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GLOBALIZATION, CLIMATE AND LAND USE AS MAJOR DRIVERS OF PLANT DISEASES IN MEDITERRANEAN AND TEMPERATE AREAS: SAME CASES OF STUDY

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Abstract

Tree health management is a world-wide priority for plant production industry, urban green and natural conservation areas. Plant Pathology is dedicated to understanding environmental conditions and biotic agents responsible for plants declining. Researchers of this discipline are required to provide solutions for the control of existing plants diseases and prevent the onset of factors related to the appearance of new problems.

Globalization, climate and land use are considered the most critical elements that influence the stability of plantations and natural ecosystems. In particular, forest and agricultural stands in Mediterranean and temperate climates are the most susceptible. Here the influence of humans on nature is very high, the trade of goods is intense and the change of climatic conditions that has occurred during the last decades has had a greater effect on plants than in the equatorial and cold areas. My talk will expose some case studies about plants stability in Western Australia and other regions of the globe. Each example will be illustrated from a biological prospective, with some notes about past and future economic implications.

My name is Duccio Migliorini.

I studied Forestry at Florence University in Italy, where I also did my PhD in Plant Pathology with a Thesis about the genus *Phytophthora*, an Oomycete responsible for root diseases of ornamental and forest trees. After that I spent two years in South Africa working at the University of Pretoria. I did a post doc on fungal pathogens of Proteaceae in nature and in plantation.

Plants health is a priority for humanity. Protection of natural forests and bushland ecosystems is a priority itself. The biodiversity of those environments has an

incalculable value. In terms of landscaping, tree stability has a crucial role too, due to the historical importance of certain species in specific areas of the world. Moreover in general, forests and woodland ecosystems are a hugely important natural resource, easily overlooked and often undervalued. Globally, people depend on forests for other critical ecosystem services, such as climate regulation, human health, and the genetic resources.

Lots of research in plant pathology is aimed at the growing industry of modern intensive tree farming which involves planting tree species that have been selected for particular environments and traits, including resistance to certain pests. One of the best examples is the global *Eucalyptus* forestry industry. This genus is mostly native to Australia, where more than 700 species are found in a wide range of environments. More than 10 species and their hybrids are commonly planted commercially around the world today. Plantations of these trees were less than 1 million ha in 1950; they now cover some 20 million ha, mostly in the tropics and Southern Hemisphere. (Wingfield et al., 2015 and articles reported in it)



Crops provide food for 7 billion people. According to FAOSTAT the estimated worldwide total value of food products derived from wood plants (fruit, wine, olive oils, etc. etc.) was something around 200 billion USD of import and the same amount of export per year. I just calculated them for the year 2015 and the year 2016 from data available on FAO web site.

Plant Pathology is dedicated to understand environmental conditions and biotic agents (pests and pathogens) responsible for plant decline. Researchers of this discipline are required to find solutions for the control of existing plants diseases and prevent new problems. Regarding woody plant (trees and bushes of forests, agriculture plantations and ornamentals, the category of plant with which I work), the scientific community agrees that 3 main factors are related to the diffusion and the outbreaks of pests and pathogens:

