in every area of geospatial informatics, and we could not have been successful without input from many people. The California Oak Mortality Task Force has succeeded in bringing together participants from many walks of life, and in particular, this project has greatly benefited from partners at the Swanton Pacific Ranch at Cal Poly – San Luis Obispo, the Remote Sensing Lab at Region 5 - US Forest Service, the Geographic Information Center at Sonoma State University, the numerous samplers across the state, staff at the California Department of Food and Agriculture pathology labs, and students and staff at UC Berkeley's Kelly Lab, including Qinghua Guo, Desheng Liu, David Shaari, and Ken-ichi Ueda (http://kellylab.berkeley.edu). Without the expertise provided by this group, this project would not be in existence. Funding for this project has come from several sources, and we are indebted to all of them. Funding sources include: National Aeronautics and Space Administration, California Department of Forestry and Fire Protection, US Department of Agriculture-Forest Service, University of California Division of Agriculture and Natural Resources, and others.

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