Aerial and Ground Surveys for Mapping the Distribution of *Phytopthora ramorum* in California[1]

Jeffrey A. Mai[2], Walter Mark[3], Lisa Fischer[4], and Amy Jirka[5]

Key words: aerial surveys, ground surveys, *Phytophthora ramorum*, sudden oak death

Abstract

Since 2001, the USDA Forest Service and California Polytechnic State University, San Luis Obispo have been collaborating for early detection and monitoring of the occurrence of *Phytophthora ramorum*, the pathogen known to cause sudden oak death (SOD). The effort consists of annual aerial surveys to map hardwood mortality in overstory tree species including coast live oak (*Quercus agrifolia*), tanoak (*Lithocarpus densiflorus*), Shreve oak (*Quercus parvula* var. *shrevei*) and California black oak (*Quercus kelloggii*). These aerial surveys are followed by ground surveys to locate and sample both symptomatic overstory and understory host plants. Over the past few years the surveys have focused on early detection within minimally infested counties or counties with no known occurrence of *P. ramorum* but share a common border with regulated (infested) counties. The team of cooperators includes assistance from the University of California (UC), the California Department of Food and Agriculture (CDFA), county agricultural commissioners and cooperation from numerous private and public entities. Success in the program can be looked at in at least two ways, 1) by identifying new disease infestations and 2) by not finding new disease infestations. Over the past four years, the combination of aerial survey and ground confirmation efforts have identified new fronts of infection and mapped the distribution of *P. ramorum* within counties, or portions of counties, not previously known to have the disease (including recent expansion into southern Monterey County and new occurrences in Lake County). Following aerial surveys, ground surveys are targeted within select areas to check for infestations that would

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[2] USDA Forest Service and Cal Poly San Luis Obispo cooperative.

[3] USDA Forest Service, State and Private Forestry, Forest Health Protection 5107 Dudley Blvd. McClellan, CA. 95652; Jeffrey A. Mai jmai@fs.fed.us

[4] California Polytechnic State University, Forestry and Natural Resources, San Luis Obispo CA. 93407; Dr. Walter Mark wmark@calpoly.edu

[5] USDA Forest Service, State and Private Forestry, Forest Health Protection 5107 Dudley Blvd. McClellan, CA. 95652; Lisa Fischer lisafischer@fs.fed.us

expand the current range of *P. ramorum*. All areas mapped from the air within counties adjacent to currently infested counties are checked on the ground. Within minimally infested counties, ground surveys are targeted toward those areas in the county not known to be infested. Established sampling protocols are followed to determine if *P. ramorum* symptoms are evident in any of the susceptible plant species present. All samples are shipped to the appropriate laboratory for confirmation of *P. ramorum* as well as other Phytophthoras. Results from aerial and ground surveys conducted over the last four years were compiled and evaluated for over 1,000 discrete areas mapped from the air and hundreds of sites visited on the ground showing the distribution of *P. ramorum*-caused hardwood mortality across the landscape.

Introduction

Tens of thousands of tanoak *(Lithocarpus densiflorus*), coast live oak *(Quercus agrifolia*), California black oak *(Quercus kelloggii*), Shreve oak *(Quercus parvula* var. *shreve*i), and have been killed by a non-native, invasive pathogen, *Phytophthora ramorum*. This pathogen, causing a disease referred to as sudden oak death (SOD), was first reported in Marin County in 1995 (McPherson and others, 2000). The pathogen also infects rhododendron species including *Rhododendron macrophyllum*, madrone *(Arbutus menziesi*i), huckleberry *(Vaccinium ovatu*m), California bay laurel also known as Oregon myrtle *(Umbellularia californic*a), and California buckeye *(Aesculus californic*a), but usually causes only leaf spot and twig dieback on these hosts. The host list is expected to grow as researchers continue their investigations of affected ecosystems. (See host information at http://suddenoakdeath.org/ for the most current host list).

The known distribution of *P. ramorum* is expanding. According to the California Oak Mortality Task Force (COMTF), there are, as of December 2004, fourteen counties with wildland confirmations of *P. ramorum:* Alameda, Contra Costa, Humboldt, Lake, Marin, Mendocino, Monterey, Napa, San Francisco, San Mateo, Santa Clara, Santa Cruz, Solano and Sonoma (*fig. 1)*. The farthest north wildland confirmed location of *P. ramorum* in California is near Redway, in Humboldt County. The farthest south confirmed wildland location is Plaskett Creek, in Monterey County. The wildland location farthest from the coast is 50 miles inland and in Solano County. The disease is widespread in Marin and Santa Cruz Counties in redwood forests that have tanoak as an understory, and in mixed hardwood forests of oaks, bay, madrone and other species (California Oak Mortality Task Force 2004).

