**Phytophthora tentaculata**

**Overview**
*Phytophthora tentaculata* Kröber & Marwitz was described in 1993 in Germany on greenhouse-grown nursery ornamentals. It has since been found in Italy, Spain, China and the U.S. (California) causing a root and stem rot of many different plant species including nursery-grown native species used for habitat restoration. *P. tentaculata* is homothallic and is classified in Stamps group I which is characterized by the production of mostly paragynous antheridia, papillate sporangia and the production of both hyphal swellings and chlamydospores in culture. *P. tentaculata* is placed in phylogenetic Clade 1 (Cooke et al., 2000) with species such as *P. cactorum, P. nicotianae, P. clandestina, P. iranica, P. hedraiandra* and *P. pseudotsugae*.

**Etymology:** refers to the spider web-like growth habit of the mycelium in culture.

**Morphology**
Sporangia of *P. tentaculata* are spherical or ovoid to obpyriform, papillate to occasionally bipapillate and measure 10-81 x 13-52 µm (average 35.7 x 27.4 µm). They are primarily noncaducous, rarely caducous with a short pedicel, and often have elongated necks or beaks (Fig. 1). Small hyphal swellings are intercalary and often occur with hyphal branching (Fig. 2). On PARP and V8 juice agar, the hyphal growth pattern resembles a non-organized web spun by spiders in the family Theridiidae; hyphae often grow forming loops in the agar (Fig. 3). Chlamydospores are intercalary to terminal, thin-walled, measuring 10-45 µm (average 26.6 µm), occasionally with a short hyphal projection (Fig. 4). *P. tentaculata* is homothallic, with mostly paragynous antheridia (Fig. 5). Antheridia are diclinous and often form tooth-like projections when they encircle the oogonia. Oosporules are spherical, aplerotic, and measure 14-38 µm (average 28.1 µm) (Fig. 6) (Erwin and Ribeiro, 1996; Kröber and Marwitz, 1993).
Genetics

*P. tentaculata* is placed in phylogenetic Clade 1 (Cooke et al., 2000) along with *P. cactorum*, *P. nicotianae*, *P. clandestina*, *P. iranica*, *P. hedraiandra* and *P. pseudotsugae*, among others (Fig. 7) (Blair et al., 2008).
Growth in culture
The optimum temperature for *P. tentaculata* is 15-25°C, while the minimum and maximum temperatures are 7°C and 32°C. At optimum temperatures, the growth rate is 2-5 mm/d. This slow growth rate contributes to the difficulty of isolating *P. tentaculata* from infected plants. Colony growth pattern on V8 juice agar is fluffy with a regular margin (Fig. 8).

Distinguishing characteristics for identification
*P. tentaculata* is classified in group I based on its primarily paragynous antheridia and papillate sporangia (Stamps et al., 1990) and is a member of phylogenetic Clade 1 (Cooke et al., 2000) along with *P. cactorum*, *P. nicotianae*, *P. clandestina* and *P. pseudotsugae*, among others. It differs from *P. cactorum* by the production of hyphal swellings, larger oogonia and oospores, higher minimum temperature and slower growth rate. It differs from *P. nicotianae* by being homothallic and producing mostly paragynous antheridia. It is distinct from *P. clandestina* and *P. pseudotsugae* by the production of chlamydospores and has a faster growth rate than *P. clandestina*.

Disease History
*P. tentaculata* was first discovered causing a stem and root rot of greenhouse-grown ornamentals in Germany in 1993 (Kröber and Marwitz, 1993), before being found in Spain and Italy (Moralejo et al., 2004; Álvarez et al., 2006; Cristinzio et al., 2006; Martini et al., 2009). It was detected in China in 2007 in field-grown medicinal plants and again in 2012 in field-grown celery (Meng and Wang, 2006; Wang and Zhao, 2014). In a USDA risk assessment, *P. tentaculata* was listed in the top 5 *Phytophthora* species of concern to the U.S. due to its potential environmental and economic impacts (Schwartzburg et al., 2009). In 2012, it was first found in North America in a California native plant nursery on sticky monkey flower (*Diplacus aurantiacus* syn=*Mimulus aurantiacus*) (Rooney-Latham and Blomquist, 2014). It has since been detected in numerous other California native plant nurseries and in outplanted nursery stock in a few restoration sites (Frankel et al., 2015). The origin of *P. tentaculata* is unknown.

