

How many *Phytophthora* species?

Clive Brasier

**Forest Research Agency
Farnham UK**



Many new *Phytophthora* species are being discovered.

This prompted me to take a look at the theoretical question:

How many *Phytophthoras* species are there?

What might the answer mean for *Phytophthora* taxonomy and phylogeny? .. and for the plant health risk to forests and natural ecosystems? (cf. *P. alni*, *P. ramorum* etc)

Going to explore these issues. It seems best to begin with a brief history of *Phytophthora* species over time.

***Phytophthora* species over time**

1876 Anton De Bary

1 species

~ up to 1920

~ generic confusion

1931 C M Tucker

ca 20 species

1963 G M Waterhouse

ca 41 species

1976 Newhook, Waterhouse, Stamps

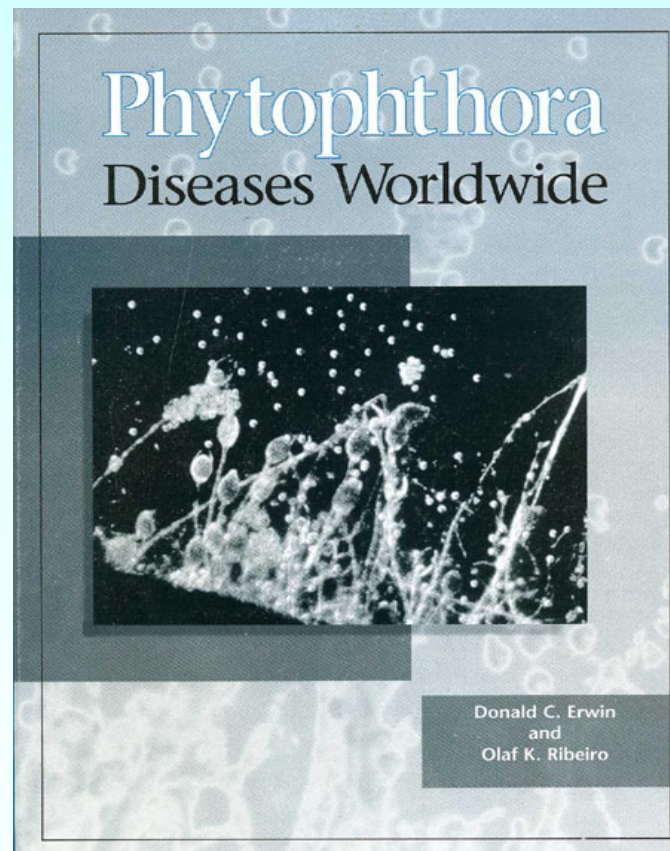
ca 50 species

1996 Erwin, Ribeiro

ca 54 species

Phytophthora species over time

1996 Erwin & Ribeiro *ca* 54 species



***Phytophthora* species described Pre 2000
In Erwin & Ribeiro 1996**

<i>P. arecae</i>	<i>P. erythroseptica</i>	<i>P. japonica</i>	<i>P. phaseoli</i>
<i>P. boehmeriae</i>	<i>P. fragariae frag.</i>	<i>P. katsurae</i>	<i>P. porri</i>
<i>P. botryosa</i>	<i>P. fragariae rubi</i>	<i>P. lateralis</i>	<i>P. primulae</i>
<i>P. cactorum</i>	<i>P. gonapodyides</i>	<i>P. macrochlamy.</i>	<i>P. pseudotsugae</i>
<i>P. cajani</i>	<i>P. heveae</i>	<i>P. meadii</i>	<i>P. quercina</i> 1999
<i>P. cambivora</i>	<i>P. hibernalis</i>	<i>P. medicaginis</i>	<i>P. quininea</i>
<i>P. capsici</i>	<i>P. humicola</i>	<i>P. megakarya</i>	<i>P. richardiae</i>
<i>P. cinnamomi</i>	<i>P. idaei</i>	<i>P. megasperma</i>	<i>P. sinensis</i>
<i>P. citricola</i>	<i>P. ilicis</i>	<i>P. melonis</i>	<i>P. sojae</i>
<i>P. citrophthora</i>	<i>P. infestans</i>	<i>P. mexicana</i>	<i>P. syringae</i>
<i>P. clandestina</i>	<i>P. inflata</i>	<i>P. mirabilis</i>	<i>P. tentaculata</i>
<i>P. colocasiae</i>	<i>P. insolita</i>	<i>P. multivesiculata</i>	<i>P. trifolii</i>
<i>P. cryptogea</i>	<i>P. iranica</i>	<i>P. nicotianae</i>	<i>P. vignae</i>
<i>P. drechsleri</i>	<i>P. italica</i>	<i>P. palmivora</i>	54 + 1

Phytophthora species over time

1876 Anton De Bary

1 species

~ up to 1920

~ generic confusion

1931 C M Tucker

ca 20 species

1963 G M Waterhouse

ca 41 species

1976 Newhook, Waterhouse, Stamps

ca 50 species

1996 Erwin, Ribeiro

ca 54 species

1999 + *P. quercina*

ca 55 species

Round off (part described taxa etc)

~ 60 species pre 2000

How many Phytophthoras?

Take as the baseline ca 60 species known pre 2000

Hawksworth (2001) estimated only 10% of fungi were known to science.

Crous & Groenwald (2005) estimated only 7% known

Take 10% as the estimate of unknowns

Then there *may* be ~ 600 *Phytophthora* species in total, of which only ~ 60 species were accounted for by 2000

Leaving ~ 540 still unknown in 1999!

How many Phytophthoras?

Instead of 600, take a much more conservative estimate: 200-600 extant *Phytophthora* species

Then there may have been anything from 140 - 540 *unknown* species in ca 2000

An average of 340 ± 200 species still unknown

How many of these 140 - 540 unknown species might damage forests or natural ecosystems if they become invasives?

***Phytophthora* species described Pre 2000**

<i>P. arecae</i>	<i>P. erythroseptica</i>	<i>P. japonica</i>	<i>P. phaseoli</i>
<i>P. boehmeriae</i>	<i>P. fragariae frag.</i>	<i>P. katsurae</i>	<i>P. porri</i>
<i>P. botryosa</i>	<i>P. fragariae rubi</i>	<i>P. lateralis</i>	<i>P. primulae</i>
<i>P. cactorum</i>	<i>P. gonapodyides</i>	<i>P. macrochlamy.</i>	<i>P. pseudotsugae</i>
<i>P. cajani</i>	<i>P. heveae</i>	<i>P. meadii</i>	<i>P. quercina</i>
<i>P. cambivora</i>	<i>P. hibernalis</i>	<i>P. medicaginis</i>	<i>P. quininea</i>
<i>P. capsici</i>	<i>P. humicola</i>	<i>P. megakarya</i>	<i>P. richardiae</i>
<i>P. cinnamomi</i>	<i>P. idaei</i>	<i>P. megasperma</i>	<i>P. sinensis</i>
<i>P. citricola</i>	<i>P. ilicis</i>	<i>P. melonis</i>	<i>P. sojae</i>
<i>P. citrophthora</i>	<i>P. infestans</i>	<i>P. mexicana</i>	<i>P. syringae</i>
<i>P. clandestina</i>	<i>P. inflata</i>	<i>P. mirabilis</i>	<i>P. tentaculata</i>
<i>P. colocasiae</i>	<i>P. insolita</i>	<i>P. multivesiculata</i>	<i>P. trifolii</i>
<i>P. cryptogea</i>	<i>P. iranica</i>	<i>P. nicotianae</i>	<i>P. vignae</i>
<i>P. drechsleri</i>	<i>P. italica</i>	<i>P. palmivora</i>	55

Phytophthora species described Pre 2000
Damaging to nursery trees, forests and natural ecosystems

<i>P. arecae</i>	<i>P. erythroseptica</i>	<i>P. japonica</i>	<i>P. phaseoli</i>
<i>P. boehmeriae</i>	<i>P. fragariae frag.</i>	<i>P. katsurae</i>	<i>P. porri</i>
<i>P. botryosa</i>	<i>P. fragariae rubi</i>	<i>P. lateralis</i>	<i>P. primulae</i>
<i>P. cactorum</i>	<i>P. gonapodyides</i>	<i>P. macrochlamy.</i>	<i>P. pseudotsugae</i>
<i>P. cajani</i>	<i>P. heveae</i>	<i>P. meadii</i>	<i>P. quercina</i>
<i>P. cambivora</i>	<i>P. hibernalis</i>	<i>P. medicaginis</i>	<i>P. quininea</i>
<i>P. capsici</i>	<i>P. humicola</i>	<i>P. megakarya</i>	<i>P. richardiae</i>
<i>P. cinnamomi</i>	<i>P. idaei</i>	<i>P. megasperma</i>	<i>P. sinensis</i>
<i>P. citricola</i>	<i>P. ilicis</i>	<i>P. melonis</i>	<i>P. sojiae</i>
<i>P. citrophthora</i>	<i>P. infestans</i>	<i>P. mexicana</i>	<i>P. syringae</i>
<i>P. clandestina</i>	<i>P. inflata</i>	<i>P. mirabilis</i>	<i>P. tentaculata</i>
<i>P. colocasiae</i>	<i>P. insolita</i>	<i>P. multivesiculata</i>	<i>P. trifolii</i>
<i>P. cryptogea</i>	<i>P. iranica</i>	<i>P. nicotianae</i>	<i>P. vignae</i>
<i>P. drechsleri</i>	<i>P. italica</i>	<i>P. palmivora</i>	11 / 55 = 20%

How many Phytophthoras?

So information prior to 2000 suggests ~20% of Phytophthoras were damaging to forests or natural ecosystems

Take as a more conservative estimate ~10%.

Then on this basis, in 2000 there may still have been between 14 - 54 ie average 34 ± 20 *unknown Phytophthora* species potentially damaging to forests or natural ecosystems

And since 2000? ...

**Phytophthora species
Pre 2000**

<i>P. arecae</i>	<i>P. japonica</i>
<i>P. boehmeriae</i>	<i>P. katsurae</i>
<i>P. botryosa</i>	<i>P. lateralis</i>
<i>P. cactorum</i>	<i>P. macrochlamydospora</i>
<i>P. cajani</i>	<i>P. meadii</i>
<i>P. cambivora</i>	<i>P. medicaginis</i>
<i>P. capsici</i>	<i>P. megakarya</i>
<i>P. cinnamomi</i>	<i>P. megasperma</i>
<i>P. citricola</i>	<i>P. melonis</i>
<i>P. citrophthora</i>	<i>P. mexicana</i>
<i>P. clandestina</i>	<i>P. mirabilis</i>
<i>P. colocasiae</i>	<i>P. multivesiculata</i>
<i>P. cryptogea</i>	<i>P. nicotianae</i>
<i>P. drechsleri</i>	<i>P. palmivora</i>
<i>P. erythroseptica</i>	<i>P. phaseoli</i>
<i>P. fragariae var frag.</i>	<i>P. porri</i>
<i>P. fragariae var rubi</i>	<i>P. primulae</i>
<i>P. gonapodyides</i>	<i>P. pseudotsugae</i>
<i>P. heveae</i>	<i>P. quercina</i>
<i>P. hibernalis</i>	<i>P. quininea</i>
<i>P. humicola</i>	<i>P. richardiae</i>
<i>P. idaei</i>	<i>P. sinensis</i>
<i>P. ilicis</i>	<i>P. sojae</i>
<i>P. infestans</i>	<i>P. syringae</i>
<i>P. inflata</i>	<i>P. tentaculata</i>
<i>P. insolita</i>	<i>P. trifolii</i>
<i>P. iranica</i>	<i>P. vignae</i>
<i>P. italica</i>	55

<i>Phytophthora</i> species Pre 2000		<i>Phytophthora</i> species Post 2000	
		Described or under construction	
<i>P. arecae</i>	<i>P. japonica</i>	<i>P. alni</i> (x3)	<i>P. alticola</i>
<i>P. boehmeriae</i>	<i>P. katsurae</i>	<i>P. andina</i>	<i>P. frigida</i>
<i>P. botryosa</i>	<i>P. lateralis</i>	<i>P. asparagi</i>	<i>P. austrocedrae</i>
<i>P. cactorum</i>	<i>P. macrochlamydospora</i>	<i>P. bisheria</i>	<i>P. lagoariana</i>
<i>P. cajani</i>	<i>P. meadii</i>	<i>P. brassicae</i>	<i>P. cuyabensis</i>
<i>P. cambivora</i>	<i>P. medicaginis</i>	<i>P. captiosa</i>	<i>P. cact x hed</i>
<i>P. capsici</i>	<i>P. megakarya</i>	<i>P. europaea</i>	<i>P. foliorum</i>
<i>P. cinnamomi</i>	<i>P. megasperma</i>	<i>P. fallax</i>	<i>P. sulawesiensis</i>
<i>P. citricola</i>	<i>P. melonis</i>	<i>P. gallica</i>	<i>P. siskiyouensis</i>
<i>P. citrophthora</i>	<i>P. mexicana</i>	<i>P. glovera</i>	<i>P. uliginosa</i>
<i>P. clandestina</i>	<i>P. mirabilis</i>	<i>P. hedraiandra</i>	
<i>P. colocasiae</i>	<i>P. multivesiculata</i>	<i>P. inundata</i>	<i>P. taxon salixsoil</i>
<i>P. cryptogea</i>	<i>P. nicotianae</i>	<i>P. ipomoeae</i>	<i>P. taxon pgchlamydo</i>
<i>P. drechsleri</i>	<i>P. palmivora</i>	<i>P. kelmania</i>	<i>P. taxon riversoil</i>
<i>P. erythroseptica</i>	<i>P. phaseoli</i>	<i>P. kernoviae</i>	<i>P. taxon oaksoil</i>
<i>P. fragariae</i> var <i>frag.</i>	<i>P. porri</i>	<i>P. nemorosa</i>	<i>P. parvasperma</i>
<i>P. fragariae</i> var <i>rubi</i>	<i>P. primulae</i>	<i>P. niederhauserii</i>	<i>P. hungarica</i>
<i>P. gonapodyides</i>	<i>P. pseudotsugae</i>	<i>P. pistaciae</i>	<i>P. sylvatica</i>
<i>P. heveae</i>	<i>P. quercina</i>	<i>P. polonica</i>	<i>P. parsiana</i>
<i>P. hibernalis</i>	<i>P. quininea</i>	<i>P. pseudosyringae</i>	<i>P. quercetorum</i>
<i>P. humicola</i>	<i>P. richardiae</i>	<i>P. psychrophila</i>	<i>P. taxon meadii-like</i>
<i>P. idaei</i>	<i>P. sinensis</i>	<i>P. ramorum</i>	<i>P. taxon Acer</i>
<i>P. ilicis</i>	<i>P. sojiae</i>	<i>P. sansomea</i>	<i>P. taxon Agathis</i>
<i>P. infestans</i>	<i>P. syringae</i>	<i>P. taxon. Banksia</i>	<i>P. taxon orphan</i>
<i>P. inflata</i>	<i>P. tentaculata</i>	<i>P. taxon. Chicory</i>	
<i>P. insolita</i>	<i>P. trifolii</i>	<i>P. cact x nic</i>	
<i>P. iranica</i>	<i>P. vignae</i>	<i>P. tropicalis</i>	
<i>P.italica</i>	55		50+