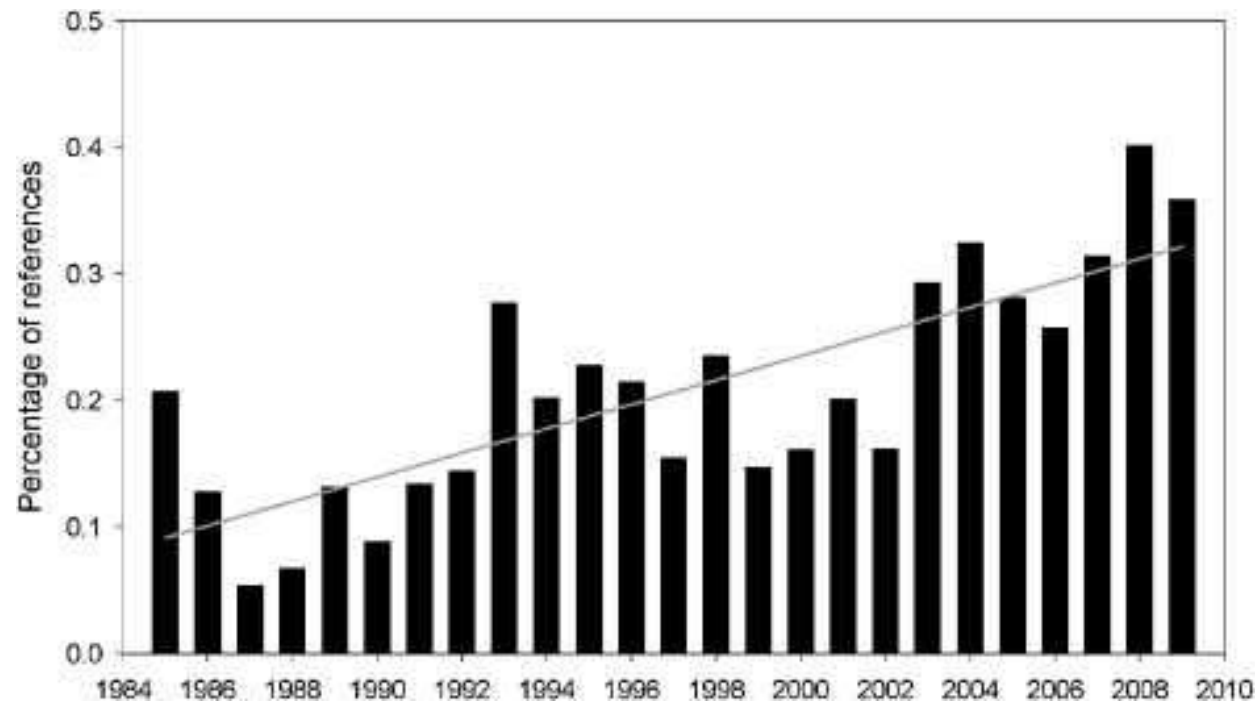
CHANGE OF CLIMATIC CONDITIONS, GLOBALIZATION, HUMAN DISTURBANCE/ LAND USE

Climate

Trend in published reports of climate-related forest mortality in the scientific literature, for the years 1985–2009 ([Allen et al., 2010](#)).

Allen et al., 2010

Trend in published reports of climate-related forest mortality in the scientific literature, for the years 1985–2009