Figure 1—Counties with confirmed *P. ramorum* locations.

Over the course of the last four years (2001 to 2004), this cooperative effort between California Polytechnic San Luis Obispo (Cal Poly) and USDA Forest Service (USDA-FS) Pacific Southwest Region, Forest Health Protection in the air and on the ground has generated 1,337 polygons mapped containing hardwood mortality. Survey methods and sampling techniques have remained generally consistent throughout all years. However, the areas aerially surveyed have varied from year to year based on several factors including funding, confirmed locations of the pathogen during any given year, and relative risk for establishment and spread (*fig. 2)*. Similarly, the sites selected from the aerial surveys for ground checking have varied from year to year depending primarily on results from the aerial surveys as well as funding.

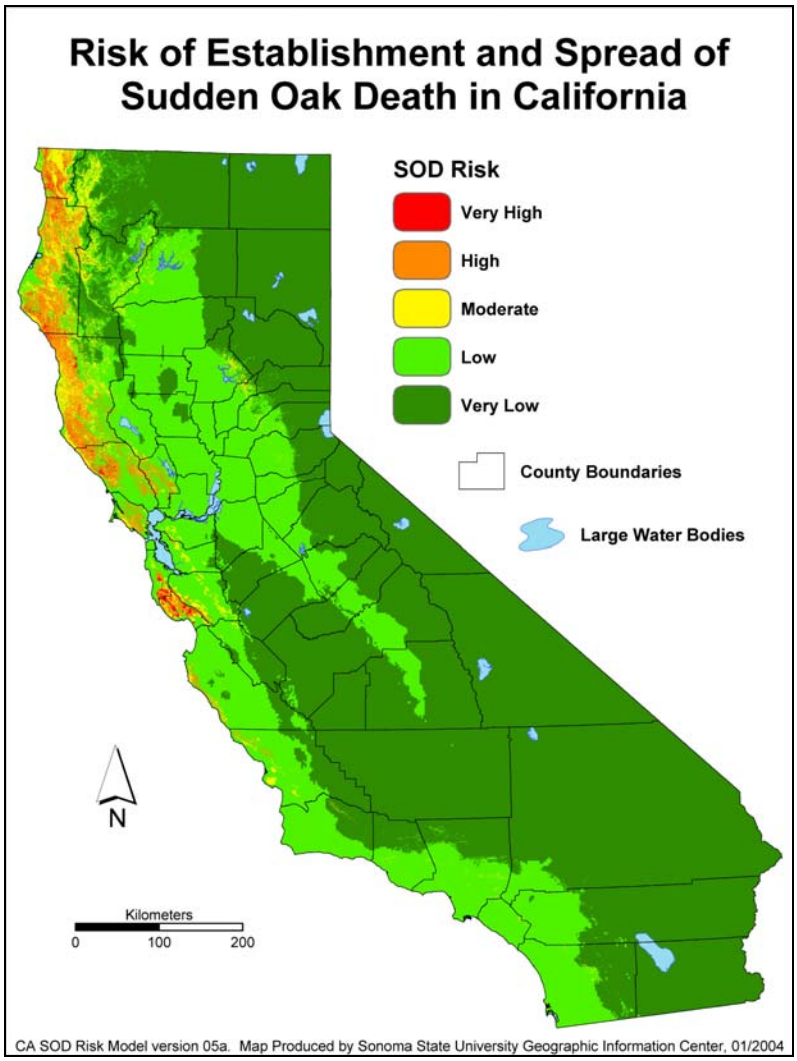

Figure 2—Statewide Risk Map (Meentemeyer, Sonoma State University) used to aid planning and implementation of aerial and ground efforts.

Aerial Survey Methods

Various fixed and rotor-wing aircraft were utilized during the aerial mapping of host hardwood mortality, these include fixed-wing Cessna models 182, 206T, 337 and rotor-wing Bell 206 B-III and 206 L-3 helicopters. During 2001, accuracy of sketch-mapping onto paper maps was aided through the use of a handheld global positioning system (GPS). Beginning 2002, a digital aerial sketch-mapping system (DASM) was used rather than the more traditional, paper mapping method. The DASM provides an outstanding navigational and data capture platform. Facilitated by GPS, laptop, and touch screen, the real-time moving map display enables relatively accurate heads-up digitizing of host hardwood mortality. Host tree mortality was mapped in California black oak, coast live oak and redwood/tanoak-dominated forest types. The intent of