Susceptible hosts include members of the Asteraceae, Ranunculaceae, Lamiaceae, Rhamnaceae, Phrymaceae, Rosaceae, and Verbenaceae plant families (Table 1). In Europe, the disease has been detected on marguerite daisy (*Argyranthemum frutescens*), chicory (*Cichorium intybus*), larkspur (*Delphinium* sp.), Gerbera daisy (*Gerbera jamesonii*), oxeye daisy (*Leucanthemum vulgare*), oregano (*Origanum vulgare*), lavender cotton (*Santolina chamaecyparissus*), and verbena hybrids (*Verbena* spp.). In China, it has been reported on celery (*Apium graveolens*) and costus root (*Aucklandia lappa*). In California it has been reported on nursery-grown native plant species including California mugwort (*Artemisia douglasiana*), tarragon (*Artemisia dracunculus*), California sagebrush (*Artemisia californica*), buckbrush (*Ceanothus cuneatus*), sticky monkey flower (*Diplacus aurantiacus*), coffeeberry (*Frangula californica*), toyon (*Heteromeles arbutifolia*), coyote mint (*Monardella villosa*), and sage (*Salvia* sp.). *P. tentaculata* has not been detected from any tree species.
In California, the pathogen appears to have been spread within and between nurseries by the use of infested pots and potentially by infected plants. Very little research has been done on specific control strategies. Like other Phytophthora diseases spread by zoospores in water, the use of strict sanitation and planting practices (i.e. use of clean soil, media, pots and propagation materials, proper irrigation, and keeping plants off the ground to prevent standing in water and water splash) are recommended to reduce the risk of pathogen spread. In addition, strict isolation of newly acquired plants from other sources must be maintained until the health of the plants is confirmed. Soil solarization and steam injection are being investigated as means to eradicate spot infestations resulting from the planting of infested nursery stock.

**Impacts in the Forest**

In Europe, *P. tentaculata* has been detected mostly in ornamental nurseries (Kröber and Marwitz, 1993) though there have been a few detections in commercial fields, usually associated with transplants (Garibaldi et al., 2010, Cristinzio et al., 2006). In California, *P. tentaculata* has only been detected in the environment on plants that have been grown in a nursery and planted out for restoration purposes. However, it has persisted on infected stock in the field for at least 4.5 years in northern California. The fact that both infected plants and the pathogen can survive for years after outplanting increases the potential for eventual spread from infected stock into native wildlands. Because the pathogen is reported to cause severe root and crown rot on a wide range of woody and semi-woody hosts, its introduction with infected nursery-grown plants could threaten key components of native plant communities being restored.

**Forest and Wildland Hosts and Symptoms**

*P. tentaculata* causes a moderate to severe root and crown rot, depending on the host species (Figs. 9 and 10). It has not been shown to be a foliar pathogen. The pathogen is known to cause high mortality in heavily infected plants (Kröber and Marwitz, 1993).
Amongst Californian hosts, sticky monkey flower (Diplacus aurantiacus) appears to be highly susceptible (Rooney-Latham and Blomquist, 2014). Artificially inoculated plants wilted and showed severe crown and root symptoms two weeks after root and crown exposure to P. tentaculata zoospores (Fig. 11). More than two thirds of the California detections of P. tentaculata to date have been on sticky monkey flower.

Field-planted nursery stock infected with P. tentaculata exhibits varying symptoms. Infected sticky monkey flower plants are stunted, with dull, yellowish leaves that turn red as the disease progresses. Roots and stem collars have necrotic, sunken lesions with few feeder roots. Plants have shown poor growth and eventual collapse within the first season in some situations (Fig. 9). In other cases, plants have grown for a year or more before developing extensive dieback with the onset of high evaporative demand in summer (Fig. 12). Transplanted Artemisia douglasiana plants infected with P. tentaculata were stunted and somewhat chlorotic more than 4.5 years after planting, but did not show obvious dieback (Fig. 13).
Table 1. *Phytophthora tentaculata* hosts, symptoms, and locations.