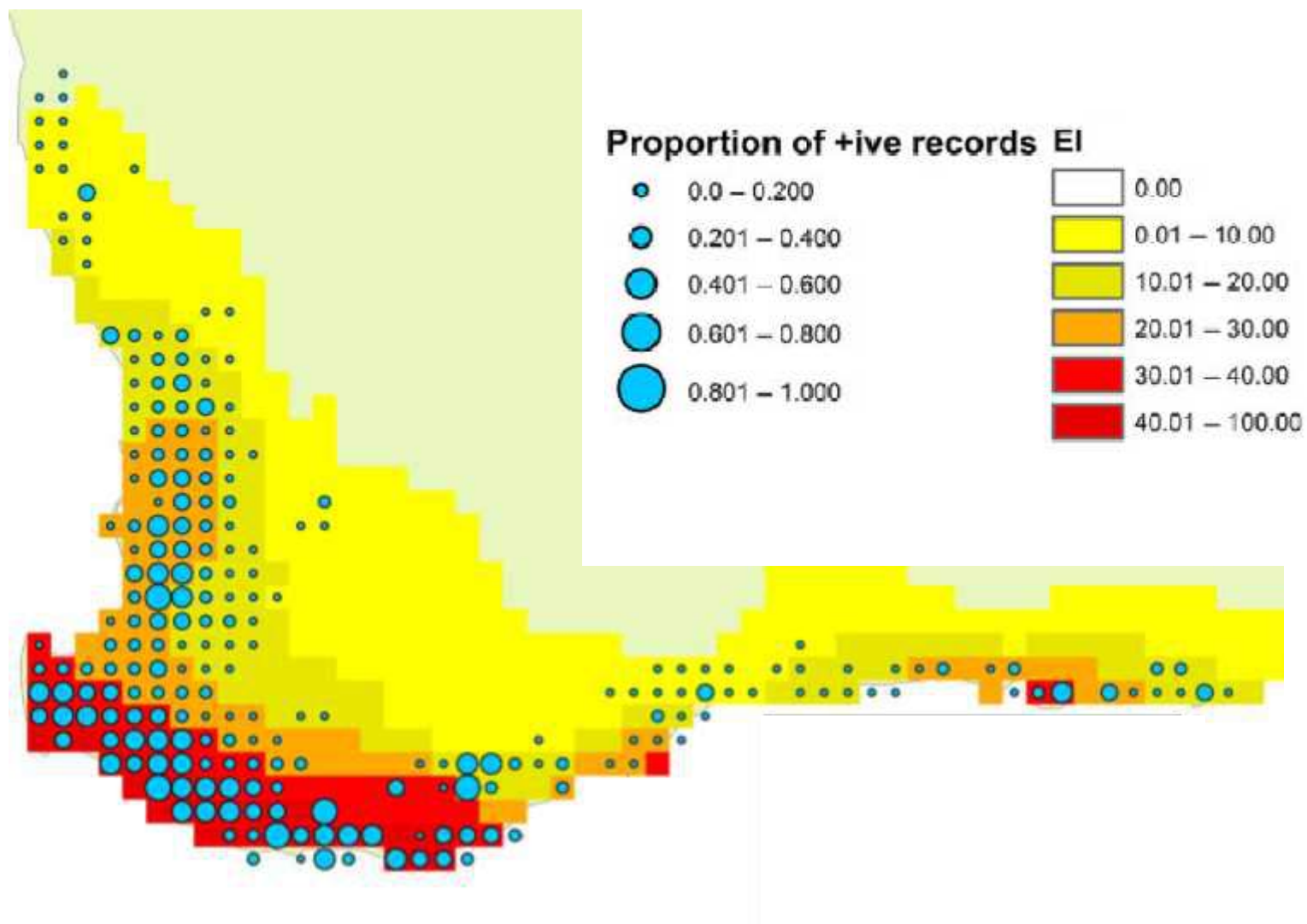
Scientific investigations using modeling aimed to predict the spread of diseases and their increasing influence have been generated. For example the possible future diffusion of *P. cinnamomi* in WA according to climatic suitability (Burgess et al., 2017).

The South West of Western Australia (SWWA) has been experiencing a drying climate trend for several decades (Evans et al., 2013a and 2013b; CSIRO 2015.) South West forests recently went through extended damages caused by climate conditions.