aerial mapping was to capture all observed host mortality possible, recognizing inherent physical limitations of the aerial observer and technical limitations of the equipment and aircraft. Nonetheless, an attempt was made to capture mortality polygons "wall to wall" within areas surveyed. Polygon areas mapped ranged in size from 0.3 of an acre to 22,297 acres. For each area mapped, attributes captured included affected host tree species and amount of mortality. Oblique 35mm photographs were taken of the mortality and surrounding area, frame numbers were also captured as attributes during data collection. Additional attributes sometimes included secondary host species if present, aspect and any comments the observer considered relevant. Comments included details on best access route and description of any structures or landmarks nearby that would be helpful as navigational aids during subsequent field checks. Finally, polygon centroid coordinates were calculated in UTM NAD83 (either zone 10 or 11) and retained within the polygon attribute table. Mortality data captured during neighboring surveys in Oregon that happened to occur just over the California border were incorporated with the California survey data; likewise California mortality data occurring just over the Oregon border was provided to the Oregon Department of Forestry and USDA-FS in the Pacific Northwest Region.

Beginning in 2003, helicopters were used to re-fly select areas mapped during the fixed-wing flights. Helicopter flights, used only for a limited number of sites, were prioritized based on a combination of factors including proximity to existing infections, number of dead trees, high risk areas based on the Meentemeyer risk model and, to some extent, range of the aircraft operating out of airports with correct fuel type. Once high priority polygons were identified, additional polygons were included in the helicopter flight plan that happened to occur along the planned route. To direct the helicopter, the polygon centroid coordinates were entered in a handheld GPS used on board. Upon arriving at each GPS waypoint, affected host and level of mortality was confirmed or updated as appropriate, additional observations were made describing the mortality and access, and a new GPS waypoint captured while hovering. This new GPS waypoint is more accurate than the original centroid coordinates calculated for the polygon and subsequently used by field crews to more easily locate trees mapped from the air. Analysis of fixed-wing mapping accuracy comparing original polygon centroids to revised helicopter GPS waypoint is displayed in *table 1*.

Table 1—*Accuracy of original digital sketch-mapping (centroid) compared to revised coordinates captured from helicopter using GPS, 2003 aerial survey data is analyzed for 92 polygons within six counties*[6]

COMPARISON OF HELICOPTER GPS TO POLYGON CENTROID

Distance to Centroid	DN	HUM	MEN	SBAR	SLO	KERN	TOTAL
# of Points within 200 feet	1	2		1	1		5
# of Points within 400 feet	2	4	1		2	1	10
# of Points within 600 feet	3	5	6	2	3	2	21
# of Points < 1320 feet (1/4 mile)	3	9	11	3	9	3	38
# of Points > 1320 feet (1/4 mile)	1	4	3	1	5	4	18
Nearest GPS to Centroid (feet)	144	145	295	110	81	372	
Average GPS to Centroid (feet)	759	859	887	695	1083	1131	

COMPARISON OF HELICOPTER GPS TO DETERMINE "IN" OR "OUT" OF ORIGINAL POLYGON & SIZE

Distance to Centroid	**DN**	**HUM**	**MEN**	**SBAR**	**SLO**	**KERN**	**TOTAL**
# of GPS points inside polygon	1	4	4	3	5	4	21
# of GPS points outside polygon	9	20	17	4	15	6	71
Smallest Polygon (acres)	0.7	0.7	0.8	3.9	2.6	10.5	
Average Polygon (acres)	2.3	14.5	29.9	24.7	22.0	61.1	
Largest Poly (acres)	4.4	169.5	237.4	38.6	171.5	455.5	

[6] '#' Quantity of GPS locations captured during subsequent helicopter flights, Global Positioning System (GPS), Centroid is the center of the original polygon mapped from fixed-wing for which UTM coordinates are calculated and the helicopter GPS is compared, county abbreviations: DN - Del Norte, HUM – Humboldt, MEN – Mendocino, SBAR – Santa Barbara, SLO – San Luis Obispo; factors to be considered that affect interpretation of this data include: error induced during geographic transformation of map data (re-projection and coordinate conversion), location of polygon centroid within the original polygon (calculated centroids are not always positioned in polygon center, polygon shape affects calculation) and size of original polygon (many of the polygons include single or very few trees and are less than an acre in size)

Ground Survey Methods

Personnel employed over the last four years have varied to some extent but ground survey methods have remained generally consistent, including:

- Structured, pre-season training for field crews in use of map materials generated from aerial survey, host and symptom recognition and how to collect samples
- Identification of landowner and contact with landowner in advance or during visit
- Host plant examination for symptoms while navigating to the GPS waypoint to locate tree(s) mapped from the air, the search area typically extends well beyond any given polygon
- Proper documentation of the visit and handling/shipment of samples for lab diagnostics
- Emphasis on equipment and personal sanitation to prevent pathogen spread

During 2001, "in kind" support was provided by USDA-FS, California Department of Forestry and Fire Protection (CDF), and UC Davis pathologists and others. During 2002, the USDA-FS contracted field work to a consulting firm and Cal Poly utilized its employees and students. During 2003 and 2004, the USDA-FS began hiring and supervising student temporary employees (STEPs) to accomplish what had previously been contracted or completed "in-kind" in the past. The STEP program is viewed as an excellent way to give college students, interested in natural resources, an opportunity to work for the USDA-FS. Cal Poly continued their program of summer recruitment throughout all four years. Whenever possible, employees with previous experience were rehired for both USDA-FS and Cal Poly crews.

