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# Progress of the *Phytophthora ramorum* eradication programme in south-western Oregon forests, 2001 – 2009†

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## Abstract

Sudden Oak Death (SOD) disease caused by *Phytophthora ramorum* Werres, de Cock & Man in 't Veld was first discovered in Oregon forests in July 2001. Since then, an interagency team has been attempting to eradicate the pathogen though a programme of early detection (aerial and ground surveys, stream baiting) and destruction (herbicide treatment, felling and burning) of infected and nearby host plants, which has evolved over time. Post-treatment monitoring has indicated that although the disease has been eliminated from many of the sites and spread of inoculum may have been reduced, the disease continues to spread slowly. The quarantine area has expanded from 23 km² in 2001 to 420 km² in 2009. We attribute continued spread of the disease to the slow development of recognisable symptoms and to delays in treatment application associated with inconsistencies in funding.

**Keywords:** eradication; *Notholithocarpus densiflorus;* Sudden Oak Death; Oregon; *Phytophthora ramorum*; tanoak.

† *Based on a paper presented at the Fifth IUFRO Meeting on Phytophthora Diseases in Forests and Natural Ecosystems, 7-12 March 2010, Auckland and Rotorua, New Zealand*

## Introduction

*Phytophthora ramorum* Werres, de Cock & Man in 't Veld is a recently established non-native invasive pathogen in the forests of coastal California and south-western Oregon (Goheen et al., 2002; Hansen et al., 2005; Rizzo et al., 2002; Rizzo & Garbelotto, 2003). The pathogen has potential to spread throughout coastal forests of the United States (US) west coast (Meentemeyer et al., 2004; Vaclavik et al., 2008) and to cause considerable ecological and economic damage to the forestry and nursery industries (Hall, 2009). It was first detected in Oregon in July 2001 during an aerial survey triggered by the previous discovery of sudden oak death (SOD) disease in California. Five separate infestations covering 0.2 – 7.3 ha were found to be distributed over an oblong area 4 km (north-south) by 2 km (east-west).



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Archived aerial photographs revealed that tanoak (*Notholithocarpus densiflorus* (Hook. & Arn.) Manos, Cannon & Oh) mortality had occurred in at least one of the infested sites in 1998.

*Phytophthora ramorum* produces aerial propagules under wet conditions and mild temperatures (Hansen et al., 2008). In Oregon its primary host is tanoak which is killed by the pathogen and acts as a source of inoculum throughout the year (Hansen et al., 2008; Reeser et al., 2009). Several other forest plant species are also susceptible to the fungus when growing close to tanoak. These include Pacific rhododendron (*Rhododendron macrophyllum* Don), evergreen huckleberry (*Vaccinium ovatum* Pursh), red huckleberry (*Vaccinium parvifolium* Smith), Oregon myrtle (*Umbellularia californica* (Hook. & Arn.) Nutt.), cascara (*Rhamnus purshiana* DC.), and poison oak (*Rhus diversiloba* Torrey & Gray).

Soon after the initial detection, an emergency meeting of personnel from the Oregon Department of Agriculture, Oregon Department of Forestry, Oregon State University, and the United States Department of Agriculture (USDA) Forest Service was convened. Because the number of apparently discrete infestations was small, and the potential for damage unknown, it was decided that eradication of the pathogen should be attempted by cutting and burning all infected and symptomatic host plants in the infested sites. The Oregon Department of Agriculture established an emergency quarantine area of 23 km$^2$ from which movement of all host material was prohibited.

Since 2001 the interagency team has continued to work with landowners to eradicate the pathogen by felling and burning all infected trees and adjacent host plants. The Oregon SOD management programme consists of detection, delimitation of infested areas, eradication treatment, host plant removal in areas of probable disease spread, research and monitoring.