***Phytophthora* species Post 2000**

Species described or under construction

<i>P. alni</i> (x 3)	<i>P. kernoviae</i>	<i>P. frigida</i>	<i>P. taxon salixsoil</i>
<i>P. andina</i>	<i>P. nemorosa</i>	<i>P. austrocedrae</i>	<i>P. tax. pgchlamydo</i>
<i>P. asparagi</i>	<i>P. niederhauserii</i>	<i>P. lagoariana</i>	<i>P. taxon riversoil</i>
<i>P. bisheria</i>	<i>P. pistaciae</i>	<i>P. cuyabensis</i>	<i>P. taxon oaksoil</i>
<i>P. brassicae</i>	<i>P. polonica</i>	<i>P. cact x hedr</i>	<i>P. parvasperma</i>
<i>P. captiosa</i>	<i>P. pseudosyringae</i>	<i>P. foliorum</i>	<i>P. hungarica</i>
<i>P. europaea</i>	<i>P. psychrophila</i>	<i>P. sulawesiensis</i>	<i>P. sylvatica</i>
<i>P. fallax</i>	<i>P. ramorum</i>	<i>P. siskiyouensis</i>	<i>P. parsiana</i>
<i>P. gallica</i>	<i>P. sansomea</i>	<i>P. uliginosa</i>	<i>P. quercetorum</i>
<i>P. glovera</i>	<i>P. taxon Banksia</i>	<i>P. pinifolia</i>	<i>P. tax. meadii-like</i>
<i>P. hedraiandra</i>	<i>P. taxon. chicory</i>		<i>P. taxon Acer</i>
<i>P. inundata</i>	<i>P. cact x nic</i>		<i>P. taxon Agathis</i>
<i>P. ipomoeae</i>	<i>P. tropicalis</i>		<i>P. taxon orphan</i>
<i>P. kelmania</i>	<i>P. alticola</i>		

Phytophthora species / taxa Post 2000

Associated with research on nursery trees, forests and natural ecosystems

<i>P. alni</i> (x 3)	<i>P. kernoviae</i>	<i>P. frigida</i>	<i>P. taxon salixsoil</i>
<i>P. andina</i>	<i>P. nemorosa</i>	<i>P. austrocedrae</i>	<i>P. tax. pgchlamydo</i>
<i>P. asparagi</i>	<i>P. niederhauserii</i>	<i>P. lagoariana</i>	<i>P. taxon riversoil</i>
<i>P. bisheria</i>	<i>P. pistaciae</i>	<i>P. cuyabensis</i>	<i>P. taxon oaksoil</i>
<i>P. brassicae</i>	<i>P. polonica</i>	<i>P. cact x hedr</i>	<i>P. parvasperma</i>
<i>P. captiosa</i>	<i>P. pseudosyringae</i>	<i>P. foliorum</i>	<i>P. hungarica</i>
<i>P. europaea</i>	<i>P. psychrophila</i>	<i>P. sulawesiensis</i>	<i>P. sylvatica</i>
<i>P. fallax</i>	<i>P. ramorum</i>	<i>P. siskiyouensis</i>	<i>P. parsiana</i>
<i>P. gallica</i>	<i>P. sansomea</i>	<i>P. uliginosa</i>	<i>P. quercetorum</i>
<i>P. glovera</i>	<i>P. taxon Banksia</i>	<i>P. pinifolia</i>	<i>P. tax. meadii-like</i>
<i>P. hedraiandra</i>	<i>P. taxon. chicory</i>		<i>P. taxon Acer</i>
<i>P. inundata</i>	<i>P. cact x nic</i>		<i>P. taxon Agathis</i>
<i>P. ipomoeae</i>	<i>P. tropicalis</i>		<i>P. taxon orphan</i>
<i>P. kelmania</i>	<i>P. alticola</i>		31+ /51 = ~60 %

Estimate for the 55 pre- 2000 species was only 20% ...

Phylotypes or 'virtual taxa'

Molecular technology, especially PCR, has provided opportunity to probe the environment for known or unknown taxa based solely on DNA sequence profiles.

Especially used in bacteriology where soil profiles revealing remarkable numbers of prokaryote organisms.

Since the product is a DNA sequence to fit to a phylogenetic tree and no culture is available the resulting 'taxa' are commonly referred to as phylotypes.

For *Phytophthora*, I have personally tended to think of them as 'virtual taxa' to underline the lack of hard information.

Virtual taxa or phylotypes

Arcate, Karp & Nelson (2006) recently applied these methods to search for Oomycetes in tomato and other rhizosphere soils in NY State.

They found -

Many Pythiums! (and a couple of Phytophthoras)

Greater diversity than by direct baiting methods

They were able to sample the dormant oospore flora as well as active propagules.

Virtual taxa or phylotypes

At least two other research groups have begun to apply these methods to screen for Phytophthoras in forests and natural ecosystems, so far mainly in water environments (streams):

- Everett Hansen's group at Corvallis**
- David Cooke's group at SCRI Dundee**

Phytophthora species Pre 2000	Phytophthora species Post 2000			
	Described or under construction		Phylotypes or virtual taxa	
<i>P. arecae</i>	<i>P. japonica</i>	<i>P.alni</i> (x3)	<i>P. alticola</i>	SW Oregon streams Hansen / Reeser / Sutton Combined SSCP of ITS, Cox 30 species <i>10 unknown / new taxa ?</i>
<i>P. boehmeriae</i>	<i>P. katsurae</i>	<i>P. andina</i>	<i>P. frigida</i>	
<i>P. botryosa</i>	<i>P. lateralis</i>	<i>P. asparagi</i>	<i>P. austrocedrae</i>	
<i>P. cactorum</i>	<i>P. macrochlamydospora</i>	<i>P. bisheria</i>	<i>P. lagoariana</i>	
<i>P. cajani</i>	<i>P. meadii</i>	<i>P. brassicae</i>	<i>P. cuyabensis</i>	
<i>P. cambivora</i>	<i>P. medicaginis</i>	<i>P. captiosa</i>	<i>P. cact x hed</i>	
<i>P. capsici</i>	<i>P. megakarya</i>	<i>P. europaea</i>	<i>P. foliorum</i>	
<i>P. cinnamomi</i>	<i>P. megasperma</i>	<i>P. fallax</i>	<i>P. sulawesiensis</i>	
<i>P. citricola</i>	<i>P. melonis</i>	<i>P. gallica</i>	<i>P. siskiyouensis</i>	
<i>P. citrophthora</i>	<i>P. mexicana</i>	<i>P. glovera</i>	<i>P. uliginosa</i>	
<i>P. clandestina</i>	<i>P. mirabilis</i>	<i>P. hedraiandra</i>	<i>P. pinifolia</i>	Central Oregon stream (Oak Creek) Remigi / sutton / Reeser / Hansen Combined SSCP of ITS, Cox 11 species <i>5 unknown / new taxa ?</i>
<i>P. colocasiae</i>	<i>P. multivesiculata</i>	<i>P. inundata</i>		
<i>P. cryptogea</i>	<i>P. nicotianae</i>	<i>P. ipomoeae</i>	<i>P. taxon salixsoil</i>	
<i>P. drechsleri</i>	<i>P. palmivora</i>	<i>P. kelmania</i>	<i>P. taxon pgchlamydo</i>	
<i>P. erythroseptica</i>	<i>P. phaseoli</i>	<i>P. kernoviae</i>	<i>P. taxon riversoil</i>	
<i>P. fragariae var frag.</i>	<i>P. porri</i>	<i>P. nemorosa</i>	<i>P. taxon oaksoil</i>	West Australian bush Burgess / Hardy ITS sequence <i>9 unknown / new taxa ?</i>
<i>P. fragariae var rubi</i>	<i>P. primulae</i>	<i>P. niederhauserii</i>	<i>P. parvasperma</i>	
<i>P. gonapodyides</i>	<i>P. pseudotsugae</i>	<i>P. pistaciae</i>	<i>P. hungarica</i>	
<i>P. heveae</i>	<i>P. quercina</i>	<i>P. polonica</i>	<i>P. sylvatica</i>	West Scotland streams Scibetta / Cooke / Cacciola ITS1 nested PCR 17 species <i>3 unknown / new taxa ?</i>
<i>P. hibernalis</i>	<i>P. quininea</i>	<i>P. pseudosyringae</i>	<i>P. carica</i>	
<i>P. humicola</i>	<i>P. richardiae</i>	<i>P. psychrophila</i>	<i>P. quercetorum</i>	
<i>P. idaei</i>	<i>P. sinensis</i>	<i>P. ramorum</i>	<i>P. taxon meadii-like</i>	
<i>P. ilicis</i>	<i>P. sojaj</i>	<i>P. sansomea</i>	<i>P. taxon Acer</i>	
<i>P. infestans</i>	<i>P. syringae</i>	<i>P. taxon. Banksia</i>	<i>P. taxon Agathis</i>	Ecuador streams Scibetta / Cooke ITS1 nested PCR 10 species <i>4 unknown / new taxa ?</i>
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<i>P. insolita</i>	<i>P. trifolii</i>	<i>P. cact x nic</i>		
<i>P. iranica</i>	<i>P. vignae</i>	<i>P. tropicalis</i>	51 +	
<i>P. italica</i>	55			

***Phytophthora* species post 2000**

Phylotypes or virtual taxa

SW Oregon streams

Hansen / Reeser / Sutton
Combined SSCP of ITS, Cox
30 species

10 unknown / new taxa ?

Central Oregon stream (Oak Creek)

Remigi / Sutton / Reeser / Hansen
Combined SSCP of ITS, Cox
11 species

5 unknown / new taxa ?

West Scotland streams

Scibetta / Cooke / Cacciola
ITS1 nested PCR

17 species

3 unknown / new taxa ?

Ecuador streams

Scibetta / Cooke
ITS1 nested PCR

10 Phy species (+ 3 Per spp)

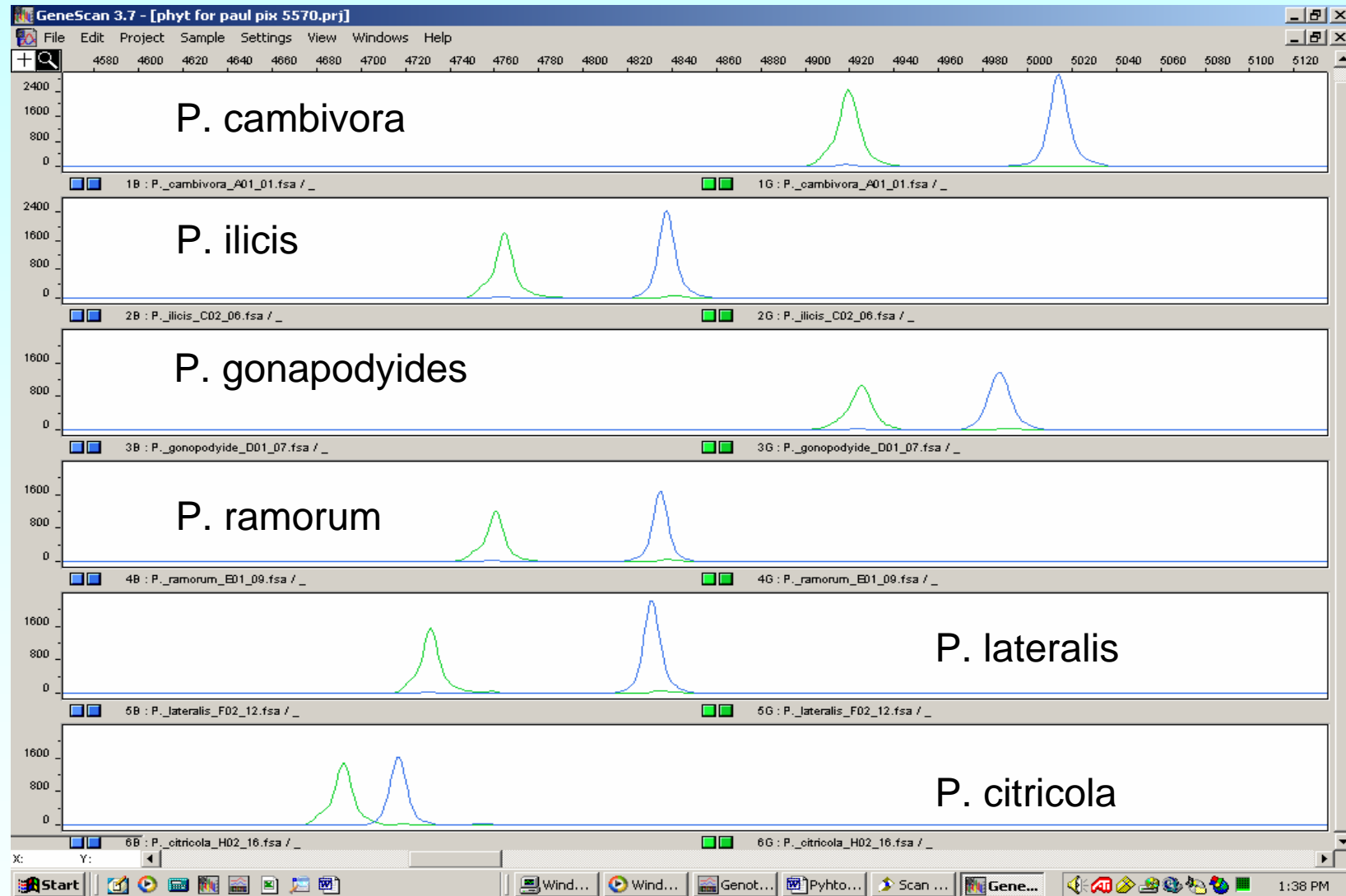
4 unknown / new taxa ?

