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# WebGIS for Monitoring "Sudden Oak Death" in coastal California

Nina M. Kelly*, Karin Tuxen

*Center for the Assessment and Monitoring of Forest and Environmental Resources, Ecosystem Sciences Division, Department of Environmental Science, Policy and Management, University of California at Berkeley, 151 Hilgard Hall, #3110, Berkeley, CA 94720-3110, USA*

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**Abstract**

Tanoak (*Lithocarpus densiflorus*), coast live oak (*Quercus agrifolia*), black oak (*Q. kelloggii*), and some shreve oak (*Q. parvula* var. *shreve*) trees in coastal California are affected by a new disease called "Sudden Oak Death." These tree communities are extremely important for habitat provision, recreation, and aesthetics. Research of and community interest in this new disease is very high. We have developed a monitoring strategy that is both informative and interactive, while also having an effective educational component. This paper introduces the monitoring strategy developed by the monitoring committee of the California Oak Mortality Task Force. The overall monitoring strategy is multi-scale, multi-source, flexible, and geographically organized. It uses an Internet-based GIS ("webGIS") software, and has collected information about trees suspected of having Sudden Oak Death from a wide community of users. This paper describes in detail how the webGIS application was developed, implemented, and used, and discusses some of the common application problems associated with the project, as well as the larger societal issues of Internet access, quality control, and privacy.


*Keywords:* Sudden Oak Death; Environmental monitoring; GIS; Internet

* Corresponding author. Tel.: +1-510-642-7272; fax: +1-510-642-1477.
*E-mail addresses:* mkelly@nature.berkeley.edu (N.M. Kelly), karin@nature.berkeley.edu (K. Tuxen).
*URL:* http://camfer.cnr.berkeley.edu.


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## 1. Introduction

A new and virulent pathogen is killing several tree species and some understory shrub species in coastal California. Throughout the central coastal area of the state, dramatic dieback of tanoaks, coast live oaks, and black oaks is occurring, presenting serious threats to the ecology, wildlife habitat, soil erosion properties, fire regime, and aesthetic value of thousands of hectares of coastal forest (Garbelotto, Svihra, & Rizzo, 2001; McPherson et al., 2000). The seemingly rapid decline of the symptomatic tree species has been named ‘‘Sudden Oak Death’’ in the popular press (Rizzo, Garbelotto, Davidson, Slaughter, & Koike, 2002). The Sudden Oak Death pathogen is a new species of *Phytophthora* (a fungus-like organism) named *ramorum,* that enters through the bark on tree trunks and causes rapid canker development that leads to girdling and death of the susceptible tree hosts (Garbelotto et al., 2001). The pathogen also colonizes the foliage of several other overstory and understory hosts without killing them (called here ‘‘foliar hosts’’) (Rizzo et al., 2002). *P. ramorum* has been officially confirmed in 10 coastal counties of California (Fig. 1), and known hosts for the pathogen exist in many more counties across the state. It has also been detected on hosts in 40 acres in southern Oregon, is known to cause leafspots and twig dieback on rhododendron in Germany and the Netherlands, and earlier this

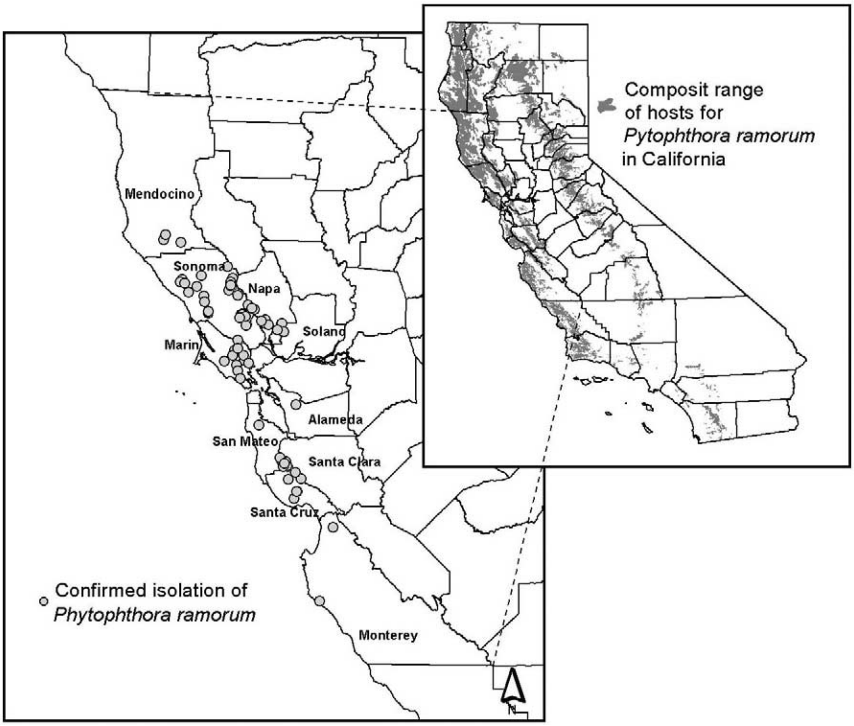


Fig. 1. Distribution of Sudden Oak Death in California as of 18 April, 2002. Data were collected from June 2000 through April 2002.

year was found on *viburnum* plants in a nursery in the United Kingdom (see http://www.suddenoakdeath.org/ for more details). The current levels of mortality in California appear to be unprecedented in recent history (Rizzo et al., 2002).