## Methods used in the Oregon SOD Management Programme 2001 – 2009

### Detection

#### *Aerial survey followed by ground checks*

The methods used are described in detail in Goheen et al. (2006) and Hansen et al. (2008). Briefly, four aerial surveys (February, May, July, and October) were conducted annually and covered a total area of 400 km$^2$ in Curry County that extended from the California border north to the Rogue river. A fixed-wing aircraft was used to fly 500 – 600 m above the forest canopy on parallel flight lines spaced 3 km apart. Observers recorded the approximate location of recently dead tanoak trees (red-brown foliage) on paper maps or a digital sketch-mapper. These records were then used to guide a helicopter to the dead-tree area. While hovering over the dead trees, the number and condition of the trees were noted and the geographic coordinates determined with the aid of hand-held Global Positioning System (GPS) units. A shape file produced from the coordinates was overlaid on topographic and ortho-photo images printed on 1:10 000 scale maps. Ground crews then used maps, GPS units and compasses to find the dead trees. All trees and plants in the vicinity were checked for symptoms of SOD or other disease. If symptoms were present, two samples of symptomatic plant tissue were collected. One was plated in the field on *Phytophthora*-selective agar (CARP: commercial corn meal agar (CMA) containing 10 ppm natamycin (Delvocid, DSM Food Specialties), 200 ppm Na-ampicillin, and 10 ppm rifampicin). The other sample was taken to the laboratory for plating on CARP and polymerase chain reaction (PCR) analysis (Sutton et al., 2009).

#### *Ground survey*

Ground surveys were used to locate dead trees hidden from aerial observers by topography or large trees. They allowed detection of symptoms such as bleeding, stem lesions, wilting shoots, leaf spots, and branch dieback on understorey plants and live trees. These surveys were based either on scanning for symptomatic trees from vantage points or on transects laid in 10 – 30 ha forest stands. Transect surveys were undertaken in areas where presence of the disease was considered to be likely based on risk maps (Vaclavik et al., 2010), proximity to known infestations or where landowners had requested attention. The transects were spaced 50 m apart. Symptoms of infection by *Phytophthora ramorum* were recorded and samples were collected and treated as described for ground checks associated with aerial surveys.

#### *Stream baiting*

Stream baiting with native rhododendron and tanoak leaves (Sutton et al., 2009) offered the possibility of detecting *Phytophthora ramorum* before tree mortality was evident. Stream monitoring was carried out in areas considered to be at risk of new infestation within and beyond the perimeter of the quarantine area. Streams draining known infested sites also were sampled. Year-round sampling at 64 bait stations was interrupted only by summer drought or winter floods. The area drained at the point of sampling ranged in size from 8 to 3634 ha and totalled 32 192 ha.

### Eradication treatment

Mandatory eradication began in the autumn of 2001 under the statutory authority of the Oregon Department of Agriculture. Funding was provided by the USDA Forest Service. Although there was


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no direct cost to landowners, no compensation was made for loss of timber or other value. After initial detection of *Phytophthora ramorum* each infested site was surveyed for affected plants and a boundary was marked. Treatments consisted of felling and burning all infected plants as soon as possible after detection. For the first two years all host vegetation 15 – 30 m from infected plants was destroyed. This distance was increased later to 30 – 100 m.

After the first year, tanoak stumps were found to be sprouting prolifically and *Phytophthora ramorum* was occasionally isolated from the new shoots. Since 2003, all tanoaks in treated areas other than those on US Department of the Interior (USDI) Bureau of Land Management land have been injected with herbicide (imazapyr or glyphosate) prior to felling.

### Preventative host removal

A limited amount of tanoak removal has been carried out in order to create a host-free zone in the probable direction of disease spread. In some areas this involved herbicide treatment or felling over large areas (10 – 30 ha). Host removal by landowners was a voluntary activity supported by State or Federal funding.

### Monitoring

Following eradication treatment, sites were surveyed periodically to determine presence of *Phytophthora ramorum* in soil or vegetation. Survey methods are described in detail in Goheen et al. (2010). Briefly, circular plots (0.02 ha) were established in 2008 and 2009 around stumps of known infected trees at 119 plots that had received eradication treatments between 2001 and 2007. At each plot, 20 one-liter soil samples were collected, returned to the laboratory and baited with leaves of *Viburnum* sp. or *Rhododendron macrophyllum*. Presence of *P. ramorum* in the baits was determined by PCR analysis and culturing on *Phytophthora*-selective medium. Host vegetation was examined for symptoms of *P. ramorum*, and a minimum of five plant tissue samples were collected and returned to the laboratory to determine the presence of *P. ramorum* using an enzyme-linked immunosorbent assay (ELISA), PCR and culturing on *Phytophthora*-selective media.

## Results and Discussion

Between 2001 and the end of 2009, eradication and host removal treatments had been applied to approximately 1200 ha of forest at a cost of US$ 4.5 million. Treated land was under the following ownership: private industrial forest 63%; private non-industrial land 25%; federal government 10%; local government 2%. In 2008 and 2009, treatment costs averaged approximately US$ 6000 $ha^{-1}$.

Treatment often was delayed or interrupted by lack of funding, other administrative obstacles, and extreme weather events. Delays became more numerous as the size and scope of the project increased. During the first 4 years (2002 – 2005) an average of 21 infested sites was discovered annually (Figure 1). After 2005, the number of new infested sites increased and appeared to stabilise at approximately 60 per year.