West Australian bush

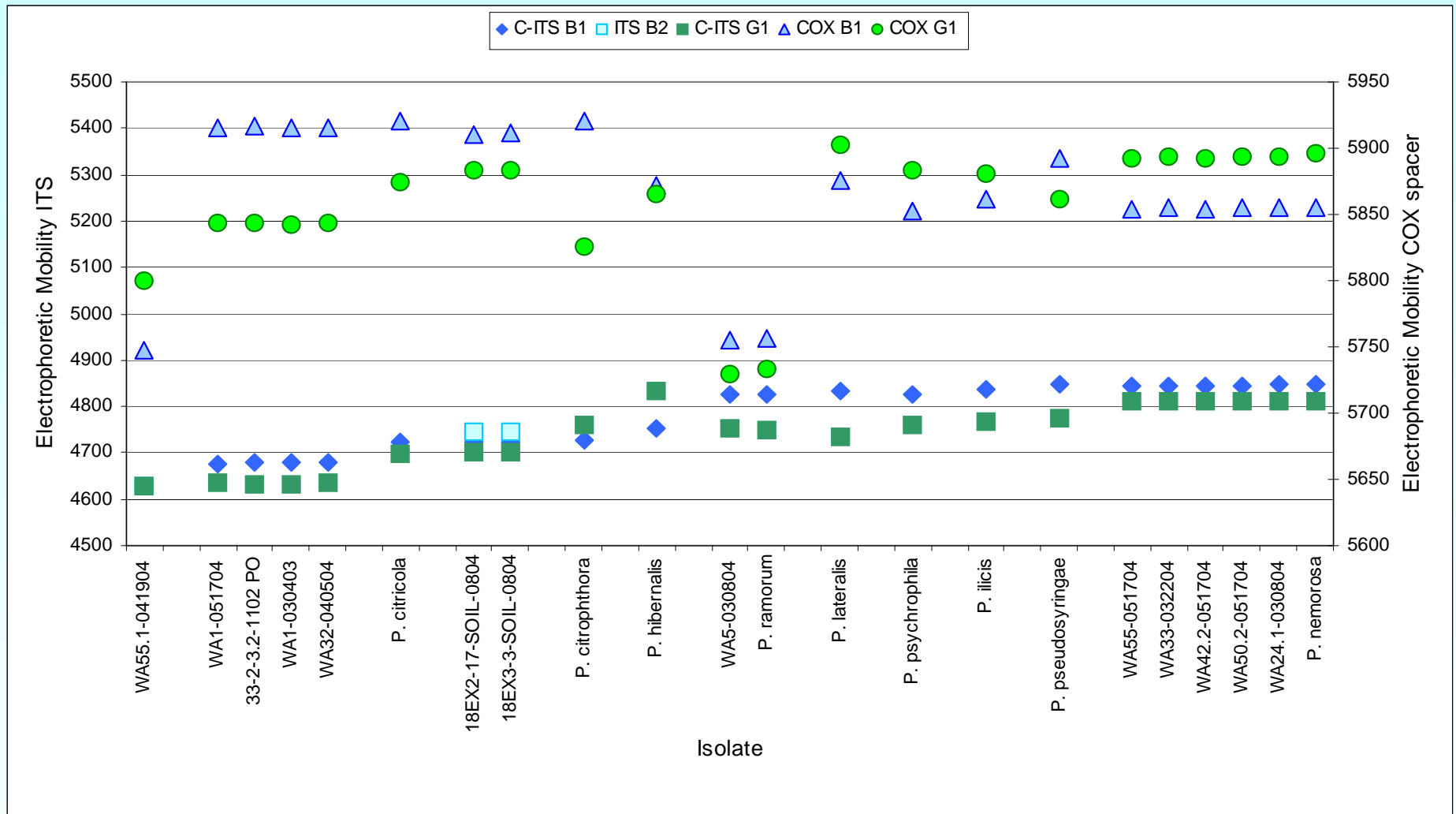
Burgess / Hardy
ITS sequence

9 unknown / new taxa ?

Electropherogram for ITS1 products generated by GeneScan



Phytophthora diversity in streams and soil - SSCP FINGERPRINTING



ITS1 and COX spacer peaks for some unknown isolates
Hansen group

Slide courtesy Hansen *et al*

South west Oregon streams

Hansen / Reeser / Sutton

Combined SSCP of ITS, Cox

30 *Phytophthora* species

~ 10 unknown / new taxa ?

Central Oregon stream (Oak Creek)

Remigi / Sutton / Reeser / Hansen

Combined SSCP of ITS, Cox

11 *Phytophthora* species

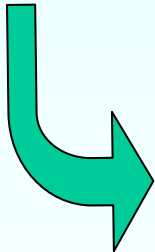
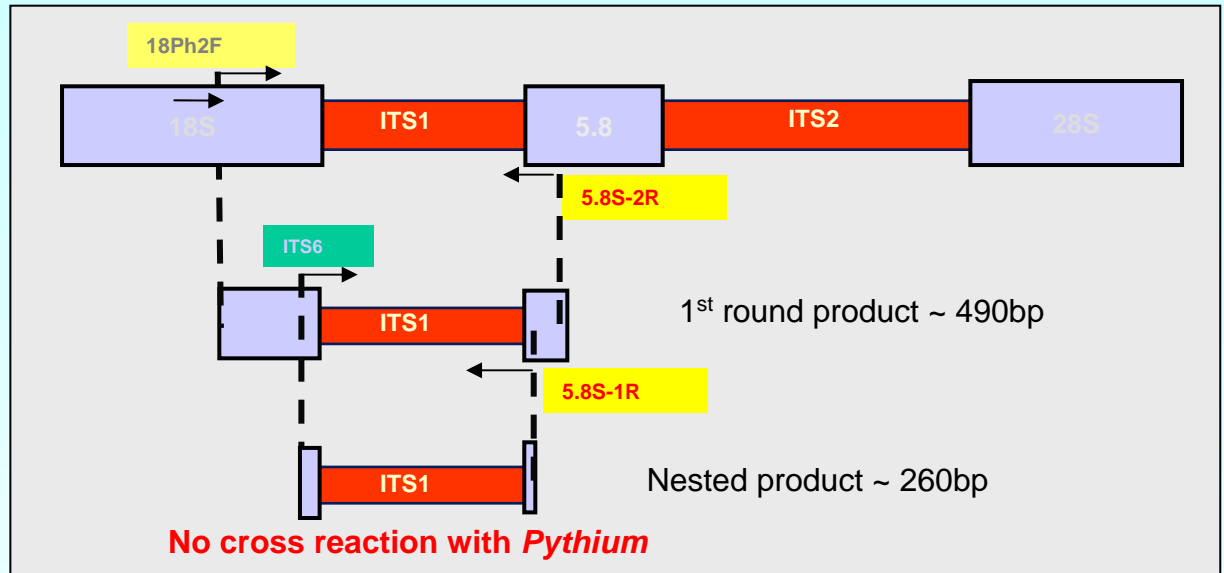
~ 5 unknown / new taxa ?

Monitoring *Phytophthora* using molecular methods

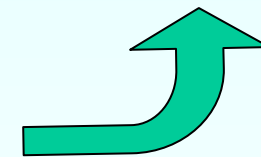
Silvia Scibetta, David Cooke & Santina Cacciola



Nature reserves sampled (water and soil)

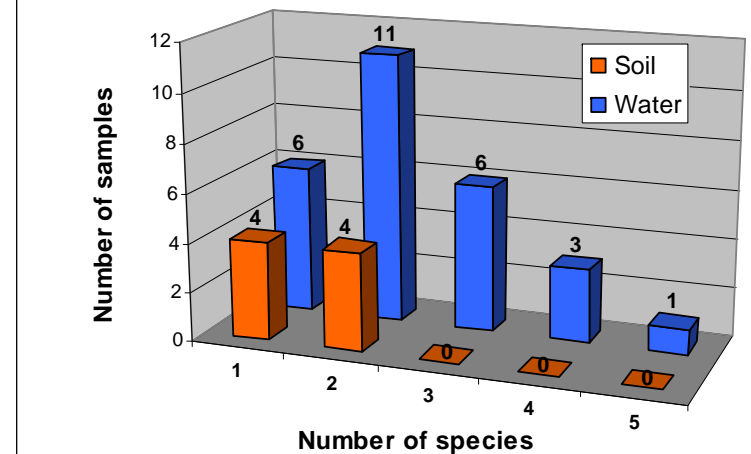
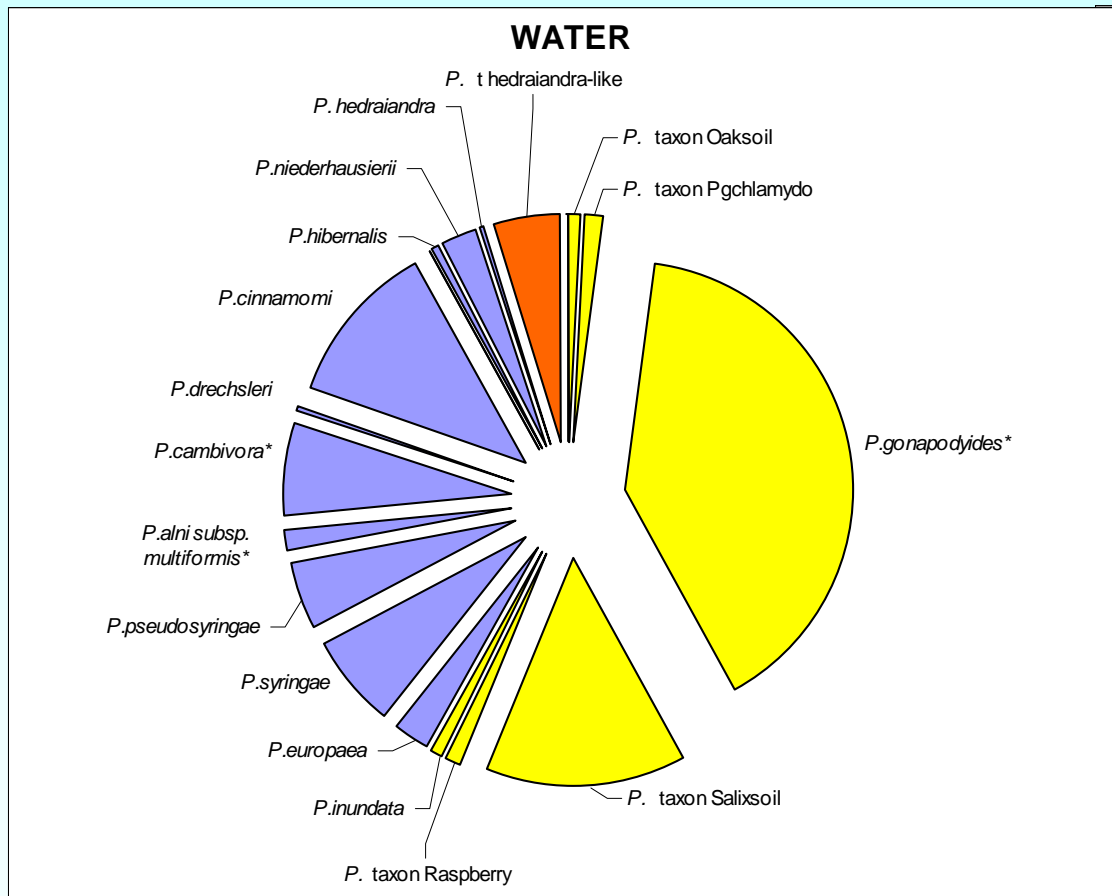


10 litre samples of standing or flowing water filtered



- DNA extraction
- PCR
- Cloning
- Sequencing

Phytophthora phylotypes found in 2006 Scottish Survey



Fewer samples from soil but up to 5 species detected in a single water sample

17 different *Phytophthora* sp. in water samples cf. only 5 in soil samples

West Scotland streams

Scibetta / Cooke / Cacciola

ITS 1 nested PCR

17 *Phytophthora* species

~ 3 unknown / new taxa ?

Ecuador streams 2 - 3000 m. asl.

Scibetta / Cooke

Combined SSCP of ITS, Cox

10 *Phytophthora* species
(+ 3 *Peronospora* spp)

~ 3 unknown / new taxa ?

West Australian Bush - unidentified isolates

Stukely/ Burgess / Hardy

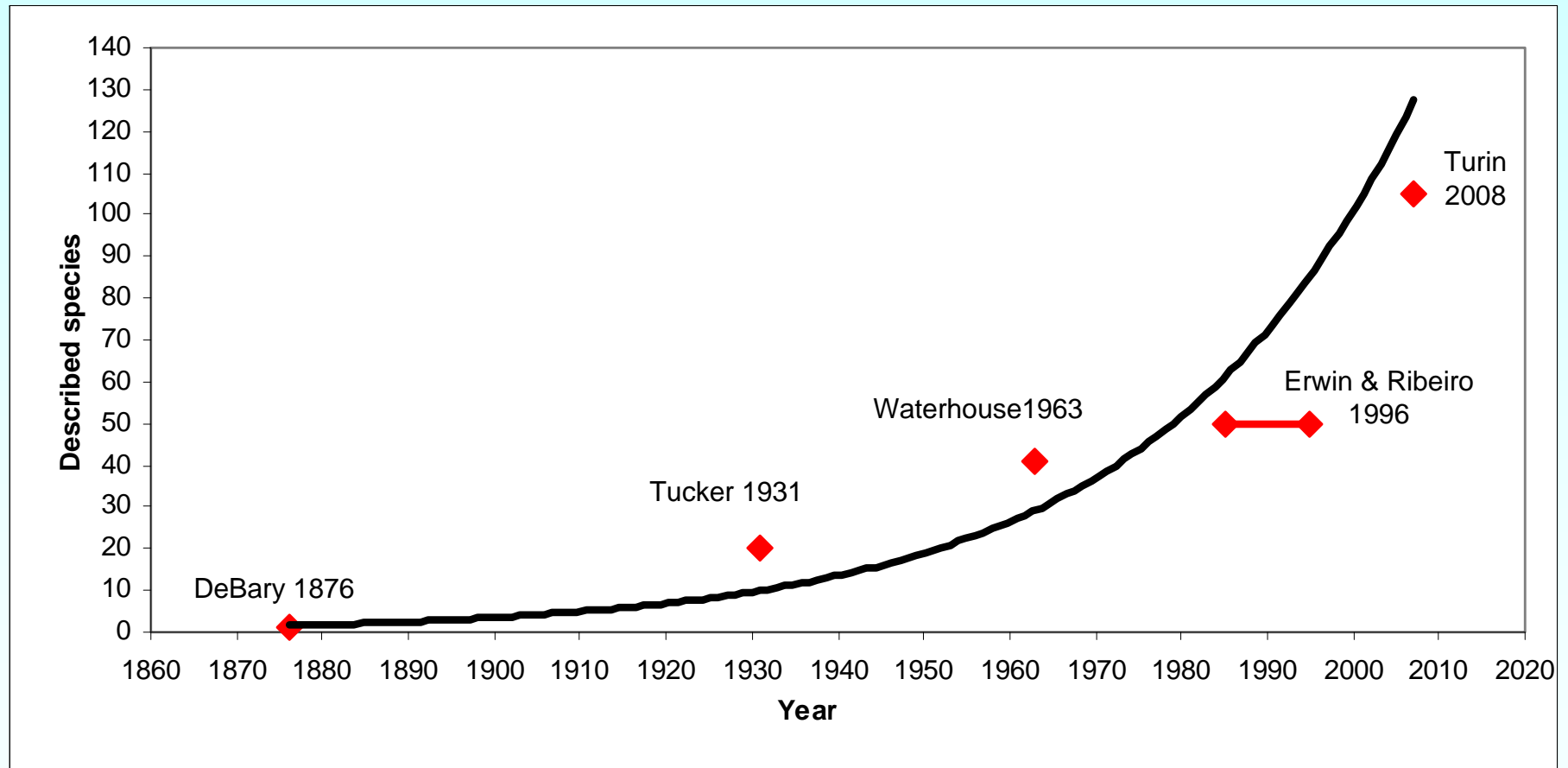
Screening of the VHS culture collection - ITS
sequence data and blast search

~ 7-9 unknown / new taxa ?