Cal Poly and USDA-FS field crews, lead by Amy Jirka and Jeff Mai respectively, trained together within infested areas (Jack London and China Camp State Parks) to recognize hosts and symptoms of the pathogen. Additionally, practical exercises in making landowner contacts and collecting samples were included as part of the training. Pathologists from CDF, UC Davis, and the USDA-FS have been a key component during each of the annual training sessions. The majority of field checks are completed during the summer months when roads are open and dry, during the period of employment for our temporary workforce and immediately following aerial survey. However, field checks typically continue beyond the summer season to the degree possible utilizing regular, full time personnel and occasionally with assistance from various county agriculture departments, UC Davis and California Department of Food and Agriculture (CDFA) pathologists.

Field materials consist of navigational equipment, including handheld GPS, data collection sheets, California's standard Pest Detection Report (PDR), 35 mm photographs, digital orthoquads (DOQs) with flightlines and polygons, and topographic map with flightlines, polygons and table of attributes collected during the aerial survey. All field materials are produced by the USDA-FS and Cal Poly. The details of every visit and status of any samples submitted are tracked by the USDA-FS. Periodic status updates are provided to the UC Berkeley-maintained Oakmapper interactive website http://kellylab.berkeley.edu, results and web link are communicated to interested parties. The website provides easy access for anyone interested in SOD or this project specifically. Public and government agencies can view all project information from the last four years including flightlines, areas mapped, and attributes of each area and the status of any completed ground checks. Additional outreach and communication is accomplished at regular intervals via email messages and accomplishment reports to COMTF cooperators, county agriculture departments, CDF and CDFA.

Aerial Survey Results and Accomplishments

The area surveyed has varied every year since 2001, see *fig. 3* and *table 2*. Factors influencing areas surveyed include 1) host habitat within un-infested counties, adjacency to regulated counties and within infested counties having relatively large unifested areas, 2) abundance of host species and modeled risk, 3) current distribution of the pathogen, and, 4) staffing and budget. During 2001 the first survey was fairly limited, focusing on infested areas and on host habitat immediately adjacent to those infested areas (generally within counties in proximity to the San Francisco Bay Area). With new discoveries of *P. ramorum* in Curry County, Oregon and elsewhere in California, 2002 saw the largest survey area to date and nearly all host habitats were flown (the exception being counties south of Los Angeles). During 2003, the survey area was reduced but more focused within areas not yet known to be infested. Further reduction in area flown occurred in 2004, with the exclusion the California black oak-type in the Sierra foothills and concentration on host habitat at risk but not yet known to be infested within minimally infested counties and un-infested counties immediately adjacent to infested areas. A list of counties surveyed and number of polygons within each county are displayed in *table 3*.