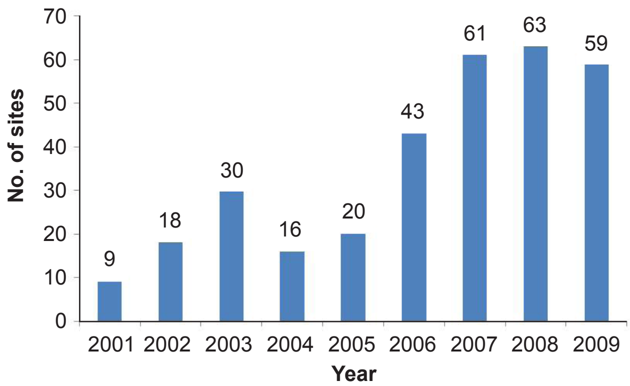


FIGURE 1: Number of new sites infested with *Phytophthora ramorum* discovered annually between 2001 and 2009 in Curry County forests.

The combined area of newly-detected sites increased to 22 ha in 2007 and then decreased to 8 ha in 2009 (Figure 2). Unusually wet spring and early summer weather in 2005, 2006 and 2007 may have contributed to the increase in disease. The decrease in infested area between 2007 and 2009, despite no change in the number of infested sites, may reflect improved survey performance which detected sites while they were quite small, often only a single tree. By 2009, the disease had spread 8.5 km to the north, 1.9 km to the

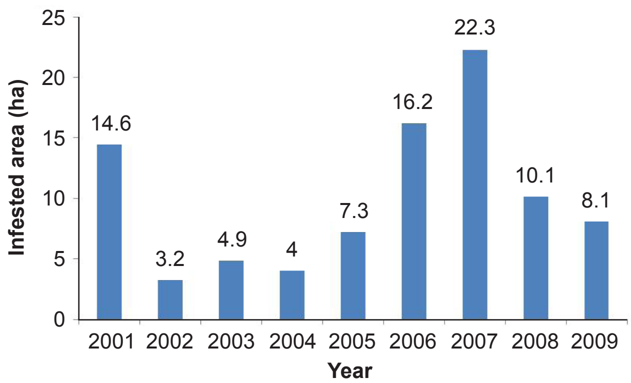


FIGURE 2: Area of Curry County forest infested with *Phytophthora ramorum*, 2001 – 2009. Not cumulative.


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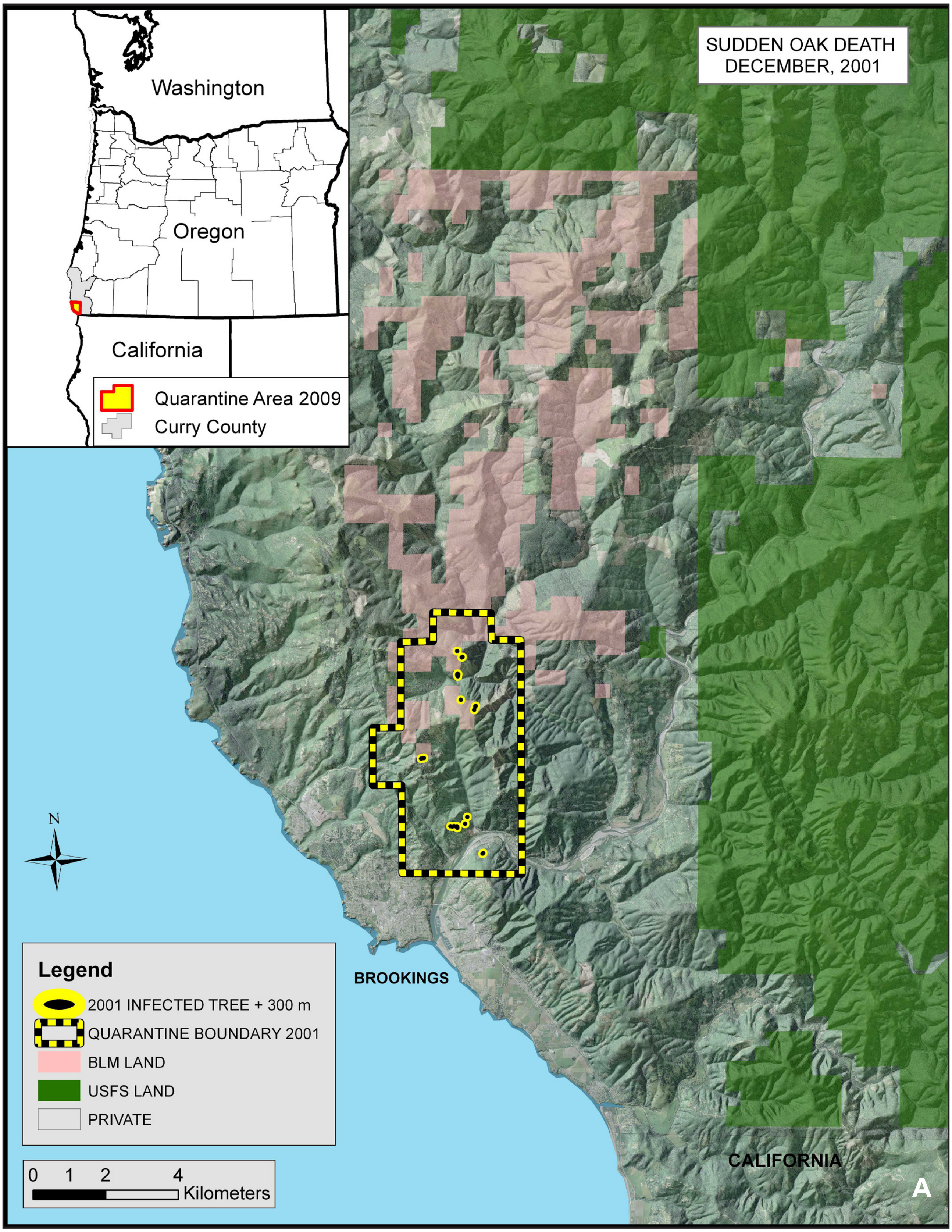