Oaks are second only to the California Redwood as emblematic of California's rural heritage and natural beauty (Pavlik, Muick, Johnson, & Popper, 1991). Thus, this epidemic is alarming for interested stakeholders who work with and live in and adjacent to the oak and tanoak woodland that surrounds coastal cities. These trees provide food and habitat for a complex food chain that in some areas involves endangered species [i.e. long-toed salamander (*Ambystoma gracile*), kit fox (*Vulpes macrotis*), loggerhead shrike (*Lanius ludovicianus*), and the California condor (*Gymnogyps californianus*) (University of California Division of Agriculture and Natural Resources, 1996)]. The trees complement homes as ornamentals, and act as a stable vegetated over-story on the steep terrain that provides water for many cities in the area. The woodlands provide wildland refuge for people in a rapidly urbanizing part of the state.

If the range and intensity of Sudden Oak Death continues to increase, the large number of dead and dying trees will result in dramatic changes to the social and ecological landscape. A monitoring process, here defined as a method to understand, assess, evaluate, and forecast resource conditions at multiple scales (Bricker & Ruggiero, 1998), is needed for several reasons. Predicting the ecological ramifications of disease requires knowledge of precise disease location, as do all county and local efforts at managing the effects of the disease. Regulatory efforts designed to moderate movement of disease harboring materials also require precise location information. Finally, if we can model the disease movement through time, preventative measures can be more appropriately targeted. In short, a monitoring process is critical to effective management and potential abatement of Sudden Oak Death.

The parties involved in the monitoring process are diverse: the research community desires to understand the spread of *P. ramorum* and other possible pathogens through different vectors; homeowners, naturalists, and recreationists are worried that beloved landscapes and trails will be irrevocably changed; park officials, rangers, and open space managers worry about changes to the wildlands under their control; and local government and natural resource managers are concerned about the fire, water quality, and public safety crises that might result from large numbers of standing and falling dead trees. While it is a challenge to coordinate these diverse groups, an opportunity exists to engage the community in the monitoring process that will provide public goodwill and extensive manpower.

## 2. Community-based monitoring of the environment via the Internet

This work reports on the development of a community-based environmental monitoring program that uses webGIS as its integrating platform. We have borrowed from traditional environmental monitoring, community-based monitoring, Geographic Information Sciences (GIS) and visualization research, and Internet technology and theory. These distinct areas of research, and their union, are briefly described here.

An effective environmental monitoring program requires multi-scale data input from users, near real-time updates, display of results, interaction with data, and relevant analysis of results. This is most commonly accomplished without community involvement or reliance on GIS or visualization, and sometimes without access to the Internet—all of which provide many potential contributors to an environmental monitoring strategy.

First, community-based monitoring involves participation from community members in collecting observations or measurements (Bliss, 2001). Community-based monitoring has become popular in the United States as a way to increase public understanding of local environments while complementing scientific research, and for increasing public understanding of the environmental management processes of all levels of public government (Fleming, 2001). Second, GIS and visualization techniques have proved to be powerful tools in facilitating community involvement in decision-making by making complex systems comprehensible (Al-Kodmany, 1999; Harris, Gimblett, & Shaw, 1995; Harris & Weiner, 1998; Helly, Kelly, Sutton, & Elvins, 2001). Third, the use of the Internet in the monitoring process allows public education and community involvement to become important components of the strategy (Carr, Adkins-Heljeson, Buchanan, & Mettille, 1996; Peng, 2001). The Internet has been used in a small number of cases as a tool to release the results of monitoring efforts to the public (e.g. Smith, 1999; Helly et al., 2001). And finally, emerging webGIS technologies allow for near real-time environmental monitoring and cartographic rendering (Peng, 2001).

However, all the examples cited above demonstrate individual, non-linked aspects of a complete system. A complete community-based, Internet-served monitoring strategy should involve all aspects of a typical monitoring strategy: data input, analysis of monitoring data, presentation of results, and database query functions, while allowing community involvement, cartographic visualization, and access via the Internet. Table 1 outlines three among numerous examples that offer some of these features. These examples clearly highlight the ability of the Internet and webGIS to facilitate interactive community involvement in environmental monitoring. However, none of these examples contain all aspects of a complete community-based, Internet-served environmental monitoring strategy. The site we describe here does have all these components.

Monitoring Sudden Oak Death in California is facilitated through the development of a collection of web pages presently called the "OakMapper," accessed at the Internet address http://hilda.espm.berkeley.edu/. The OakMapper site is the front-end to the webGIS monitoring strategy, meeting the data input, presentation, and interactive querying needs of a large and diverse community of homeowners, recreationists, regulators, natural resource managers, and researchers.

## 3. Monitoring Sudden Oak Death

Sudden Oak Death is characterized by a distinct set of symptoms (Garbelotto et al., 2001; Rizzo et al., 2002) that include brown or black discolored bark on the lower trunk, exudation of viscous sap ("bleeding") from cankers on the bark, the