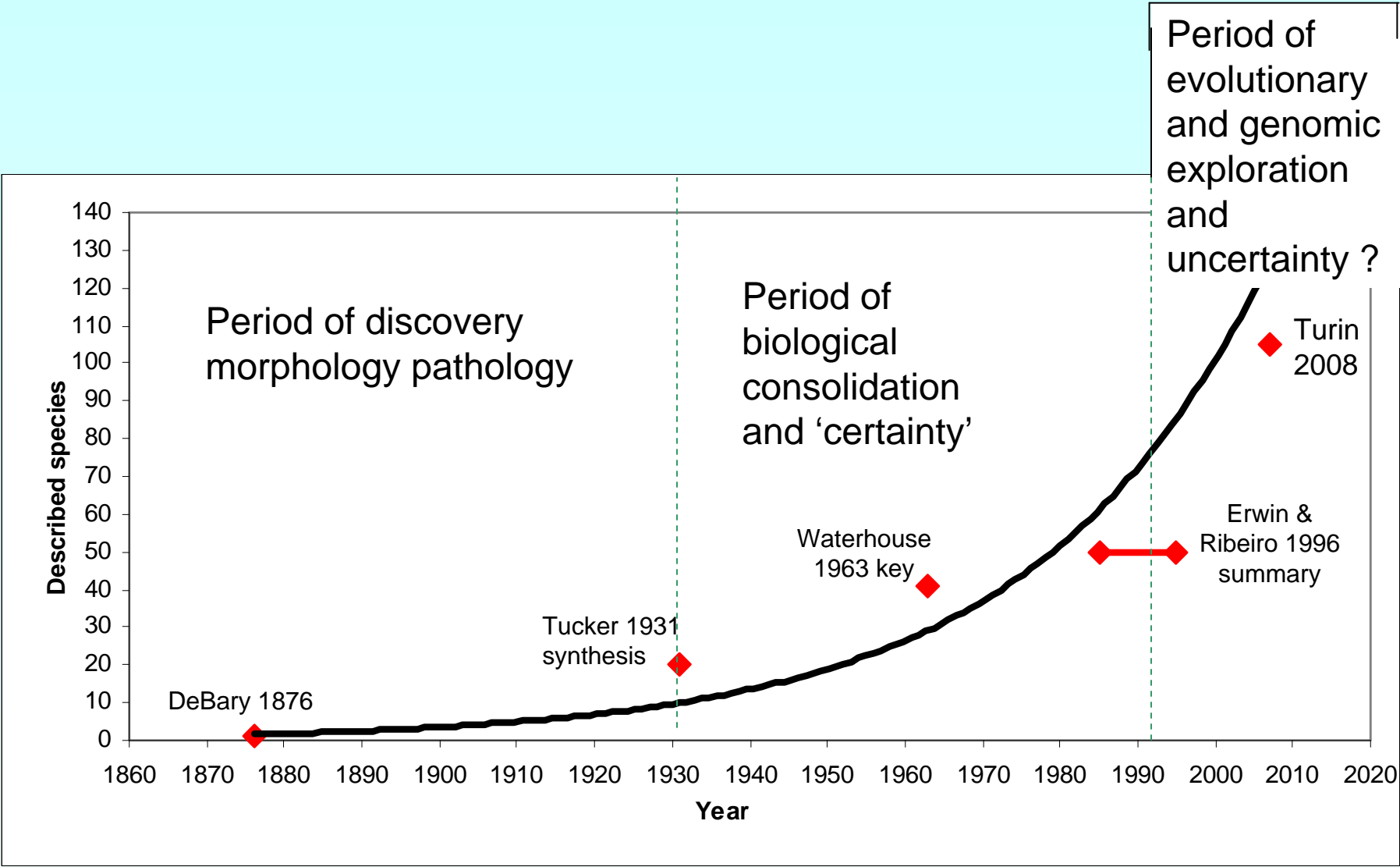
***NB. Not phylotaxa, because cultures are
available***

Phytophthora species Pre 2000		Phytophthora species Post 2000		Virtual taxa or phylotypes
		Described or under construction		
<i>P. arecae</i>	<i>P. japonica</i>	<i>P.alni</i> (x3)	<i>P. alticola</i>	SW Oregon streams Hansen / Reeser / Sutton Combined SSCP of ITS, Cox 30 species <i>10 unknown / new taxa ?</i>
<i>P. boehmeriae</i>	<i>P. katsurae</i>	<i>P. andina</i>	<i>P. frigida</i>	
<i>P. botryosa</i>	<i>P. lateralis</i>	<i>P. asparagi</i>	<i>P. austrocedrae</i>	
<i>P. cactorum</i>	<i>P. macrochlamydospora</i>	<i>P. bisheria</i>	<i>P. lagoariana</i>	
<i>P. cajani</i>	<i>P. meadii</i>	<i>P. brassicae</i>	<i>P. cuyabensis</i>	
<i>P. cambivora</i>	<i>P. medicaginis</i>	<i>P. captiosa</i>	<i>P. cact x hed</i>	
<i>P. capsici</i>	<i>P. megakarya</i>	<i>P. europaea</i>	<i>P. foliorum</i>	
<i>P. cinnamomi</i>	<i>P. megasperma</i>	<i>P. fallax</i>	<i>P. sulawesiensis</i>	
<i>P. citricola</i>	<i>P. melonis</i>	<i>P. gallica</i>	<i>P. siskiyouensis</i>	
<i>P. citrophthora</i>	<i>P. mexicana</i>	<i>P. glovera</i>	<i>P. uliginosa</i>	
<i>P. clandestina</i>	<i>P. mirabilis</i>	<i>P. hedraiandra</i>	<i>P. pinifolia</i>	Central Oregon stream (Oak Creek) Remigi / sutton / Reeser / Hansen Combined SSCP of ITS, Cox 11 species <i>5 unknown / new taxa ?</i>
<i>P. colocasiae</i>	<i>P. multivesiculata</i>	<i>P. inundata</i>		West Australian bush Burgess / Hardy ITS sequence <i>9 unknown / new taxa ?</i>
<i>P. cryptogea</i>	<i>P. nicotianae</i>	<i>P. ipomoeae</i>	<i>P. taxon salixsoil</i>	
<i>P. drechsleri</i>	<i>P. palmivora</i>	<i>P. kelmania</i>	<i>P. taxon pgchlamydo</i>	
<i>P. erythroseptica</i>	<i>P. phaseoli</i>	<i>P. kernoviae</i>	<i>P. taxon riversoil</i>	
<i>P. fragariae var frag.</i>	<i>P. porri</i>	<i>P. nemorosa</i>	<i>P. taxon oaksoil</i>	
<i>P. fragariae var rubi</i>	<i>P. primulae</i>	<i>P. niederhauserii</i>	<i>P. parvasperma</i>	
<i>P. gonapodyides</i>	<i>P. pseudotsugae</i>	<i>P. pistaciae</i>	<i>P. hungarica</i>	
<i>P. heveae</i>	<i>P. quercina</i>	<i>P. polonica</i>	<i>P. sylvatica</i>	
<i>P. hibernalis</i>	<i>P. quininea</i>	<i>P. pseudosyringae</i>	<i>P. carica</i>	
<i>P. humicola</i>	<i>P. richardiae</i>	<i>P. psychrophila</i>	<i>P. quercetorum</i>	
<i>P. idaei</i>	<i>P. sinensis</i>	<i>P. ramorum</i>	<i>P. taxon meadii-like</i>	West Scotland streams Scibetta / Cooke / Cacciola ITS1 nested PCR 17 species <i>3 unknown / new taxa ?</i>
<i>P. ilicis</i>	<i>P. sojiae</i>	<i>P. sansomea</i>	<i>P. taxon Acer</i>	Ecuador streams Scibetta / Cooke ITS1 nested PCR 10 species <i>4 unknown / new taxa ?</i>
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<i>P. iranica</i>	<i>P. vignae</i>	<i>P. tropicalis</i>	51+	
<i>P. italica</i>	55			

Described *Phytophthora* species over time



Described *Phytophthora* species over time



Pandoras box?

Why such an increase in species since 2000?

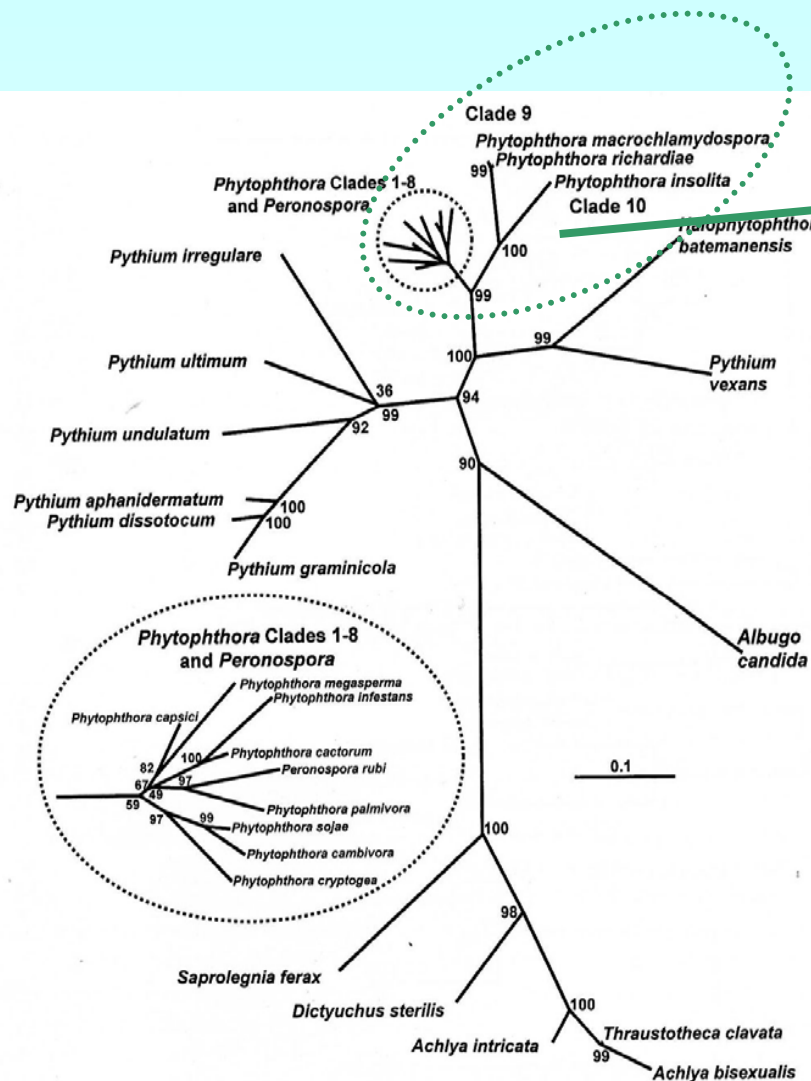
The emergence of more holistic, population-based species concepts since the 1980s

The rapid application of molecular tools for defining evolutionary units in fungi

Increasing international trade in rooted plants

Increased environmental screening for *Phytophthora* species – sample surveys

Growing number of described *Phytophthora* species: significance for Phylogeny?