FIGURE 3A: Location of areas in Curry County infested with *Phytophthora ramorum* in 2001. Orange polygons depict eradication treatment 2001 – 2009.


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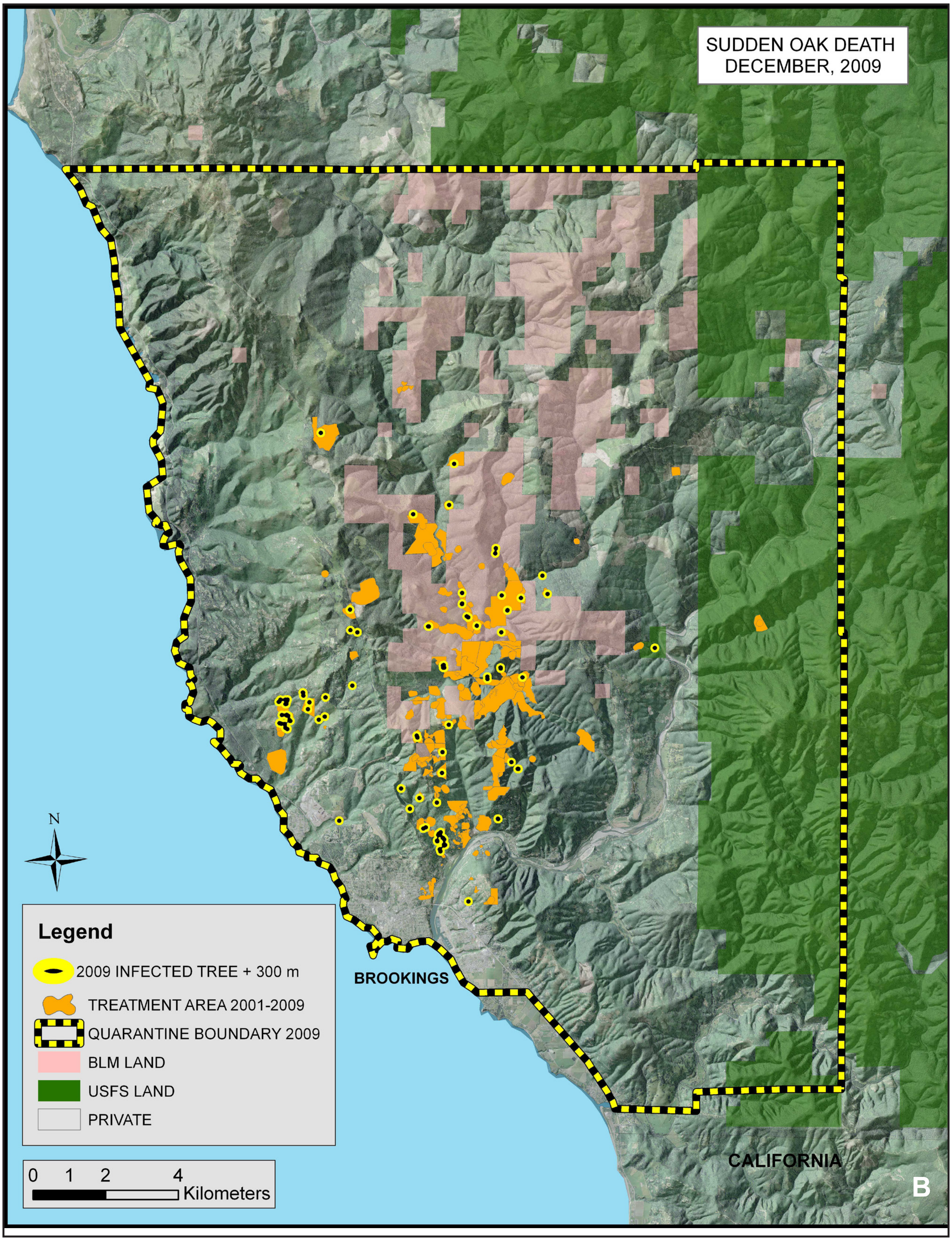