Table 1
Selected Internet-based monitoring strategies

| Component of monitoring project | Example and dscription | Reference |
| --- | --- | --- |
| Monitoring results are presented in a geographical format. | The Audubon Christmas Bird Count provides critical information on wintering bird population abundance, distribution, and change over time. On their website they provide maps that allow users to access bird abundance data from the CBC. Results are presented as both large-scale maps of average, effort-adjusted abundance, and as maps that allow users to access all information available for any location in North America. The submissions are not interactive, but are compilations of the reports submitted after the annual Christmas Bird Count. | National Audubon Society, 2001. http://www.audubon.org/bird/cbc/ |
| Allows submission of monitoring reports from web users. | The Surfrider Foundation, USA maintains a "Document Pollution" program that allows users to submit details and photographs of pollution events in the coastal zone. A follow-map is not provided on the website, and the process is not interactive. | SurfRider Foundation, 2001. http://www.surfrider.org/what7.htm |
| Site is updated with user-contributed reports. | The United States Geological Survey collects information about ground shaking following significant earthquakes. The public assists the effort by filling out a questionnaire about each earthquake that they feel. "A Community Internet Intensity Map" is updated every few minutes following a major earthquake. This is an example of a truly interactive monitoring project that involves data submission from the community and near real-time updating of results. The users cannot query the database. | United States Geological Survey, 2002. http://pasadena.wr.usgs.gov/shake/ca/ |

presence of fruiting bodies of the fungus *Hypoxylon thouarsianum*, and fine granular powder produced by up to three species of bark and ambrosia (*Coleoptera: Scolytidae*) beetles. Though not all of the symptoms may be present on a tree, the bleeding is a primary symptom, indicating the presence of a canker. In addition, foliage of some affected trees may appear to die rapidly, turning from apparently healthy green to reddish-brown within a few weeks (Svihra, 1999). However, other trees in which foliage rapidly turns brown after an initial change in color from yellow or gray-green are likely to have been infected for more than 1 year (McPherson et al., 2000). These distinct visual symptoms allow for reporting of trees that are suspected of having Sudden Oak Death; these can then be visited and sampled for confirmation.

The California Oak Mortality Task Force (COMTF, 2001) is a multi-agency organization that was created in August 2000 to bring together public agencies, non-profit organizations, and private interests to address the issue of elevated levels of oak mortality. The task force seeks to minimize the impacts of Sudden Oak Death on oak woodland communities and to coordinate an integrated response by all interested parties to address Sudden Oak Death. A critical portion of the COMTF is its monitoring strategy. The monitoring strategy developed by the monitoring committee of COMTF has two distinct efforts. The first involves a stratified sample of 2% of the area containing hosts for the disease, with site visits to survey for the disease. Because this first portion of the monitoring process covers so little actual area, a second monitoring effort was developed that is driven by visual symptom recognition. The second effort is not statistically based, and it involves (1) gathering reports of occurrences of elevated oak mortality from around the state, (2) confirmation of those reports as Sudden Oak Death, (3) presentation of near real-time results of confirmations, and (4) analysis of the mapped results. The strategy is multi-scale (it collects and displays data at multiple scales from individual trees to regions of elevated oak mortality), multi-source (gathering and storing information from many different sources), and flexible (it can be adapted to include different sources) (Kelly & McPherson, 2001).

The data gathered is organized in a spatial framework for several important reasons. First, GIS and spatial databases provide a standard framework with which to collect, analyze, and display natural resource data (Burrough & McDonnel, 1998). Second, precise geographical information is critical to regulation and policy development (Arnold, Civco, Prisloe, Hurd, & Stocker, 2000; Franklin, Woodcock, & Warbington, 2000; Sanders & Tabuchi, 2000), especially in the case of diseases and pest infestations; situations like these require the establishment of zones of infestation developed from precisely mapped data within which certain restrictions on material movement apply. Third, geographical distribution data are necessary for developing models of the potential habitat of pathogen hosts and potential risk maps (Dettmers & Bart, 1999; Condit et al., 2000).

### 3.1. Reported oak mortality

Reports of elevated levels of oak and tanoak mortality come from multiple sources and can be grouped into three broad categories: point information (i.e. symptomatic individual trees), polygonal information (i.e. zones of elevated tree mortality), and continuous coverages (i.e. results from airborne scanners or sensors). This paper concentrates on reports generated through our webGIS monitoring platform that are represented as point data. Therefore the discussion is focused on descriptions of reported disease occurrence. For more detail on the other monitoring efforts, see the mentioned references (i.e. Garbelotto, Rizzo, Daividson, & Frankel, 2002; Kelly & McPherson, 2001; McPherson et al., 2000; Rizzo et al., 2002).

Information about individual trees comes from several sources including researchers, state park and open space rangers, county staff, and the public. The presence or absence of key Sudden Oak Death symptoms is collected along with the location of each suspect tree surveyed (an $x$, $y$ coordinate from hand-held GPS, address, or point on a map) and recorded using a field protocol document. All reports of trees suspected of having Sudden Oak Death within the infested area are forwarded to the California Department of Food and Agriculture County office for follow-up confirmation of presence of the pathogen *P. ramorum*. Those reports outside of this area are forwarded to Dr. David Rizzo's laboratory at University of California at Davis.

Polygonal or extent information comes from a variety of sources. Aerial surveys are commonly used by the California Department of Forestry to monitor fires and insect infestations, and are now being used to collect a broad coverage of polygons depicting areas of elevated oak mortality. To date, aerial surveys have been flown in 2001 over San Mateo, Santa Cruz, San Benito, Monterey, Alameda, Contra Costa, and Marin Counties and stored as polygons in the geospatial database. Surveys will continue in spring 2002.

Large area continuous coverage of forest and woodland condition can be provided by analysis of remotely sensed data (Danson & Rollin, 1997; Everitt, Escobar, Appel, Riggs, & Davis, 1999; Macomber & Woodcock, 1994; Pinder & McLeod, 1999). The Task Force has acquired both high-resolution imagery (Airborne Data Acquisition and Registration (ADAR) at 1m spatial resolution) and coarse resolution imagery (Thematic Mapper at ~30 m spatial resolution) and is involved in mapping forest mortality in areas affected by Sudden Oak Death (Kelly, 2002; Kelly & Meentemeyer, submitted for publication).