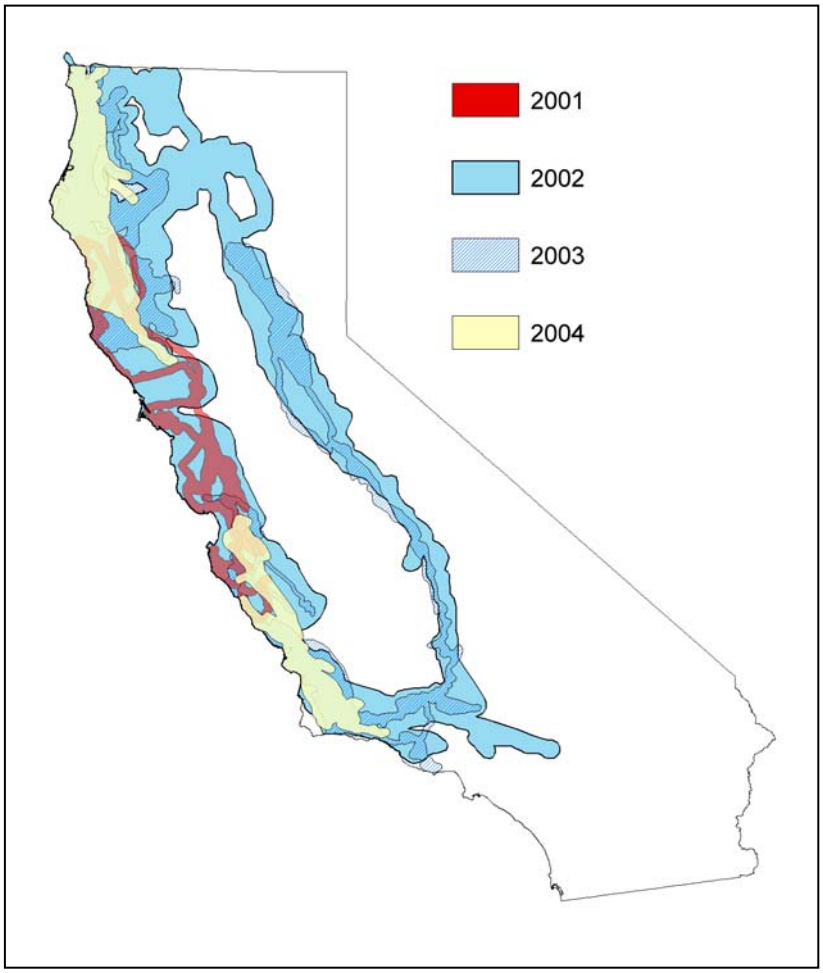

Figure 3—California aerial survey coverage by year.

Table 2—*Aerial survey accomplishments summarized by year.*

Year	Miles Flown	Surveyed Area (acres)	Mortality Mapped (acres)
2001	2,100	5,000,000	13,200
2002	14,500	20,000,000	149,000
2003	10,200	13,000,000	8,200
2004	7,100	8,000,000	3,300

Table 3—*Counties Surveyed and Polygons Mapped Each Year; Subtotal by county and total number of polygons by year displayed will differ from previous reports due to some polygons split by county boundaries and additional sites visited in route to aerial survey polygons (not included above); many counties listed had only partial coverage during the aerial survey due presence of host tree species.*

California Counties Surveyed	Surveyed 2001	Polygons Mapped 2001	Surveyed 2002	Polygons Mapped 2002	Surveyed 2003	Polygons Mapped 2003	Surveyed 2004	Polygons Mapped 2004
Alameda			X	36				
Amador			X		X	3		
Butte			X	7	X	25		
Calavaras			X	1	X			
Colusa			X					
Contra Costa			X	14				
Del Norte			X	7	X	12	X	23
Eldorado			X	6	X	10		
Fresno			X		X	1		
Glenn			X		X	1		
Humboldt			X	84	X	120	X	194
Kern			X	1	X	17		
Lake			X		X	6	X	6
Lassen			X					
Los Angeles			X		X			
Madera			X		X			
Marin	X	9	X	20				
Mariposa			X		X			
Mendocino	X	3	X	42	X	117	X	123
Monterey	X	13	X	44	X	40	X	2
Napa	X	1	X	26				
Nevada			X	4	X			
Placer			X	8	X	3		
Plumas			X					
San Benito			X	18	X	5	X	3
San Bernardino			X					
San Luis Obispo			X	10	X	33	X	45
San Mateo	X	3	X	5				
Santa Barbara			X	3	X	18	X	7
Santa Clara	X	7	X	39				
Santa Cruz	X	5	X	17				
Shasta			X		X			
Sierra			X					
Siskiyou			X	1	X	1		
Solano	X	1	X	13				
Sonoma	X	4	X	40				
Tehama			X		X	1		
Trinity			X	5	X	8	X	4
Tulare			X		X	2		
Tuolumne			X	3	X			
Ventura			X	4	X	2	X	7
Yolo			X					
Yuba			X	1	X	3		
TOTAL		**46**		**459**		**428**		**414**

An important consideration for the aerial survey is timing which has remained fairly consistent during each year of the project. Flights typically occur during June and July after spring flowering in host trees, particularly coast live oak and tanoak, and before much of the drought-deciduous California buckeye foliage turns brown. Approximately 6 to 22 days of flight have been required in each project year (excluding helicopter) with up to 8 hours per day in the plane. Flight days are scheduled for drier counties first then progress into moister habitats, thus further minimizing confusion from flowering hardwood or browning buckeye foliage. Presence of summer fog has been problematic but not insurmountable. Simply maintaining flexibility and surveying what is visible one day, then moving into areas previously not visible the next has largely been successful in minimizing fog obstruction.

During 2002, the year with the largest survey area, the aerial survey portion of this project covered approximately 20 percent of California. For all years combined, the project has accumulated approximately 34,000 miles flown which is a distance nearly equal to 1.5 times around the earth. Ignoring annual overlap, the polygons mapped cover 174,000 acres which equals an area half the size of San Mateo County.