FIGURE 3B: Location of areas in Curry County infested with *Phytophthora ramorum* in 2009. Orange polygons depict eradication treatment 2001 – 2009.


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south, and 7.6 km to the east of the initial infected site. Northerly progression was probably influenced by the direction of the prevailing wet-season wind. Between 2001 and 2009, the initial State quarantine area was increased four times, the most recent expansion to 420 $km^2$ taking place in 2008 (Figure 3). The pathogen has not been found beyond the boundary established in 2008.

The initial objective of the eradication programme was the elimination of *Phytophthora ramorum* at infested sites. Post-treatment monitoring suggested that the pathogen was eliminated from many of the sites, but there also was evidence that *P. ramorum* persisted (Goheen et al., 2010; Kanaskie et al., 2009). Of the 119 plots sampled post treatment, *P. ramorum* was recovered from soil on 38% of plots and from vegetation on 10% of plots. The pathogen was not recovered from soil or vegetation on 59% of plots. On plots where *P. ramorum* was baited from soil, recovery was generally low, usually only one of 20 soil samples. Tanoak was the only plant species found to be infected (Goheen et al., 2010).

Continued spread of SOD in Oregon is likely to result from failure to detect all sources of infection and from delays in completion of eradication treatments. Early detection depends on the visibility of plant symptoms. We know that there is a lag between initial infection and the appearance of recognisable symptoms or tree death. We do not know the length of this lag period, but it may be one or more years (McPherson et al., 2005; McPherson et al., 2010).

The eradication treatments appear to have prevented disease intensification and may have slowed spread of *Phytophthora ramorum*. This is impossible to prove because a comparative study is incompatible with quarantine regulation. A similar situation in northern California may provide some insight: here the presence of *P. ramorum* was detected in 2004 near Redway in southern Humboldt County. The original infestation covered a smaller area than the original Oregon infestation. In the absence of a comprehensive disease control programme, the Humboldt infestation has expanded more rapidly than the Oregon infestation. By the end of 2009, mortality attributed to SOD in Humboldt County was recorded over more than 6000 ha (C. Lee, personal communication, January 21, 2010), whereas in Oregon, mortality from disease plus eradication treatment had only extended to 1200 ha. Given that the climate in coastal southwest Oregon is at least as conducive to SOD as it is in California (Hansen et al., 2008) it is likely that the difference in mortality is due to the eradication programme.

Nine years after *Phytophthora ramorum* was first detected in Oregon forests, the pathogen is still limited to a small area in the southwest corner of the State and the rate of spread is slow. The total cost of eradication treatments, survey and administration was approximately US$ 10 million. Economic analysis of the effects on nursery and forest industries indicates that continuation of the project is worthwhile, mainly because the slowing of spread of the disease delays costs incurred in expansion of the quarantine area (Hall, 2009). Environmental benefits associated with slowing the spread of SOD have not been quantified.

It is unlikely that *Phytophthora ramorum* will be eradicated from Oregon forests. An assiduous, well-funded control programme will slow its progress and perhaps confine it to a relatively small area. If inoculum levels are reduced and the public is informed and involved in observance of quarantine regulations, the probability of spread to other forests is likely to be reduced and environmental and economic damage minimised.

## Conclusion

Eradication of *Phytophthora ramorum* is difficult because the fungus produces aerial propagules and because there is a time lag between initial infection and the development of recognisable disease symptoms. Early detection and immediate felling, burning and herbicide treatment of host plants may reduce local intensification of the disease and the rate of spread in forests.

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