### 3.2. *Confirmation of Sudden Oak Death*

Reports of oak mortality must be treated with caution until a confirmation process has been performed on an individual sample. There are many fungus-born and other tree diseases that produce symptoms similar to those produced by this new species of *Phytophthora* (Garbelotto et al., 2002). The existence of bleeding on the trunk or other symptoms is insufficient for confirmation of Sudden Oak Death. Confirmation is a time-consuming process that involves culturing the pathogen from material removed from the border of the "bleeding" canker. After about a week, the pathogen can be identified based on morphological traits (Garbelotto et al., 2001). The presence of *P. ramorum* in the culture confirms the presence of Sudden Oak Death in the sampled tree. The large majority of this type of confirmation work has, up to this date, been done in the laboratory of Dr. David Rizzo at the University of

California at Davis. He and his field staff have sampled every tree reported to them and tested each for the presence of *P. ramorum*. In late spring of 2001 the task of confirming disease presence in infested areas was transferred to the California Department of Food and Agriculture.

The morphological confirmation method can result in "false negatives" when a sample has not been successful in culturing the pathogen. This happens with contamination or when cankers are old (Garbelotto et al., 2001). Because of these "false negatives" there is considerable effort being placed in developing a more reliable and consistent molecular detection method. Much progress has been made in the laboratory of Dr. Mateo Garbelotto at the University of California at Berkeley on refining a Polymerase Chain Reaction (PCR) method that can be used to diagnose the pathogen's presence directly from host material (Rizzo et al., 2002).

## 4. Method

### 4.1. OakMapper website development

Reports of Sudden Oak Death and confirmation sample results are maintained in a spatial relational database system that is accessible to the public via the OakMapper website by geographic and tabular searching and viewing. The software used to present and query the data is ArcIMS version 3.1, a webGIS software package developed by ESRI, Inc. (Environmental Systems Research Institute, 2001). The back-end database uses Microsoft Access 2000 to store the data in an integrative and relational database management system. Various programming languages, such as Java, Microsoft Visual Basic, and Microsoft Active Server Pages, support connectivity between ArcIMS and the Access database.

Most webGIS applications use standard protocols like http and tcp, and languages like HTML and Java, to provide users access to geospatial data that resides on a server, using any Internet browser, such as Microsoft Internet Explorer and Netscape Navigator. Typical webGIS packages are a combination of map design software combined with server software. The map design software creates the view of the data that will be presented via the website. This includes views of various map layers with appropriate color, line weight, pattern, and other symbology. The ArcIMS software also allows for scale-dependent behaviors; zooming into a region will prompt larger-scale data to be displayed. At the heart of webGIS is the server software, a collection of modules with an interface for administration that controls the functionality and performance of the website. The ArcIMS server software can be implemented as an image server or feature server. An image server serves the data on the server side and creates images in .JPEG format, which it sends to the browser client in response to user operations (i.e. pan, zoom, select). A feature server is client-side and streamlines the spatial data from the server to the user's machine, where it is then reconstructed into maps using the point, line, polygon, and pixel data that is sent from the server to the client.

The University of California at Berkeley has a site license for ESRI, Inc. products, and ArcIMS version 3.1 was chosen to develop the interactive OakMapper webGIS application as part of the Task Force's monitoring strategy. ArcIMS provides a highly scalable server architecture, with high-quality cartographic rendering on several supported platforms: Windows 2000/NT and Solaris 2.6/7. Currently, we are running the OakMapper as an image server on a Windows 2000 server.

#### *4.1.1. Creation of GIS database*

A GIS database was created in both ArcView 3.2 and ArcInfo 8.1 (ESRI, 2001). Data types and sources are listed in Table 2. All base data were imported and reprojected to Teale-Albers Equal Area, the projection recognized by the State of California, and maintained in vector shapefile or raster GRID format. All reports of oak mortality (point and polygon) and confirmed Sudden Oak Death (point and polygon) are also maintained as shapefiles in Teale-Albers Equal Area. Continuous data are stored in GRID format. All data reside on a Quad-Pentium3 PC with 2GB of system RAM and 200GB of hard disk storage. This server is part of the Kelly Laboratory at the Center for the Assessment of Forest and Environmental Resources (CAMFER) at UC Berkeley.

#### *4.1.2. Reports of symptomatic trees*

In order to gather more reports of Sudden Oak Death, in addition to the sample reports sent to the CDFA, we have modified the Task Force's basic field protocol to a web-based submission form. This online form collects locations of and information about affected trees in California, submitted by rangers, arborists, hikers, homeowners, and other interested parties. While this online submission process is not intended to depict official confirmations of the disease, it serves as a repository for reports and observations of symptomatic trees, making it possible to further visualize the potential distribution of Sudden Oak Death. The interactive form allows users to identify the tree species under observation using a CalFlora floristic guide (CalFlora, 2000) to assist in tree identification, to describe the symptoms of the affected tree or trees, and to enter the location of the tree or group of trees. The symptoms listed include those typical to Sudden Oak Death (i.e. bleeding, bark beetle activity, hypoxylon, crown and leaf discoloration, etc.). Reports can also be made by phone or fax for those that do not have access to the Internet, or by email for those who might be prohibited from downloading the time-intensive graphics produced by typical web displays. Reports of Sudden Oak Death are then forwarded to the local County office staff trained in sampling the disease.

On submission of the form, the data is automatically entered in the Microsoft Access 2000 database. Reports submitted with a specific address are geocoded into spatial data in ArcView/ArcGIS, using TIGER ©2000 street data. This geocoding creates a shapefile that is accessible by the OakMapper webGIS application (Fig. 2).