ca 50 *Phytophthora* species

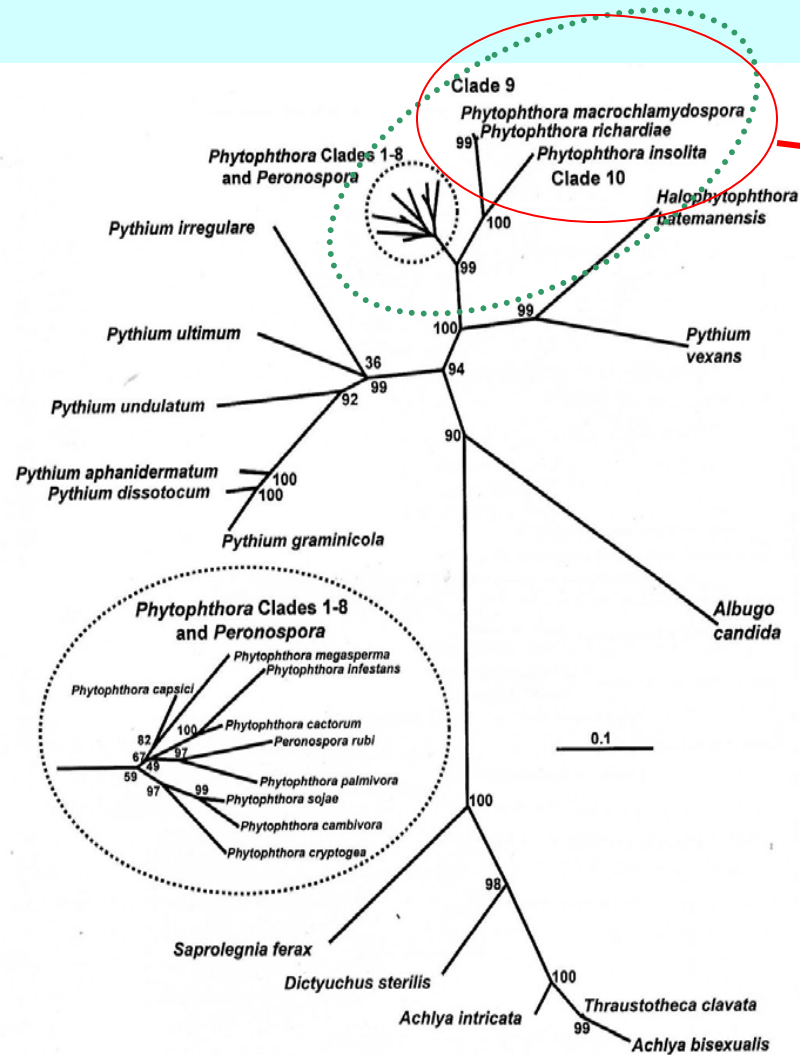
Cooke *et al* 2000
Oomycete ITS tree

Hansen group

Water filtering method in use (Yunnan)



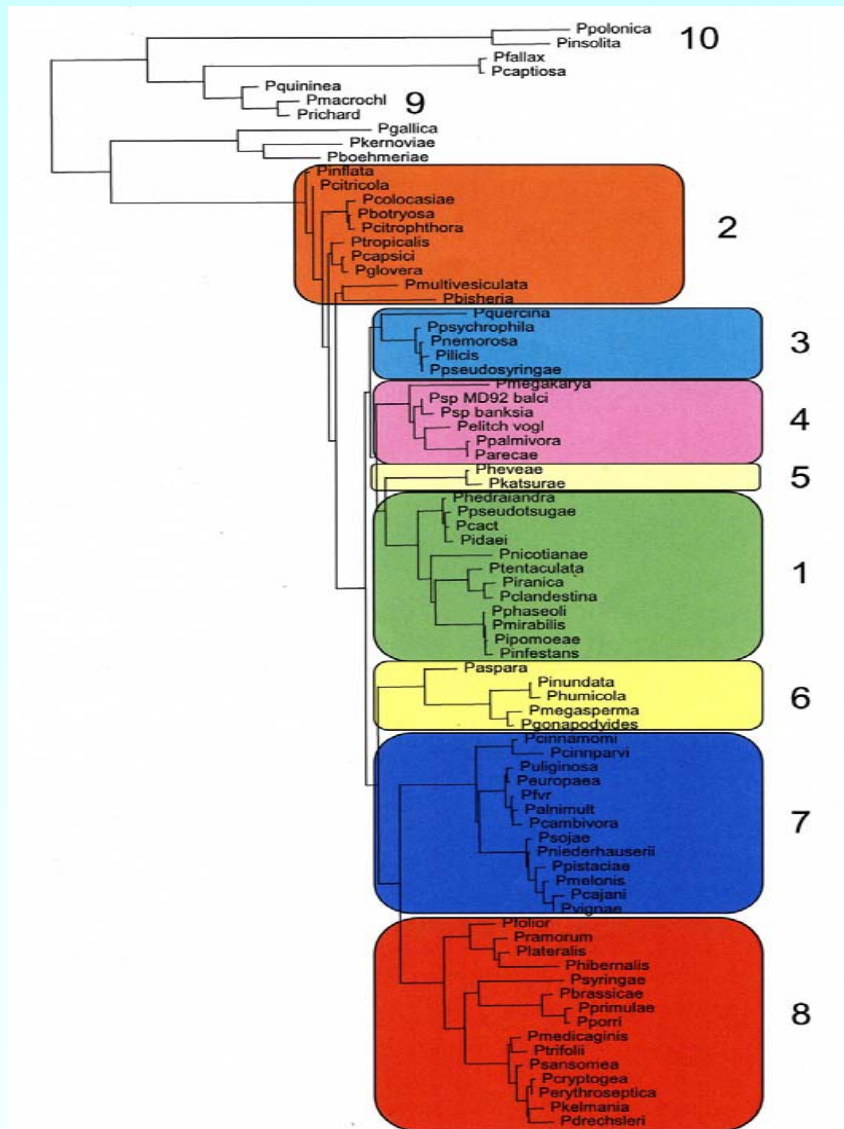
Growing number of described *Phytophthora* species: significance for Phylogeny?



Since 2000 seeing marked increase in species in Clades 9 and 10 (only about 3 species known in 2000)

Cooke *et al* 2000
Oomycete ITS tree

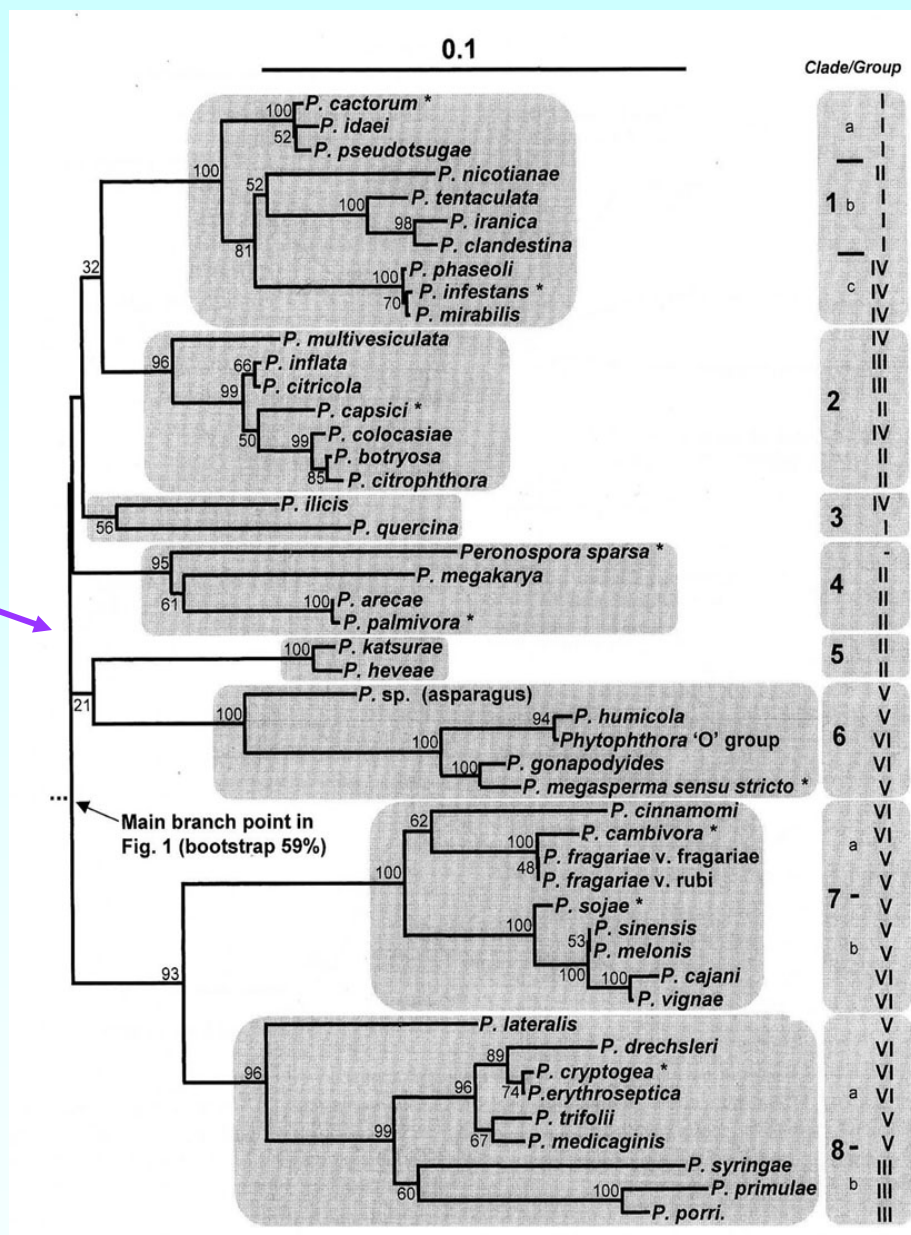
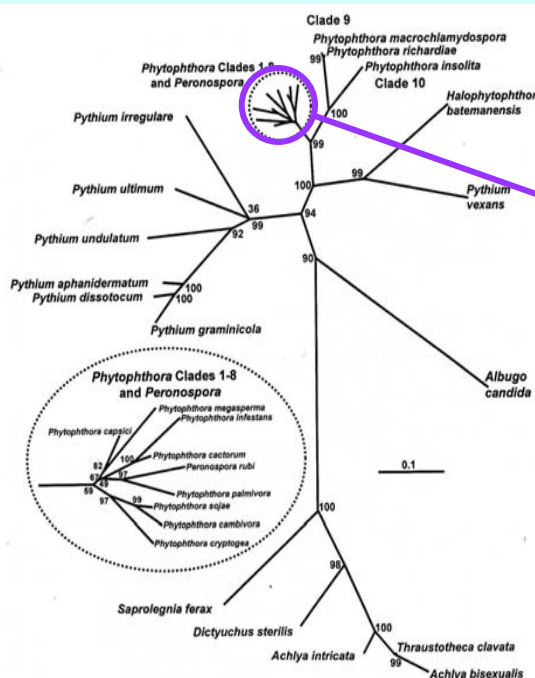
Blair et al 2006 seven locus consensus tree

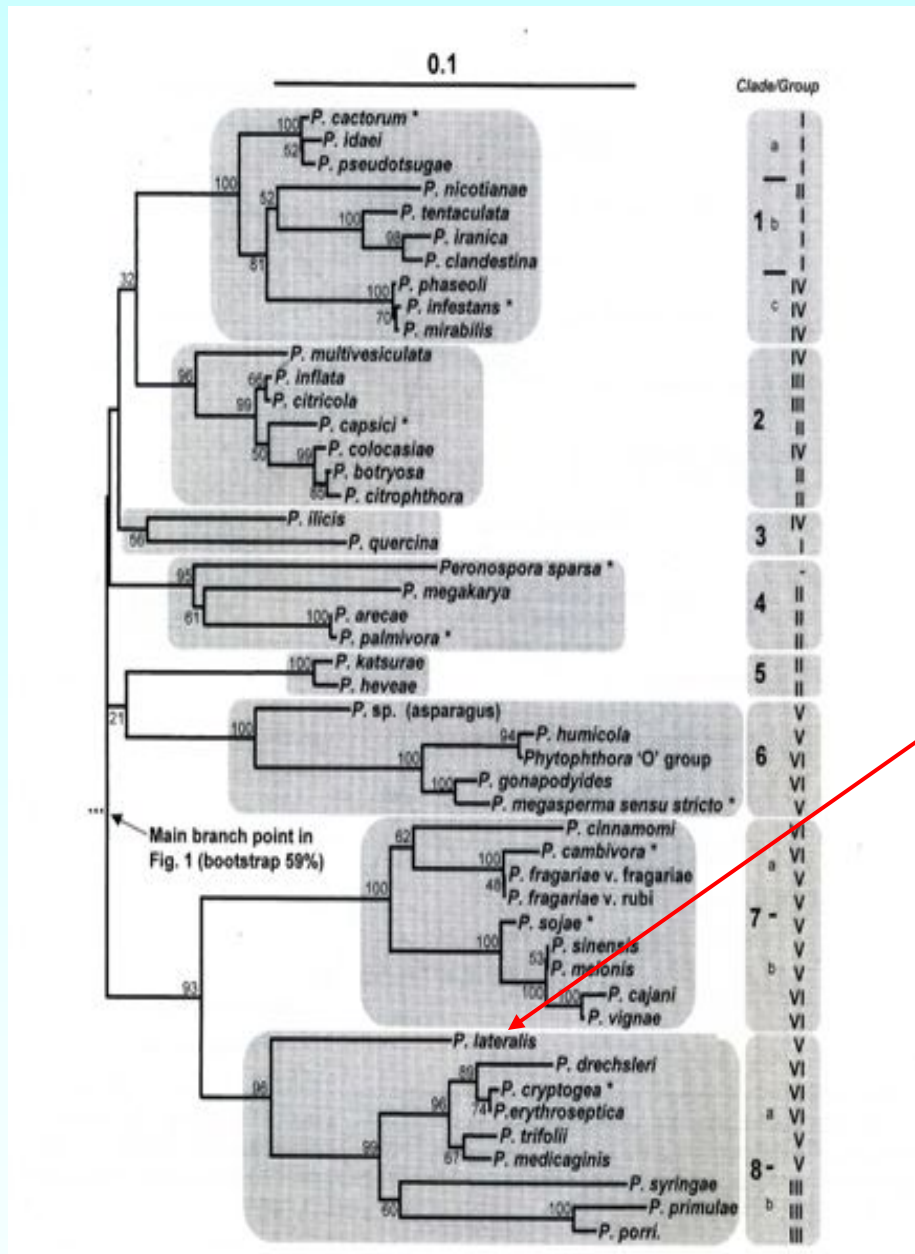


Today already *ca* 10
'new' species in these
clades....