Field Survey Results

Approximately 400 of 1,337 sites have been visited by trained field crews on the ground. Samples were collected from approximately two thirds of all sites visited (*fig. 5)*. Studies by Davidson and others (2003) have shown that timing of field visits and sample collection has a bearing on the likelihood of recovering *P. ramorum*. Climatic conditions and sporulation are most favorable for handling of samples and pathogen recovery during spring months, however, workforce and access issues limit the number of visits conducted during this time of year. As of December 2004, most of the priority sites have been checked. Weather and access permitting, the remainder will be checked in spring of 2005. The most limiting factor in completing ground checks is obtaining landowner permission to access sites since the majority of mortality mapped occurs on private ownerships (*fig. 6)*. Ground visits must be conducted when access conditions are most favorable, surface roads are open for travel and reasonably dry to avoid damage to road surface and minimize the chance of spreading *P. ramorum* and other pathogens such as *P. lateralis*.

For all years, laboratory diagnostics include culture and isolation for *P. ramorum* and a few other commonly occurring but less pathogenic *Phytophthoras*. Revisits to sites checked during the previous survey year are conducted if laboratory results are negative but host plants were described as highly symptomatic. To date, only one

such revisit has resulted in a positive isolation of *P. nemorosa*. Beginning 2004, the Rizzo Laboratory at UC Davis began incorporating ELISA screening to determine presence of the genus *Phytophthora*. In the event that ELISA was positive but culture negative for any *Phytophthora*, a sample was forwarded to the Garbelotto Laboratory at UC Berkeley for PCR diagnostics. To date, all PCR results have been negative for *P. ramorum*. In the event a PCR positive is determined, the site would be revisited to collect another sample and culture attempt. For all years combined, samples collected during the field checks have resulted in positive cultures for *P. ramorum* (27 positives), *P. nemorosa* (11 positives), *P. pseudosyringae* (one positive), and *P. gonapodyides* (one positive). California bay laurel has been the host with greatest success of recovering *P. ramorum* from, as shown in *fig. 7*. However crews examine all host species for symptoms and, due to Oregon myrtle's minimal importance as a host in Oregon, look more closely at wild rhododendron when working in the northernmost area of California.

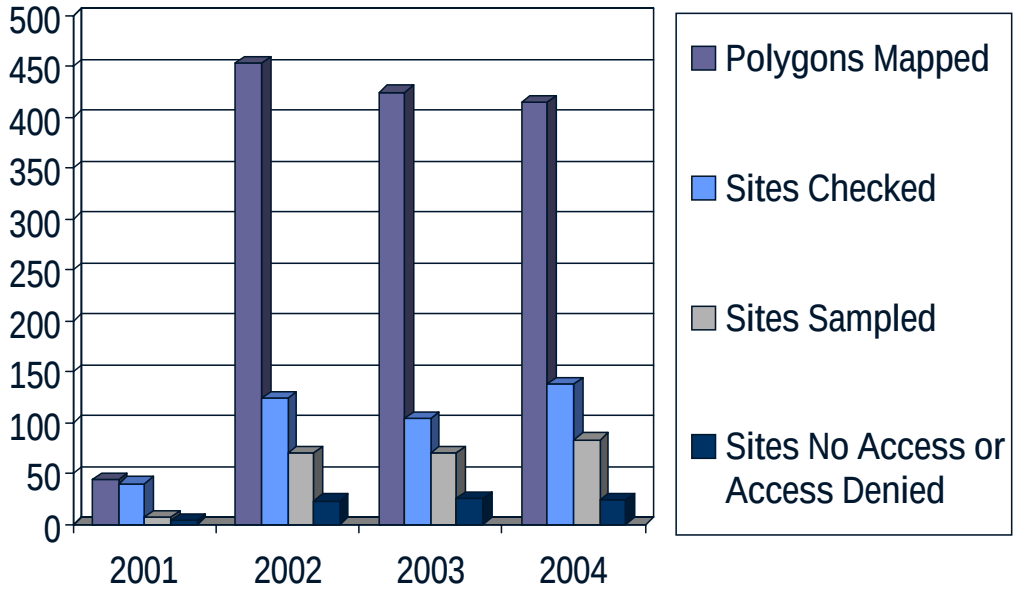

Figure 5—Number of Polygons by Survey Year; the majority of polygons mapped and not checked are located in low-priority areas within currently infested counties, the majority of sites in the no access or access denied category are situations where multiple attempts to contact landowner failed.