#### *4.1.3. Visualizing, querying and analyzing the database*

The database of reported and confirmed Sudden Oak Death is updated when new records arrive from CDFA or the Rizzo Laboratory and the database is subsequently

Table 2
Base geographic data types and sources

| Data Type | Source | Source scale, or relevant spatial information | Notes/acknowledgements |
|---|---|---|---|
| *Sudden Oak Death reports, negative samples, and confirmed cases of Sudden Oak Death* | | | |
| Sudden Oak Death confirmations reported by CDFA or UCD/UCB | California Department of Food and Agriculture, UC Davis Researchers | Gathered with hand-held GPS (Garmin GEOIII). Accuracy is between 3 and 10 m. | CDFA, Dave Rizzo, Garey Slaughter |
| Sampled and negative for Sudden Oak Death | California Department of Food and Agriculture, UC Davis Researchers | Gathered with hand-held GPS (Garmin GEOIII). Accuracy is between 3 and 10 m. | Cheryl Bloomquist, Dave Rizzo, Garey Slaughter |
| Symptomatic trees submitted via OakMapper | Various sources (submitted to OakMapper Tree Submission, e-mail, fax, from County Ag. Comm. Office) | Location varies from handheld GPS (5 and 10 m accuracy) to geocoded street address (up to 1000 m). | Data captured from OakMapper site, and through reports from rangers, the public, and others. |
| *Base Data for OakMapper website* | | | |
| Topography—digital elevation models | United States Geological Survey | 1:24,000 quads, 10-m and 30-m spatial resolution | Free, downloadable. |
| | | | Rural area quads are 30-m and urban area quads are 10-m resolution. |
| Vegetation: tree species affected, foliar host species | California Gap Analysis Project | 1:1,000,000 | Free. |
| | | | Used to produce Host species coverage. |
| Streets of California | U.S. Census Bureau TIGER ©2000 | 1:24,000 | Free, downloadable. |
| Highways & Interstates | California Gap Analysis Project | 1:1,000,000 | Free, downloadable. |
| County boundaries | California Spatial Information Library | 1:1,000,000 | Free, downloadable. |
| Major Cities | Digital Chart of the World | 1:1,000,000 | Free, downloadable. |
| Park area, Open Space | Bureau of Transportation Statistics | 1:1,000,000 | Free |
| Digital Raster Graphs | United States Geological Survey | 1:100,000 scanned maps | Free, downloadable. |

Metadata for all data is listed in the OakMapper webGIS application at: http://hilda.espm.berkeley.edu/. To view metadata, click on the data layer in the OakMapper's table of contents.

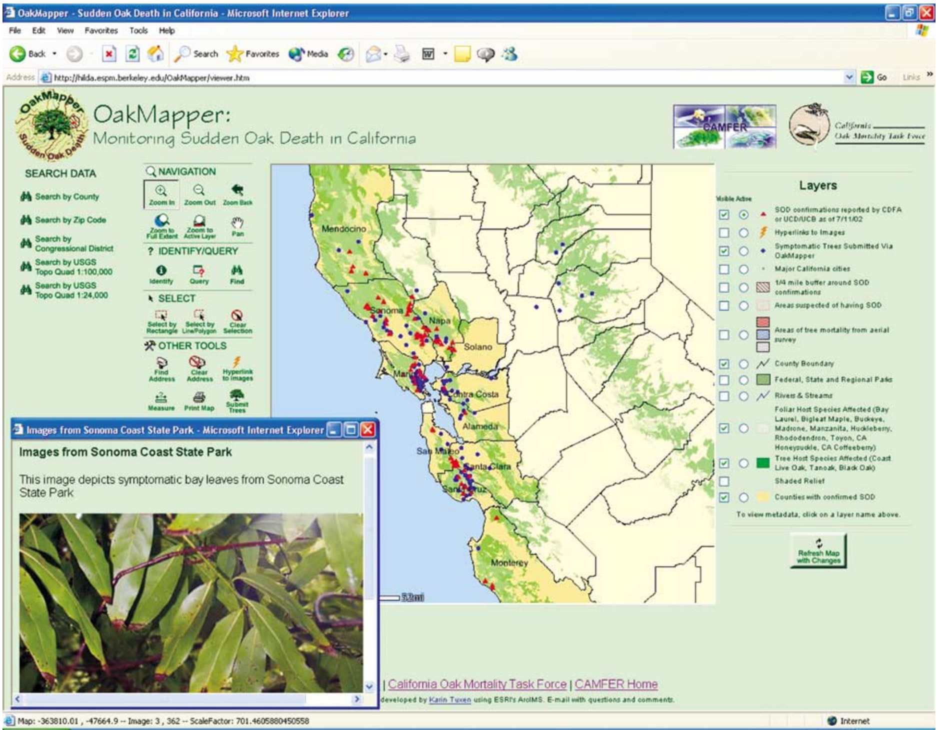


Fig. 2. Online version of OakMapper Distribution Browser. Window displaying the infested area showing reports from counties outside of the infested area. In the lower left corner is a pop-up window showing an image of disease symptoms.

mapped to the ArcIMS server and reflected on the OakMapper website. The cartographic rendering portion of the process involved development of a color scheme that clearly distinguishes between reported oak mortality and confirmed Sudden Oak Death, while allowing symbolization of symptom intensity, and spatial accuracy and precision in the reporting. The resulting four-color scheme is based on Brewer (1994); it is shown in Fig. 3, and described here.