Cooke et al 2000 ITS tree Clades 1-8 only ca 47 species

In Clades 1-8:



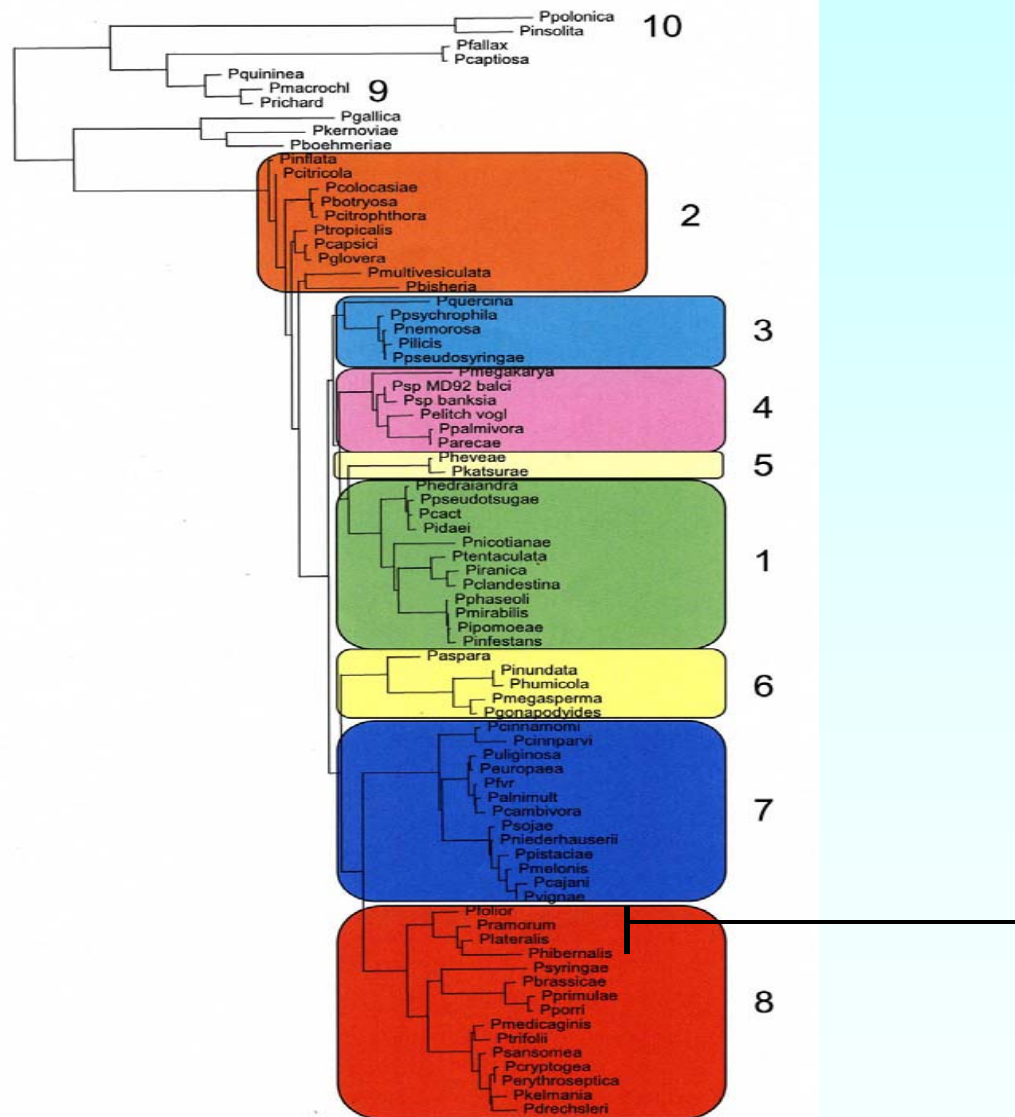


Since 2000 - a rapid increase in species in Clades 1-8

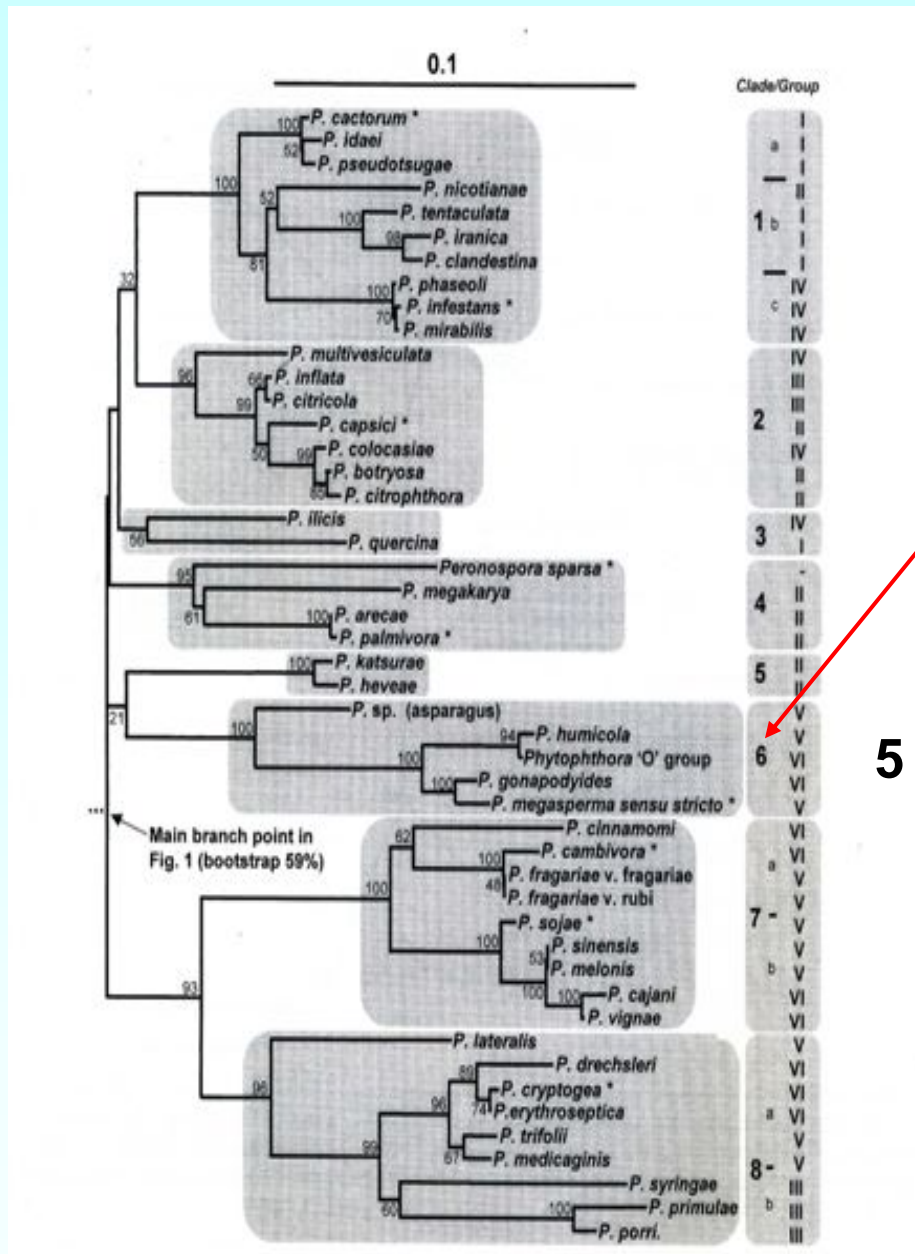
e.g. 3 new species associated with the previously remote *P. lateralis* subclade in Clade 8

Cooke et al 2000 ITS tree Clades 1-8 ca 47 species

Blair et al 2008 seven locus consensus tree



P. lateralis now
 joined by
P.hibernalis,
P.ramorum,
P.foliorum

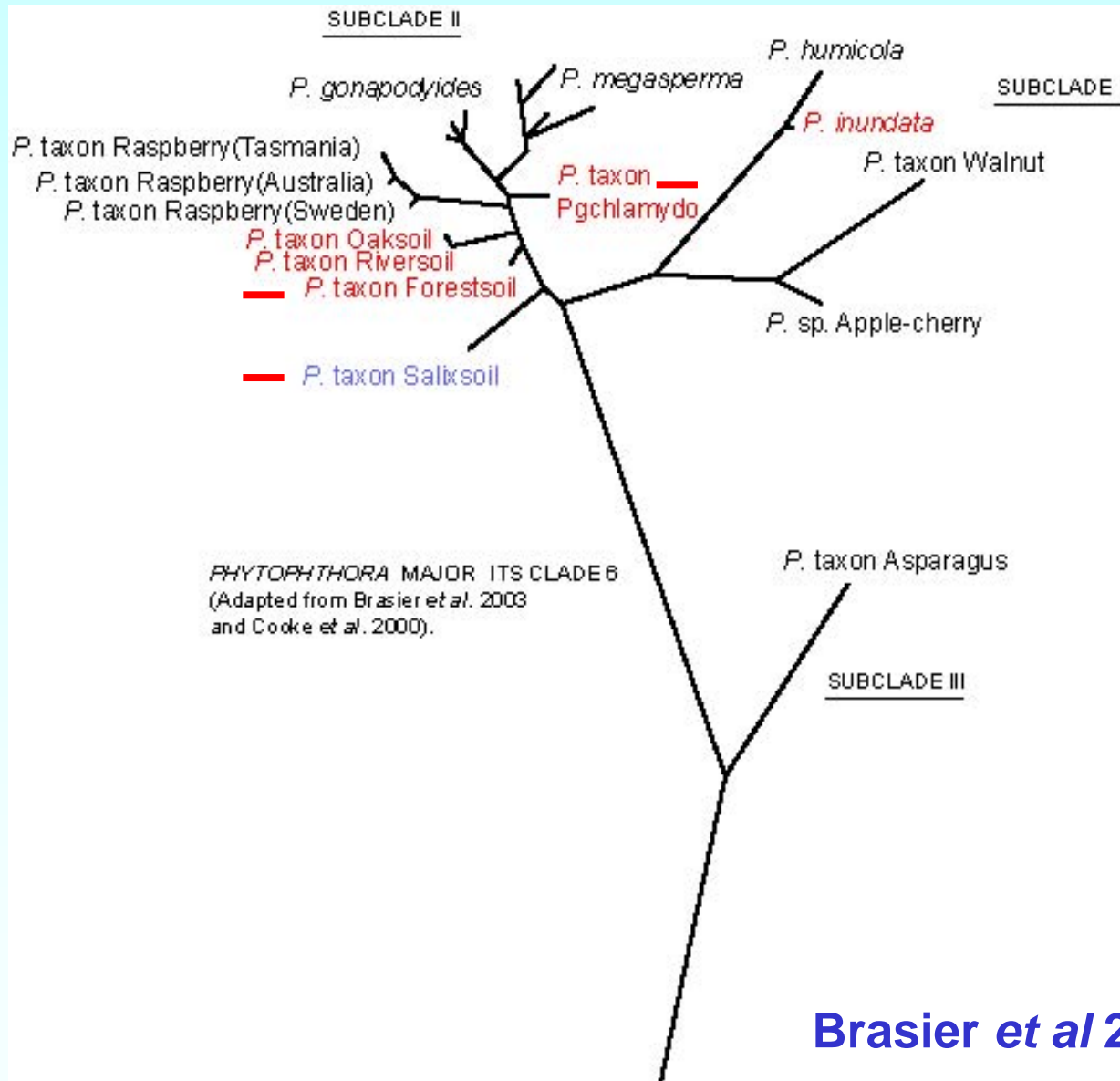


Since 2000 a dramatic increase in Clade 6 species

5 species in 2000

Cooke et al 2000 ITS tree Clades 1-8 ca 47 species

15 taxa in Clade 6 by 2004:

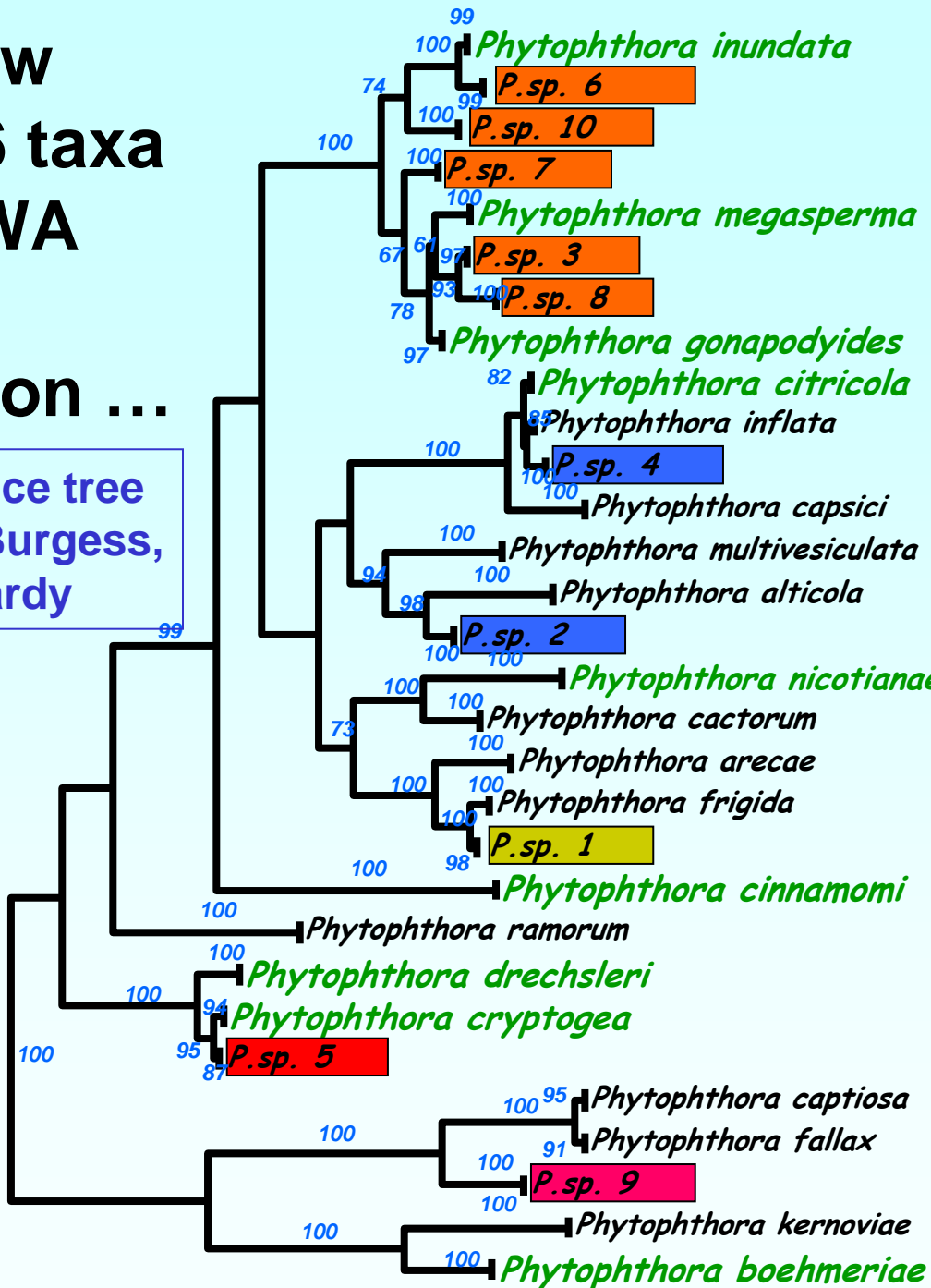


Strill growing: would now need to add *P. hungarica* sp.nov; *P. taxon orphan*: *P. pinifolia* ...