<table>
<thead>
<tr>
<th>Host Latin name</th>
<th>Host common name</th>
<th>Symptoms</th>
<th>Habitat</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apium graveolens</td>
<td>celery</td>
<td>Stem and root rot</td>
<td>Field</td>
<td>China - Bengbu, Anhui Province</td>
</tr>
<tr>
<td>Argyranthemum frutescens</td>
<td>(= Chrysanthemum frutescens)</td>
<td>Root and stem base</td>
<td>Nursery</td>
<td>Germany</td>
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<tr>
<td>Artemisia douglasiana</td>
<td>California mugwort</td>
<td>Root rot</td>
<td>Nursery, outplanted nursery stock</td>
<td>USA - California</td>
</tr>
<tr>
<td>Artemisia dracunculus</td>
<td>tarragon</td>
<td>Root rot</td>
<td>Nursery</td>
<td>USA - California</td>
</tr>
<tr>
<td>Artemisia californica</td>
<td>California sagebrush</td>
<td>Root rot</td>
<td>Nursery</td>
<td>USA - California</td>
</tr>
<tr>
<td>Aucklandia lappa</td>
<td>costus root</td>
<td>Stalk rot</td>
<td>Field</td>
<td>China - Yunnan Province</td>
</tr>
<tr>
<td>Ceanothus cuneatus</td>
<td>buckbrush</td>
<td>Root rot</td>
<td>Nursery</td>
<td>USA - California</td>
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<tr>
<td>Cichorium intybus</td>
<td>Witloof chicory</td>
<td>Collar and root rot</td>
<td>Field</td>
<td>Italy - Tarquinia</td>
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<tr>
<td>Delphinium sp.</td>
<td>larkspur</td>
<td>Root and stem base</td>
<td>Nursery</td>
<td>Germany</td>
</tr>
<tr>
<td>Diplacus aurantiacus</td>
<td>(= Mimulus aurantiacus)</td>
<td>Root and crown rot</td>
<td>Nursery, outplanted nursery stock</td>
<td>USA - California</td>
</tr>
<tr>
<td>Frangula californica</td>
<td>coffeeberry</td>
<td>Root and crown rot</td>
<td>Nursery, outplanted nursery stock</td>
<td>USA - California</td>
</tr>
<tr>
<td>Gerbera jamesonii</td>
<td>Gerbera daisy</td>
<td>Crown and stem rot</td>
<td>Field</td>
<td>Italy – Torre del Greco</td>
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<tr>
<td>Heteromeles arbutifolia</td>
<td>toyon</td>
<td>Root rot</td>
<td>Outplanted nursery stock</td>
<td>USA - California</td>
</tr>
<tr>
<td>Leucanthemum vulgare</td>
<td>(= Chrysanthemum leucanthemum)</td>
<td>Root and stem rot</td>
<td>Nursery</td>
<td>Germany</td>
</tr>
<tr>
<td>Monardella villosa</td>
<td>coyote mint</td>
<td>Root rot</td>
<td>Nursery</td>
<td>USA - California</td>
</tr>
<tr>
<td>Origanum vulgare</td>
<td>oregano</td>
<td>Root and stem rot</td>
<td>Nursery</td>
<td>Italy - Liguria</td>
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<td>Salvia sp.</td>
<td>sage</td>
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<td>Santolina chamaecyparissus</td>
<td>lavender cotton</td>
<td>Root rot</td>
<td>Nursery</td>
<td>Spain - Valencia Province</td>
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<tr>
<td>Verbena sp. and hybrids</td>
<td>verbena</td>
<td>Root, stalk and collar rot</td>
<td>Nursery</td>
<td>Germany; Spain - Balearic Islands</td>
</tr>
</tbody>
</table>
Management and education resources


Kosta, K. 2014. Best management practices to minimize the risk of *Phytophthora* introduction into nurseries. [Video 23:15 min.] https://www.youtube.com/watch?v=oKEQqDBU3vw

Lyman, G. 2014. *Phytophthora* effects on native habitat restoration. [Video 19:39 min.] https://www.youtube.com/watch?v=vpRe4nX6fSo&list=UUpzaBF1U82SzP1E8eqdTZNA


Swiecki, T. and Bernhardt, E. 2015. Revealing an unseen enemy: detecting *Phytophthora* (Pythiaceae) species in native plant nurseries and restoration sites. [Video 17:35 min.] https://www.youtube.com/watch?v=8NXRl86i3_i


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