1. All reports of elevated oak/tanoak mortality are depicted in blue, with increasing color saturation denoting severity of symptoms.
   a. Reported oak mortality in polygonal form (i.e. aerial sketch maps) is depicted with partially transparent shaded polygons. The polygonal data was less precise than point data, and we wanted to convey that through a partially transparent shading.
   b. Reports of individual trees are depicted as point symbols. We receive reports from users throughout the state that are geocoded and mapped as point data in shades of blue.

2. All reported oak mortality that did not yield positive confirmation of *P. ramorum* in follow-up sampling is symbolized with gray color. Currently, negative samples are not mapped to the public distribution map. This decision was made in deference to the County Agricultural Commissioner's offices staff, who were concerned that the high level of potential false negatives, if mapped, would give a false sense of security to those in the area by implying that the disease was definitely not present.
3. Trees confirmed with Sudden Oak Death are symbolized as red triangles. Polygons describing areas of known infestation are rendered in red.

All affected tree species (i.e. coast live oak, tanoak, and black oak) are depicted in a dark shade of green, and all foliar hosts (i.e. California Bay Laurel, Madrone, and Rhododendron) are depicted in a light shade of green. Park areas, open space districts, and other wildlands are depicted in light green with a thick dark green boundary.

The database can be queried by data field or by a user-defined spatial feature. Users can search and query by various criteria (i.e. county, zip code, congressional district, symptom, species), and also can draw a box or polygon around an area of interest, and attributes for the spatially selected features will result. For example, if a user knows the congressional district in which he or she is located, it can be entered as criteria for a query (i.e. 'Congressional District' = "1"), and all confirmation results for that district are displayed. A user can also search for confirmed Sudden Oak Death by entering an address. The query results are presented in a separate

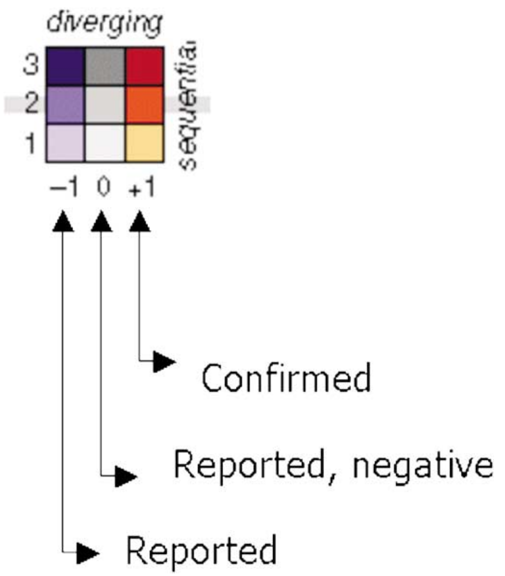


Fig. 3. Cartographic symbology of points and polygon features depicting reported, negative and confirmed Sudden Oak Death, from Brewer (1994).

window. Georeferenced hyperlinks to images of tree condition are also provided for users to see the disease symptoms from locations around the infested area.

## 5. Results from the use of the OakMapper

The OakMapper has been in place since August 2000, with an extensive re-design in the fall of 2001. In the first months of the project, the site was primarily a server for spatial data, displaying the current distribution of confirmed Sudden Oak Death. Since January 2001, the online tree submission functionality has been active, and users from around the state are logging locations of trees with Sudden Oak Death symptoms. The number of visitors accessing the OakMapper application averages about 20 per day, with more than 1200 visitors since February 2002. We have received 184 sub-

Table 3
OakMapper submissions by county of origin

| County | Number of submitted reports |
|---|---|
| Alameda * | 8 |
| Contra Costa | 9 |
| El Dorado | 4 |
| Kern | 1 |
| Lake | 1 |
| Los Angeles | 5 |
| Madera | 1 |
| Marin * | 50 |
| Mendocino * | 4 |
| Monterey * | 1 |
| Napa * | 7 |
| Nevada | 2 |
| Orange | 1 |
| Sacramento | 1 |
| San Diego | 10 |
| San Luis Obispo | 3 |
| San Mateo * | 2 |
| Santa Barbara | 1 |
| Santa Clara * | 6 |
| Santa Cruz * | 25 |
| Shasta | 1 |
| Solano * | 1 |
| Sonoma * | 22 |
| Ventura | 1 |
| Out of state | 2 |
| Unknown, or misleading location | 15 |
| Total | 184 |

*Indicates a county that is within the California Board of Forestry's declared Sudden Oak Death Zone of Infestation. Data were collected from June 2000 through April 2002 mitted reports, with the current rate being about five per week. Of the total submitted reports, 172 (94%) provided an e-mail address for follow-up, and among those submitted reports, 162 (94%) were unique submitters. Submitted reports have come from those who self-identified as professional arborists (10%), hobbyists (6%), and academics (6%); however, most commonly, the question that asked about the background of the submitter was left blank (59% of the submitted reports). Seven percent of the submitters claimed "limited" experience, and 12% claimed "other" background status. Table 3 displays the breakdown of submitted reports by county and Table 4, by tree species. These reports have come from 24 counties in California; among these counties, all 10 infested counties are represented. While reports come from all over the state, 69% of submitted reports come from within the infested counties, and another 8% from counties that border infested areas. This statistic is important, as it suggests that educational efforts aimed at the local population are succeeding in encouraging people to observe and report potentially problematic trees.