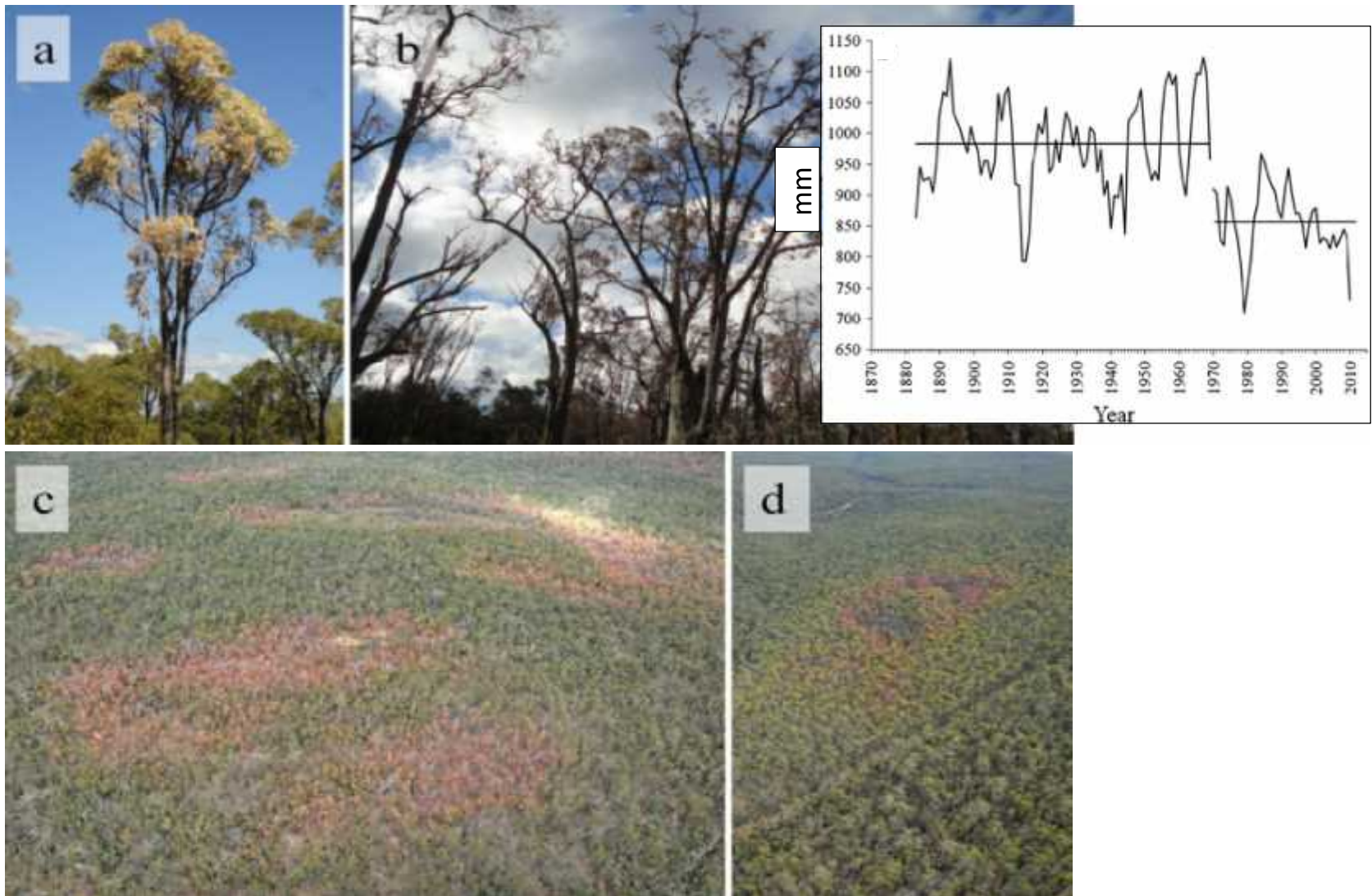
Examples of strong abiotic stress were recently described in the region: Matusick et al. (2013) observed a sudden and unprecedented forest collapse in Western Australia corresponding with record dry and heat conditions in 2010/2011. It was one of the most severe droughts on record in the Northern Jarrah (*Eucalyptus marginata*) Forest of Southwestern Australia.

Burgess et al., 2016

Climatic suitability of new area *by P. cinnamomi*



Climate



Matusick et al., 2013, Murdoch University

Climate

Seaton et al., 2015 described how the area of severely drought-affected Jarrah-Marri forest in 2011 was associated with an unprecedented outbreak of the native Eucalyptus longhorned borer *Phoracantha semipunctata*, with densities 80 times higher than those observed in surrounding healthier forest.