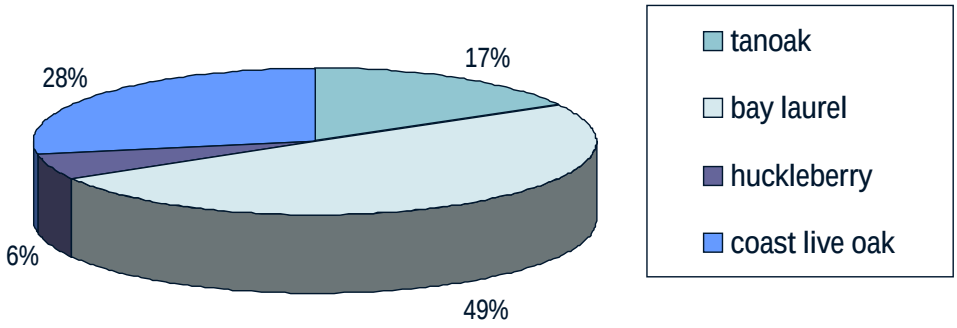

Figure 6—Species distribution with positive lab cultures; includes 18 specimens from 2004 only.

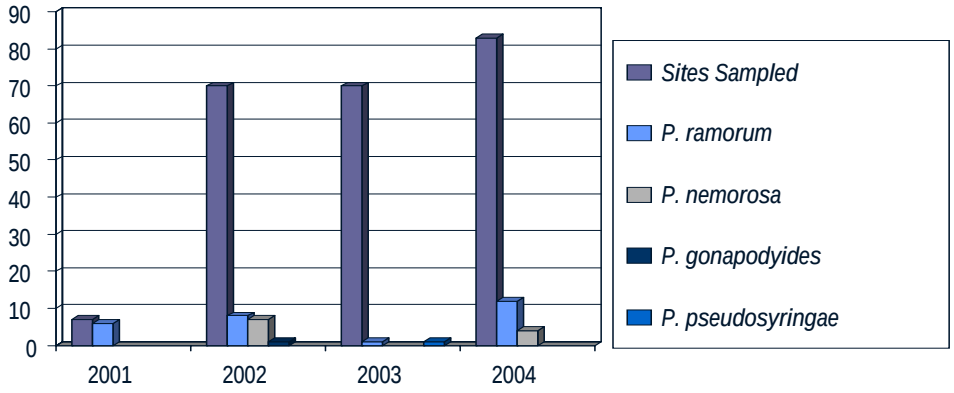

Figure 7—Summary of Lab Results by Year for Sites Sampled; results displayed are for positive cultures only and exclude PCR positives (of which there have been three to date for other *Phytophthoras*).

During the history of aerial surveys in California, there have been several important confirmations as a result of subsequent ground checks. Significant field confirmations include:

- 2001 - Solano County collection by Adams & Kliejunas shortly after first detection by others
- 2002 - Contra Costa County collection by Jirka & Piazza shortly after first detection by others
- 2003 - Monterey County collection by Corrella & Wicklander approximately 25 miles south of previous confirmations and 10 miles from uninfested San Luis Obispo County
- 2004 - Lake County collection by Mai & Jirka and the first confirmation in the county adding it to the list of regulated counties; Humboldt County collections by Harrington & Langenbeck 2 miles east and 2 miles south of previous confirmations in Redway.

Also of significance is the documentation of pathogen spread. Areas flown overlap during various years of survey and *fig. 9* documents how one infested area near Big Sur in Monterey County has grown in size.