The most common tree species reported was coast live oak (46% of the submitted reports), followed by tanoak (17%) and black oak (11%) (Table 4). A small percentage of reports described symptoms on tree species that are as of yet not hosts for *P. ramorum*. It is not known whether the users are identifying the trees incorrectly, or if they are observing look-a-like symptoms on other trees. The symptom most commonly reported was not the key indicator of possible Sudden Oak Death (i.e. bleeding), but the more ubiquitous symptom of dead leaves (Table 5). Dead leaves, leaf discoloration, and crown discoloration are possible symptoms of several oak diseases, and therefore might present a weak association between symptom and

Table 4
Species records submitted to OakMapper

| Common name | Species name | Number of submitted reports |
|---|---|---|
| Bigleaf Maple * | *Acer macrophyllum* | 1 |
| California Bay Laurel * | *Rhamnus californica* | 2 |
| Coast Live Oak * | *Quercus agrifolia* | 92 |
| Tanoak * | *Lithocarpus densiflorus* | 33 |
| California Black Oak * | *Quercus kelloggii* | 22 |
| Huckleberry * | *Vaccinium ovatum* | 1 |
| Interior Live Oak | *Quercus wislizeni* | 5 |
| Madrone * | *Arbutus menziesii* | 2 |
| Redwood | *Sequoia sempervirens* | 1 |
| Shreve Oak * | *Quercus parvula var. shrevei* | 1 |
| Valley Oak | *Quercus lobata* | 1 |
| Other | | 21 |
| Unknown, or misleading information | | 17 |
| Total | | 199[a] |

*Indicates species that are know to be affected by Sudden Oak Death

[a] The total does not match total submitted reports as users are able to enter more than one species, if desired.

Table 5
Symptom records submitted to OakMapper

| Symptom | Number of submitted reports |
|---|---|
| Dead leaves | 94 |
| Hypoxylon | 65 |
| Bleeding | 77 |
| Frass | 49 |
| Crown discoloration | 74 |
| Bark discoloration | 57 |
| Beetle boring activity | 36 |
| Shoot dieback | 19 |

Sudden Oak Death confirmation. Seventy-seven reports were submitted that described bleeding. There was no correlation between reports of bleeding and reports of any other symptom (Tables 6 and 7). Bleeding alone was reported in one case, and associated with every other symptom at least once, but no common combination of bleeding and any other symptoms or suite of symptoms was found. These results seem to indicate that the public submitting Sudden Oak Death reports is getting the tree species correct, but that considerable outreach and training in disease symptomology is still needed.

Due to the accessibility and ease of use of the OakMapper, there have not been any e-mail or fax submissions substituted for the online submission. As part of the sampling effort, an additional 418 submissions have been faxed by official trained samplers (local arborists, foresters, and field technicians) from various counties. As these are not part of the OakMapper online submission process, they are used in conjunction with the OakMapper as part of the Task Force's overall monitoring strategy and analysis.

Table 6
Combination of symptoms submitted to OakMapper

| Symptom | Number of submitted reports |
|---|---|
| Bleeding alone | 34 |
| Bleeding with frass | 31 |
| Bleeding with dead leaves | 37 |
| Bleeding with crown discoloration | 29 |
| Bleeding with leaf discoloration | 8 |
| Bleeding with bark discoloration | 39 |
| Bleeding with beetles | 22 |
| Bleeding with shoot dieback | 8 |
| Bleeding with hypoxylon | 37 |

Table 7
OakMapper reports listing by combination of bleeding with number of other symptoms

| Symptom | Number of submitted reports |
|---|---|
| Bleeding Alone | 16 |
| Bleeding with 1 additional symptom | 9 |
| Bleeding with 2 additional symptoms | 7 |
| Bleeding with 3 additional symptoms | 11 |
| Bleeding with 4 additional symptoms | 9 |
| Bleeding with 5 additional symptoms | 9 |
| Bleeding with 6 additional symptoms | 7 |

## 6. Discussion

### *6.1. Advantages of the monitoring strategy*

The webGIS and database technology used in the monitoring process of the Sudden Oak Death Project is at the forefront of technological advancement in the environmental monitoring arena today. The infrastructure that houses the OakMapper and it various components is stable and robust, and has the flexibility to adjust to much more data if needed, including large quantity of submitted reports about trees. Data integrity is inherently maintained with the use of a comprehensive relational database. Also, the ArcIMS software comes with administrative tools designed to aid in the management of the map server's response to client requests. The ArcIMS administrator is able to track the number of visitors and change the server properties to best accommodate for any number of simultaneous visitors at a given time. The anytime–anywhere access to the OakMapper through the Internet has acted as an education tool, offering a vehicle for the public to continue to become acquainted with the Sudden Oak Death data and to learn more about the disease. With the advancement of Internet technology and the continual increase of public use of the web, an increasing amount of users will be able to learn about Sudden Oak Death and get involved in the monitoring of the disease.

### *6.2. Societal issues*

#### *6.2.1. Access constraints*

The Internet can streamline some aspects of the monitoring process; data input, map presentation, database queries, and community involvement are all facilitated through a webGIS structure (Sugumaran, Davis, Meyer, Prato, & Fulcher, 2000). However, the use of the Internet brings up new and important concerns, such as access to data. This point is reflected in previous work in Public Participation Geographical Information Systems (PPGIS). The reliance on GIS in decision making can marginalize average citizens in the public policy debate (Aiken & Michel, 1995; Harris, & Weiner, 1998; Harris, Weiner, Warner, & Levin, 1995), just as differential access to the Internet can marginalize a class of people who do not own or are not skilled in using computers and the Internet. Because of the wide geographic region that is affected by Sudden Oak Death, such differential access most likely exists, and is a concern to us.