Brasier et al 2004 ITS tree Clade 6

Five new Clade 6 taxa in the WA VHS collection ...

ITS sequence tree
courtesy Burgess,
Stukely, Hardy



— 10 changes

← **Clade 6**

Clade 2

Clade 1

Clade 4

Clade 7

Clade 8

Clades 9, 10

South west Oregon streams

Hansen / Reeser / Sutton

Combined SSCP of ITS, Cox

30 *Phytophthora* species

~ 10 unknown / new taxa ?

Majority probably in Clade 6

So how many species in Clade 6?

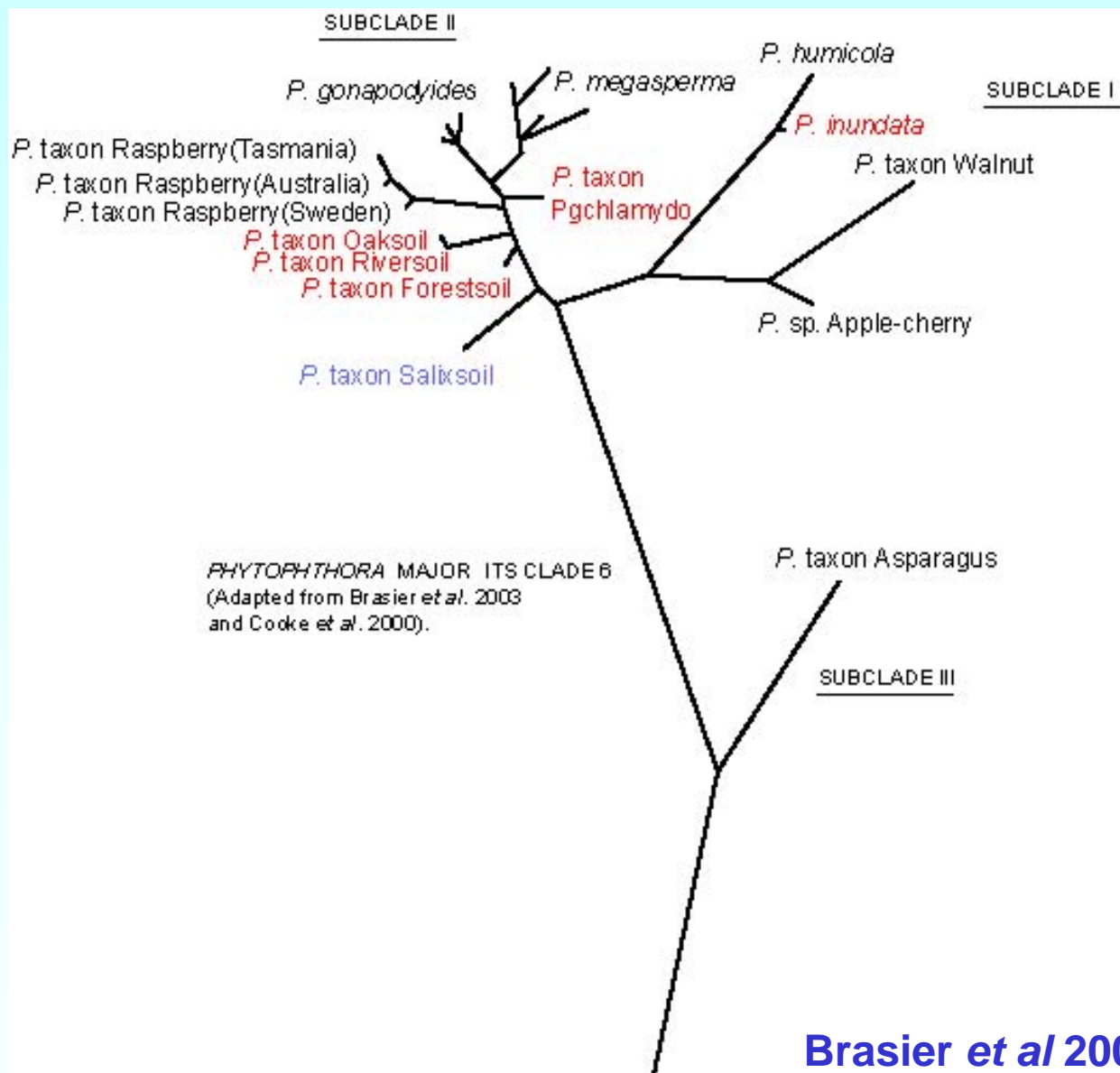
Take the 2007 data:

***ca* 17 of the 105 known *Phytophthora* species are in Clade 6
= 16% - 'biggest' Clade of all?**

Taking the estimate of 200 - 600 total *Phytophthora* species

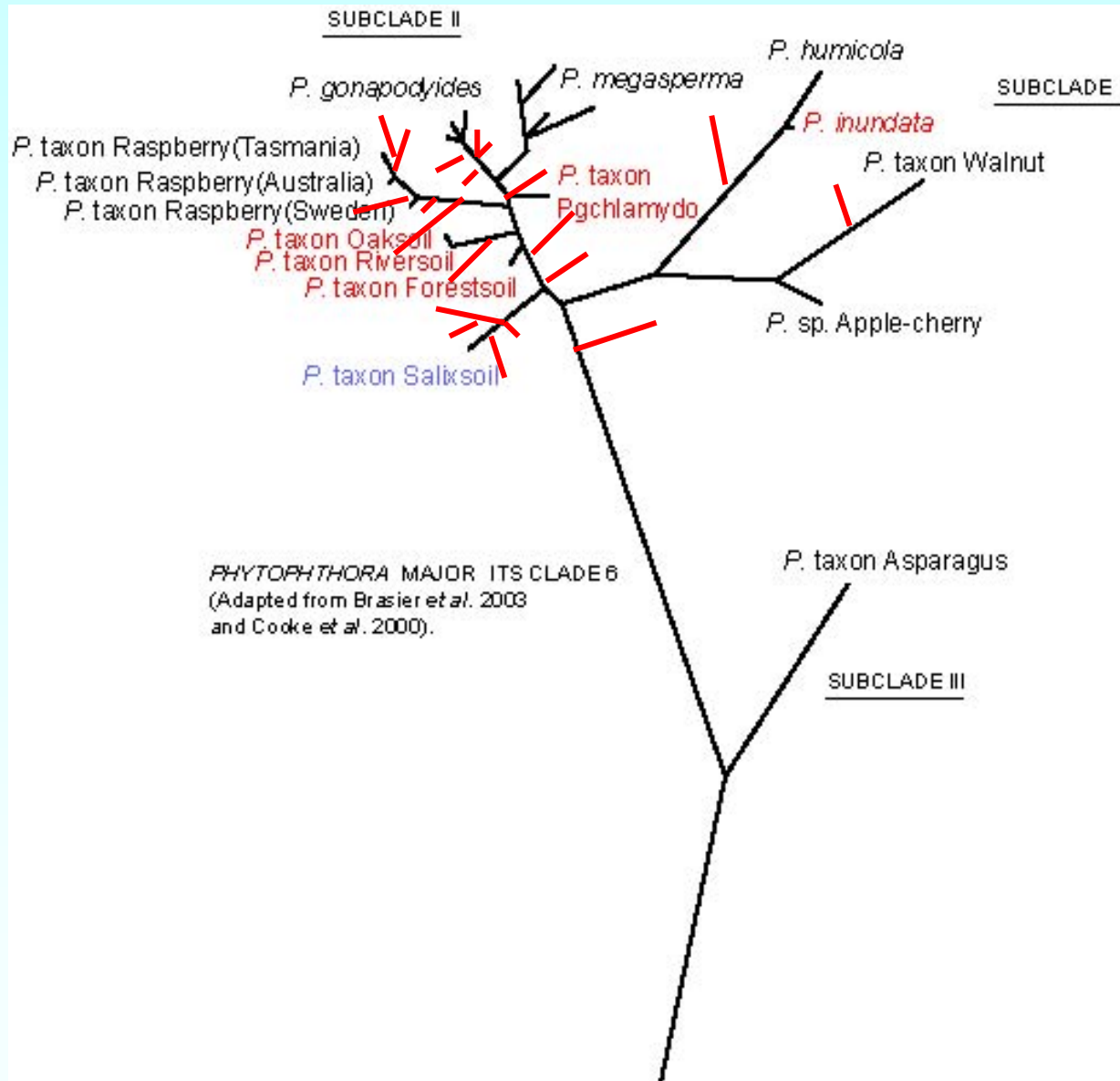
This gives an estimate of 32-96 species in Clade 6

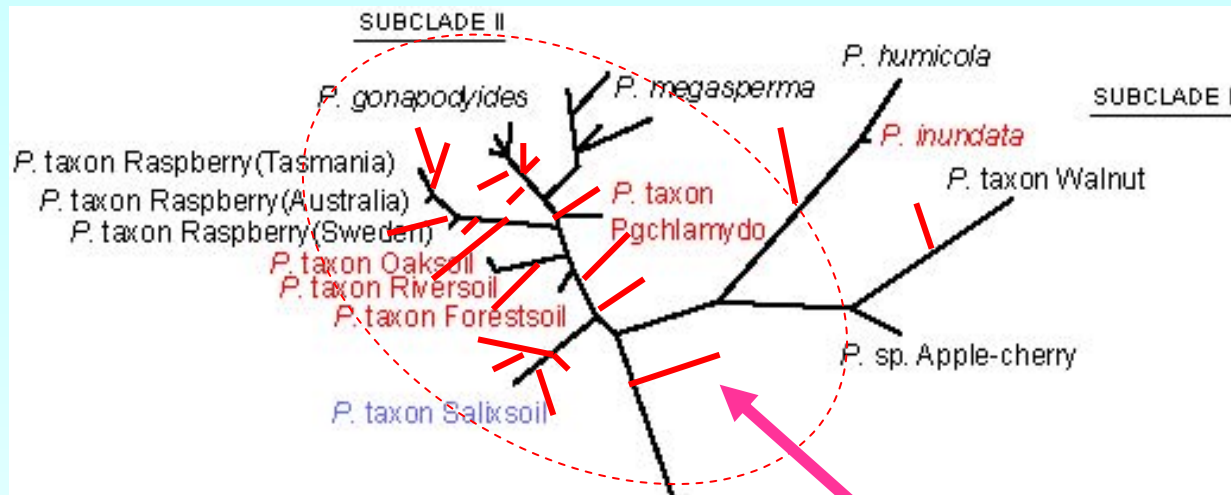
(Clade 6 by 2004)



Brasier et al 2004 ITS tree Clade 6

'Enlarge' hypothetically to ca 32 spp:





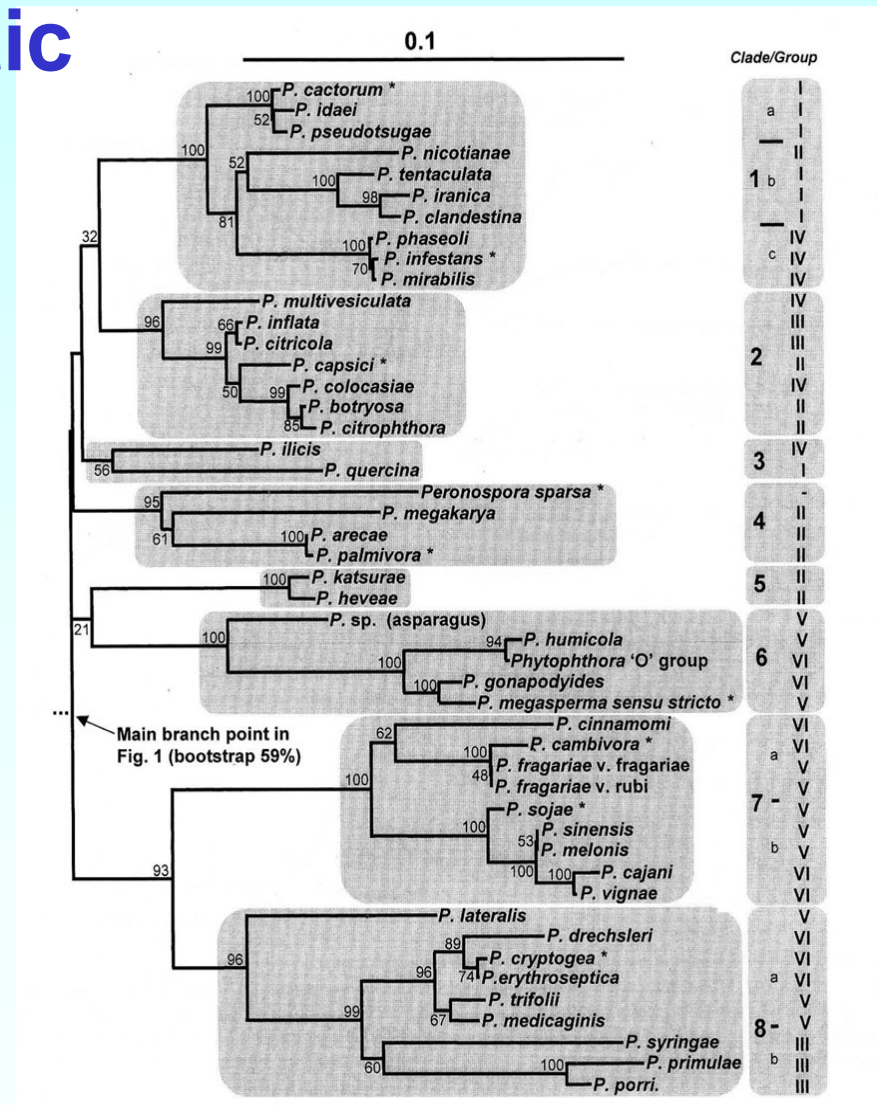
PHYTOPHTHORA MAJOR ITS CLADE 6
 (Adapted from Brasier et al. 2003
 and Cooke et al. 2000).

If many of these 32 (- 96) 'new' species are also aquatic, sterile or inbreeding, high temperature species like *Pg*, *P t pgchlamydo* etc –

– we may even have to rethink our species concept for this subclade

So we now have new and rapidly expanding molecular phylogenetic trees :

But what do these trees mean in terms of how we understand Phytophthoras?