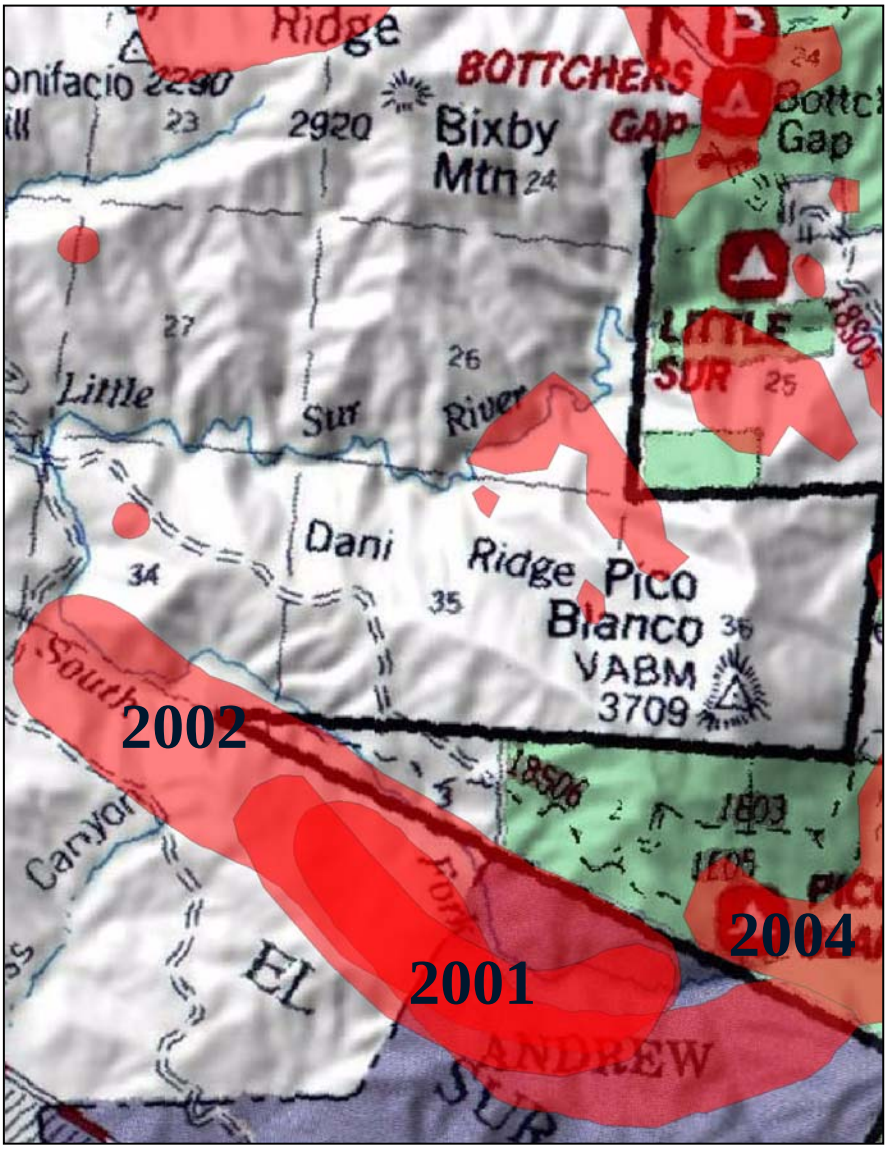

Figure 9—Spread of *P. ramorum*; the magnitude of change documented from three aerial surveys, area at north end of Andrew Molera State Park near Big Sur in Monterey County was initially mapped in 2001 at 500 acres, in 2002 grew to 1200 acres and, finally, 1800 acres in 2004.

Conclusion and Recommendations

The methods employed to conduct aerial survey and focused ground checks have effectively detected new areas of infestation and documented spread of *P. ramorum*. Timing of various phases of the project is optimized considering the logistical,

physical and climatic limitations described previously. Helicopters are beneficial for pinpointing locations that are often very difficult to find due to terrain, dense cover and minimal visibility of the target from the ground. Use of helicopters for the entire project is cost-prohibitive and not practical for the scope of survey in California. The prioritization of areas to be flown with helicopter and/or checked on the ground, a subset of all areas mapped with emphasis on host habitats at relatively higher risk in un-infested areas and in counties adjacent to infested counties, is appropriate for the scope of the problem in California and effective in finding the pathogen in the most critical locations. Communication of project progress and accomplishments at key intervals has been sufficient to provide information to important partners and cooperators during all phases via email, accomplishment reports, USDA-FS Pacific Southwest Region State and Private Forestry Forest Health Protection and Oakmapper websites. Additional public relations efforts would increase awareness of *P. ramorum*, potentially reducing the chance of spreading the pathogen and improving access to private property. Notification and coordination with other agencies to participate and/or conduct field checks independently has been moderately successful. However, increased interest and involvement by other qualified individuals with the USDA-FS, CDF, CDFA, UC Cooperative Extension and county agriculture departments to conduct additional field checks would be beneficial.

The project has had success in both finding and in not finding new disease locations. While not finding *P. ramorum* in any given location does not definitively indicate absence, there is perhaps some comfort in negative detection. Not finding the pathogen with the level of effort expended on this and other detection efforts can be viewed as a success. However, one of the most compelling unanswered questions remains, is the pathogen present in Del Norte County? To date, results from this project and other detection efforts (stream baiting and focused ground surveys based on modeled risk) have all been negative. Emphasis will continue for additional aggressive detection efforts in Del Norte County. This is particularly important to Oregon's effort to eradicate *P. ramorum* in a regulated area within Curry County, adjacent to the California border.

Future surveys are planned to be implemented similarly with improvements. During 2005, the USDA-FS will likely add staff to conduct localized outreach in communities of particular interest to facilitate more effective landowner contact and aid in tracking status of field checks. Surveys have not been conducted over the infested counties surrounding the Bay Area since 2001 and 2002. There is interest in updating the database for mortality that has occurred since that time. The area

planned for 2005 survey will be similar to 2004 with ground checks prioritized as described; however, current plans consider inclusion of infested areas in proximity to the Bay Area for the aerial portion of the project.

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