The Economics and Statistics Administration (ESA) and the National Telecommunications and Information Administration (NTIA) recently reported that as of September 2001 54% of Americans use the Internet (US Department of Commerce, Economics and Statistics Administration, 2002), and the western region of the United States was among the areas that showed the highest Internet usage. According to this report, household income is one of the strongest correlates with home computer and Internet usage. Reported mean county income levels describe very diverse amounts of possible Internet use across the area affected with Sudden Oak Death. In Marin County, where the disease is very advanced, mean household income is the highest in the region at 60.9 thousand dollars annually, well above the state's average household income, suggesting a high home computer usage. (This is backed by an informal poll taken at a recent conference designed to train local arborists to identify Sudden Oak Death symptoms in Marin County. Ninety-five percent of this specialized group reported that they use the Internet often, and feel comfortable doing so—(Andrew Storer, personal communication, 31 March 2001) In Monterey County, the average household income drops below the state's average to 38.3 thousand dollars annually. Differential access to the Internet and thus to the submission process is probably considerable. However, the submission process does accommodate those with limited access, or without access to the Internet. Members of the public can submit reports about affected trees through e-mail, fax, or the conventional means of reporting to local county staff. In fact, submitters are also asked to report the tree to their County Agricultural Commissioner's Office in addition to their online submission to the OakMapper. These reports are then funneled to our database. We do not guard against duplicate entries, but we can report if multiple submissions come from a single address, or from a single location. While the report by the ESA and NTIA reported that the rate of increase in Internet usage is highest among those with lower income levels, the issue of differential access to the Internet is one that should be monitored by collecting information about users and the demographics of counties concerned with Sudden Oak Death.

Further differential access may be affected by the size of the OakMapper's webpages. Bandwidth limitations with user's Internet connections could affect the time it takes to use the application. The OakMapper's two largest pages are the submission page and the ArcIMS map viewer page, 180 and 600 KB, respectively. The submission page includes several thumbnail graphics of symptoms and tree species. The submission page has some delay associated with the graphics, but most 56K dial-up Internet connections can load and submit the page in seconds. The ArcIMS page is back-ended by JavaScript which requires several separate pages of programming code. Because of this, the page may be especially time-consuming for home computer users. For users accessing the ArcIMS site with a dial-up Internet connection, it takes between 60 and 90 s to load the initial map, and the same amount of time to perform a spatial action (i.e. pan, zoom, etc.). When loaded from a high-speed Internet connection or Local Area Network (LAN), it takes between 10 and 30 s. As web software and technology improve, the time required to run a webGIS application will be greatly reduced.

#### 6.2.2. Quality control

Community-based environmental monitoring includes a range of measurement and observational activities involving community participation (Bliss, 2001). While the importance of community ''ownership'' of a monitoring process is recognized as an important component to public education of environment (Jacoby, 1997), the quality of the submissions from the public in community monitoring projects is often questioned (Mayfield, Joliat, & Cowan, 2001). At this point, there are no sample results from the online reports, but future plans include comparisons of the reports with sample results to better understand the ability of the public to identify problematic trees. Also, currently the Task Force sends status reports of the online submittals from the OakMapper to the appropriate county's Agricultural Commissioner's Office, so the distribution of Sudden Oak Death might be further depicted. Previous reports and sample results show that distance to zone of infestation is the most reliable predictor of a report resulting in a positive confirmation. This might indicate that those members of the public closer to affected trees are better at diagnosing the disease, but it also might be the case that reports of symptomatic trees from infested areas are more likely to have the disease than those from uninfested areas. This relationship between public reports and confirmation rates will continue to be explored.

#### 6.2.3. Privacy

Protection of personal privacy in the Internet age continues to be an issue of public concern. Since people are submitting information about the location of their home (with an address), we incorporate an element of error of some amount up to 1000 m to ensure that no individual home can be pinpointed via the OakMapper website. Submissions are accompanied by a message expressing the submitter's understanding that their approximate location information will be available to the public. Still, there is possibly reluctance in the public arena to contribute personal information to such databases. It is unknown if the site suffers from this reluctance, but this issue will continue to be evaluated through ongoing outreach meetings about Sudden Oak Death that are sponsored by the California Oak Mortality Task Force.

## 7. Conclusions

WebGIS database access is a new and useful method that facilitates community involvement in environmental monitoring. Most web-based monitoring applications have thus far involved either the gathering of information, and/or the presentation of previously acquired monitoring results online. However, there is progress to be made in environmental monitoring by combining aspects of community involvement, GIS and visualization, and access through the Internet. The OakMapper is one example of such a web-based monitoring system that utilizes this integrated approach to monitoring, with sufficient attention being paid to important issues like privacy and quality control. It has been accessed by users in numerous counties in the state. It has facilitated public access to comprehensive, easily understood environmental information; it is our opinion that the site provides an effective tool for communication, interpretation, and application of environmental data and information; and it has created a geographically based data framework that helps communities visualize Sudden Oak Death location and spread. In addition, researchers can develop hypotheses of local and landscape scale patterns of disease occurrence to investigate their possible environmental controls.

As Internet technology and webGIS software improve in the near future, current limitations will be resolved, allowing for further use of the Internet as an integral part of a monitoring effort. Among these limitations is restricted access to large webpages due to factors such as bandwidth, computer capability, and Internet connection speed. These factors produce differential access that inherently exists in many geographic regions. Further exploration in quality control of the OakMapper tree reports is needed; the quality of the reports affects the data integrity, and measures must be in place to ensure the most accurate, complete, and standardized data possible. Finally, issues concerning the privacy of the submitters to the OakMapper must be addressed and evaluated to find more ways to guarantee that each user's information and location is kept confidential and accurate.

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