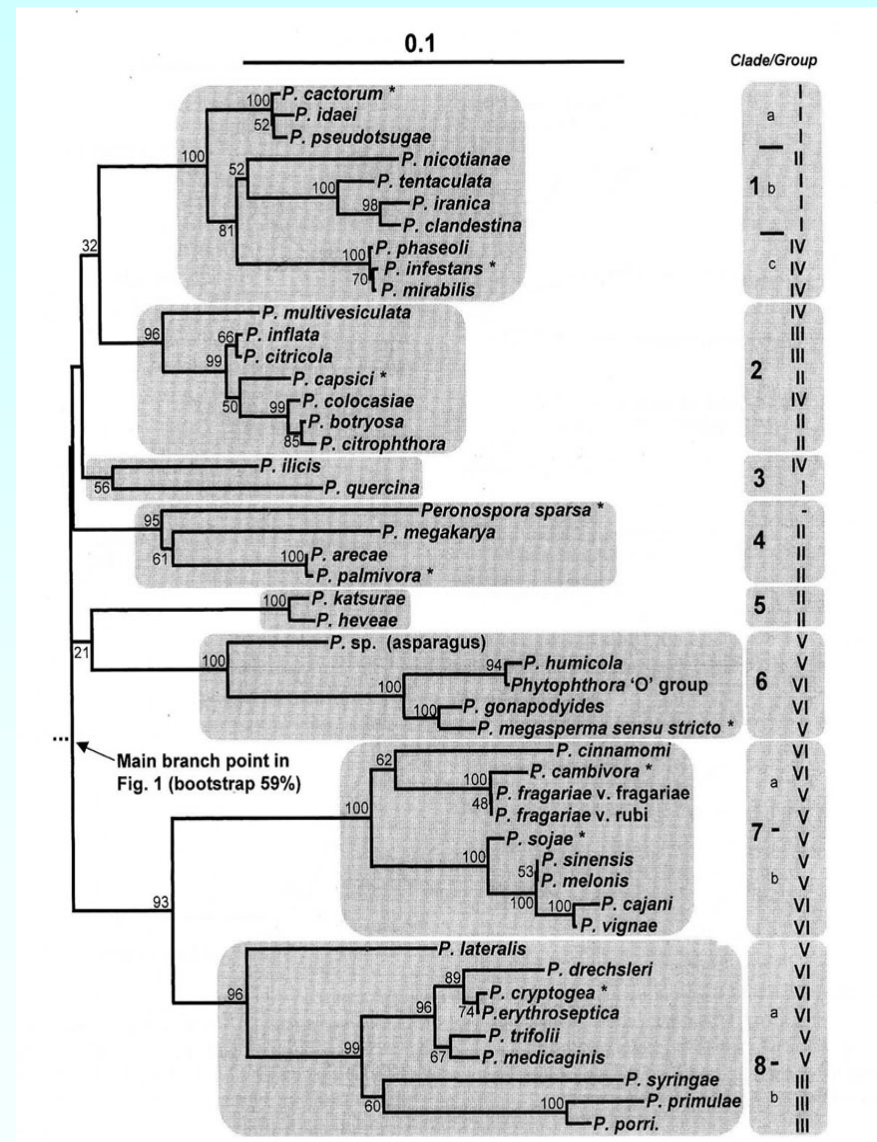
Obviously the trees are a major step forward from the Waterhouse 1963 morphological Groups 1-6

- The former were identification aids and were necessarily artificial constructs -**
- Whereas our molecular trees are closer to 'natural relationships'**

Noneless I suggest we treat them with a degree of caution:

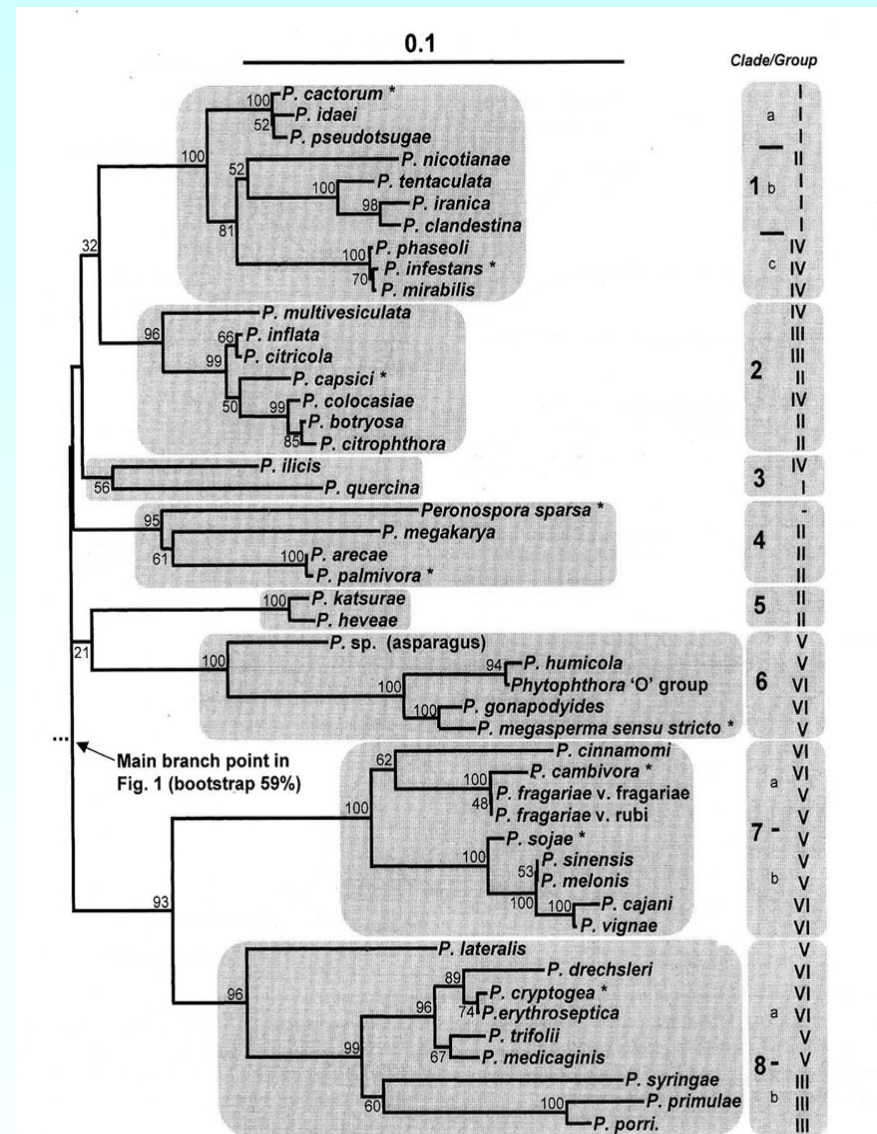
1. Much data is missing because of extinctions!

2. Much data is missing because we still have to add the ~100 – 500 extant species!



3. Much evidence of past reticulation events is missing ...

...the footprints of hybridisation and genetic introgression will have been lost over time ...

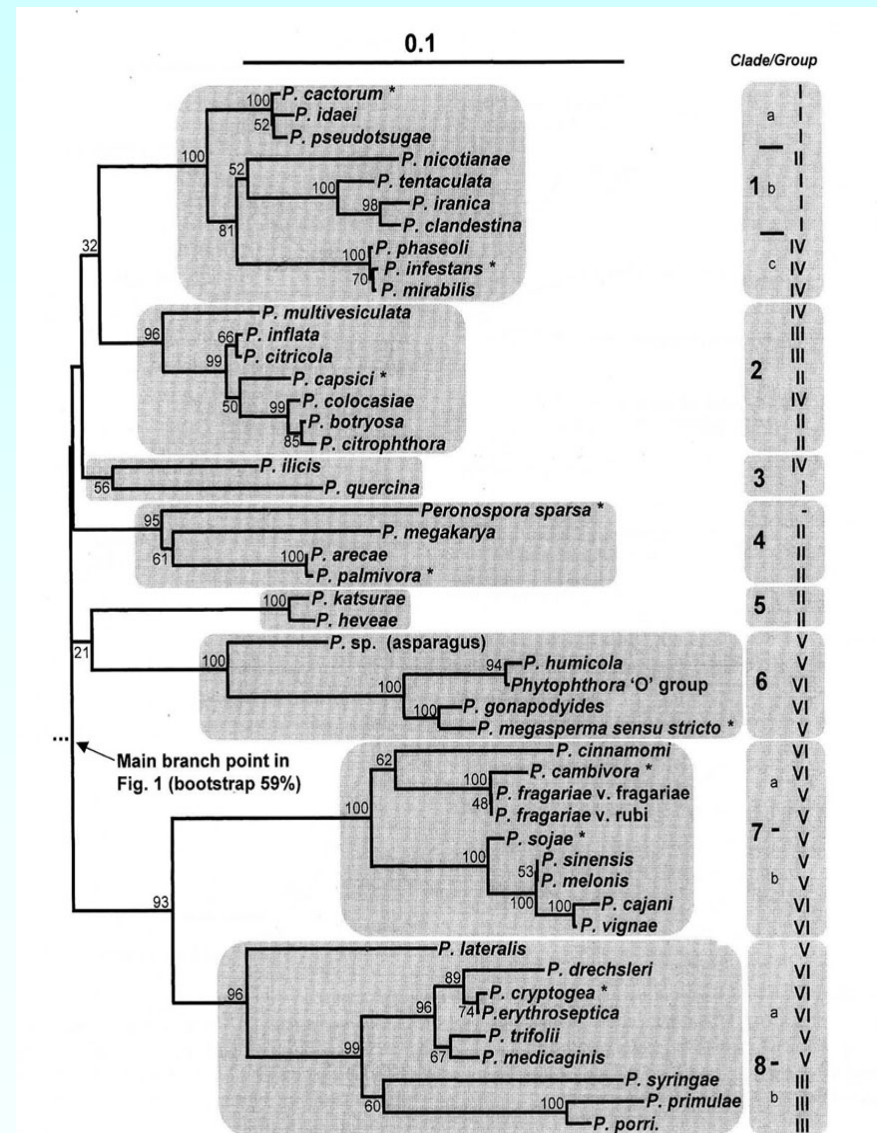


What *is* important is not so much that we can show that species X and species Y are related... eg that *P. ramorum* and *P. lateralis* are related

So what?

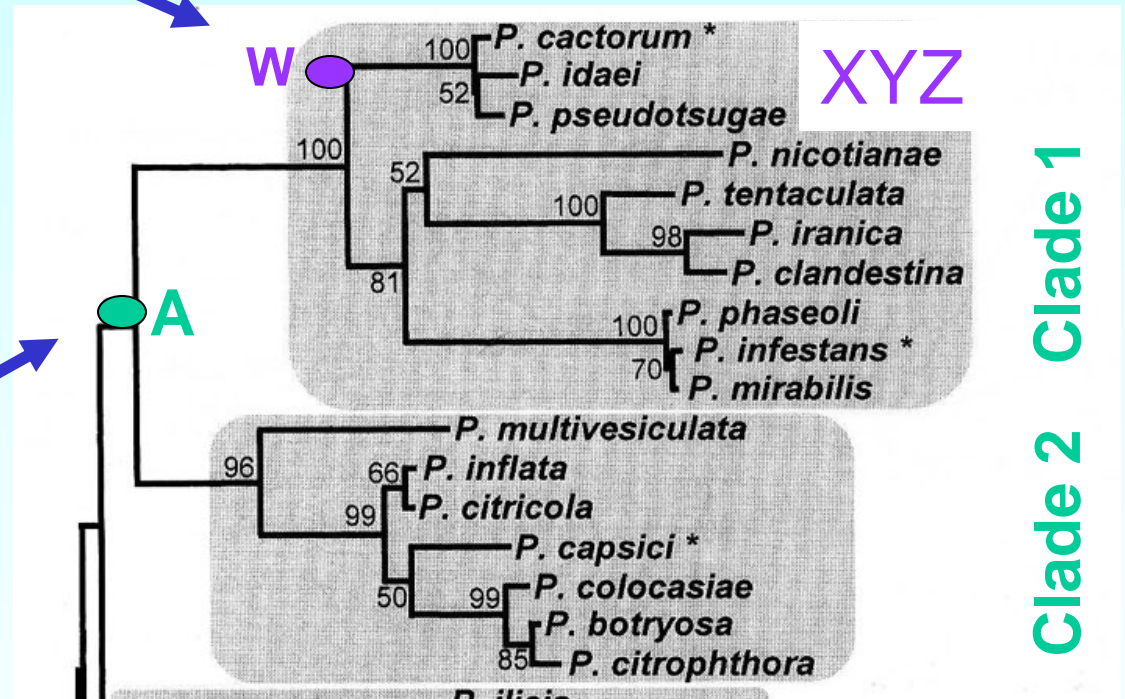
In Darwinian terms, what is more important is to understand the processes and events that gave rise to their divergence...

The Darwinian meaning is all in the nodes ...



Why did ancestral species W give rise to three species X, Y and Z...?

Why did ancestral species A give rise to two clades 1 and 2?



and so on...

Concluding comments ...

This dip into *Phytophthora* numerical biodiversity and phylogenetic uncertainties has put me in mind of just how little we know about the origins of the genus.

Indeed, it seems reasonable to suggest that the construction of a phylogenetic tree is simply the point at which the *real* evolutionary challenges begin.

So, given that there are probably 200-600 species of *Phytophthora* out there -

- I see two key challenges for the future:

1. Understanding *why* there are so many Phytophthoras. ie. What environmental processes and events (geographic, climatic, biotic) drove their evolution? Why did eg *P. ramorum* diverge from *P. lateralis*?

- *the job of the evolutionary biologist*

2. Understanding at the genetic level *how* eg *P. ramorum* behaves so differently from *P. lateralis*?

- *the job of the genomicist*

Fortunately, these *how* and *why* challenges are not mutually exclusive, and answers obtained for one will enormously benefit the understanding in the other.

I suggest, therefore, that we are in for an exciting time over the next decade!

Thank you

A written version of this talk will be published shortly:

Brasier C. M (2008). *Phytophthora* biodiversity: How many *Phytophthora* species are there? In Proceedings of the 4th IUFRO Workshop on Phytophthoras in Forests and Natural Ecosystems (E. Goheen ed). *in press* USDA Forest Service.