Climate

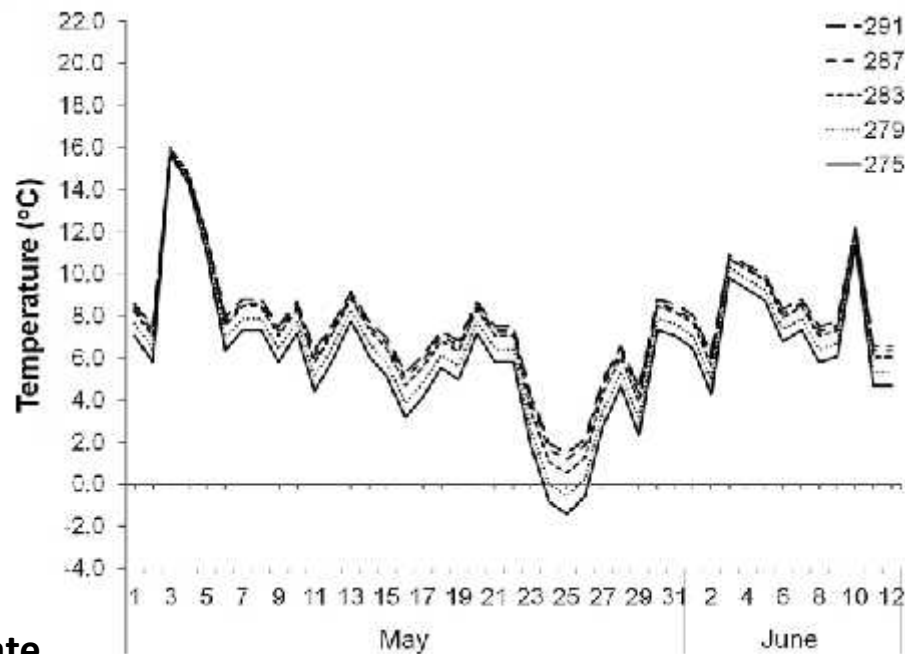
Seaton et al., 2015

Unprecedented outbreak of the native Eucalyptus longhorned borer *Phoracantha semipunctata*, with densities 80 times higher than those observed in surrounding healthier forest



The effect of drought in predisposing trees to fungal diseases has been long established. Drought induced diseases are often caused by facultative parasites having saprotrophic or endophytic abilities, with water stress triggering host susceptibility and/or breaking pathogen dormancy. For example, *Biscogniauxia mediterranea* (De Not.) Kuntze, responsible for “charcoal disease” necrosis on stems and branches of *Quercus* L. species in Mediterranean areas, commonly lives as an endophyte in leaf, twig and bark tissues of healthy vigorous oaks. It has the ability to shift from an endophytic to pathogenic phase, mediated by water stress conditions of the host; under severe water stress, *B. mediterranea* develops rapidly within the xylem with the potential to kill the entire host (Paap et al., 2017a and articles reported in it)

Diminishing of days of rain during the cold semester, when areas with Mediterranean climate receive the majority of water, are linked with a seasonal continentalization of the climate. In absence of cloud, local frosts are more frequent (this is a personal opinion). Matusick et al., 2014 described how topography and cold-air pooling explain the geographic distribution of frost dieback in susceptible tree species in SWWA.



Climate

Matusick et al., 2014

Geographic distribution of frost
dieback in susceptible tree species
in SWWA

Murdoch University

Growers of Protea flowers in Portugal where I did part of my PostDoc project said that frost damages (South African Proteaceae are very susceptible to frosts (Malan, 2012)) are getting more frequent due to the influence of eastern continental flux of cold weather during winter, as the oceanic wet and temperate flux is less constant than during the past.



Leucospermum plantations (Proteaceae), Southern Portugal

Climate

Globalization

Globalization and the expanded transport of goods around the planet are the main reasons for the increase in Invasive Forests Pathogens (IFP) introductions. Rapid transportation and reduced delivery times increase the chances for pathogen propagules to survive and consequently establish successfully in a new environment. More than half of the emerging world plant infectious diseases of the last few decades have resulted from the arrival of previously unrecognized pathogens, including the movement of virulent strains, or the emergence of new aggressive strains. (Santini et al., 2013 and articles reported in it).

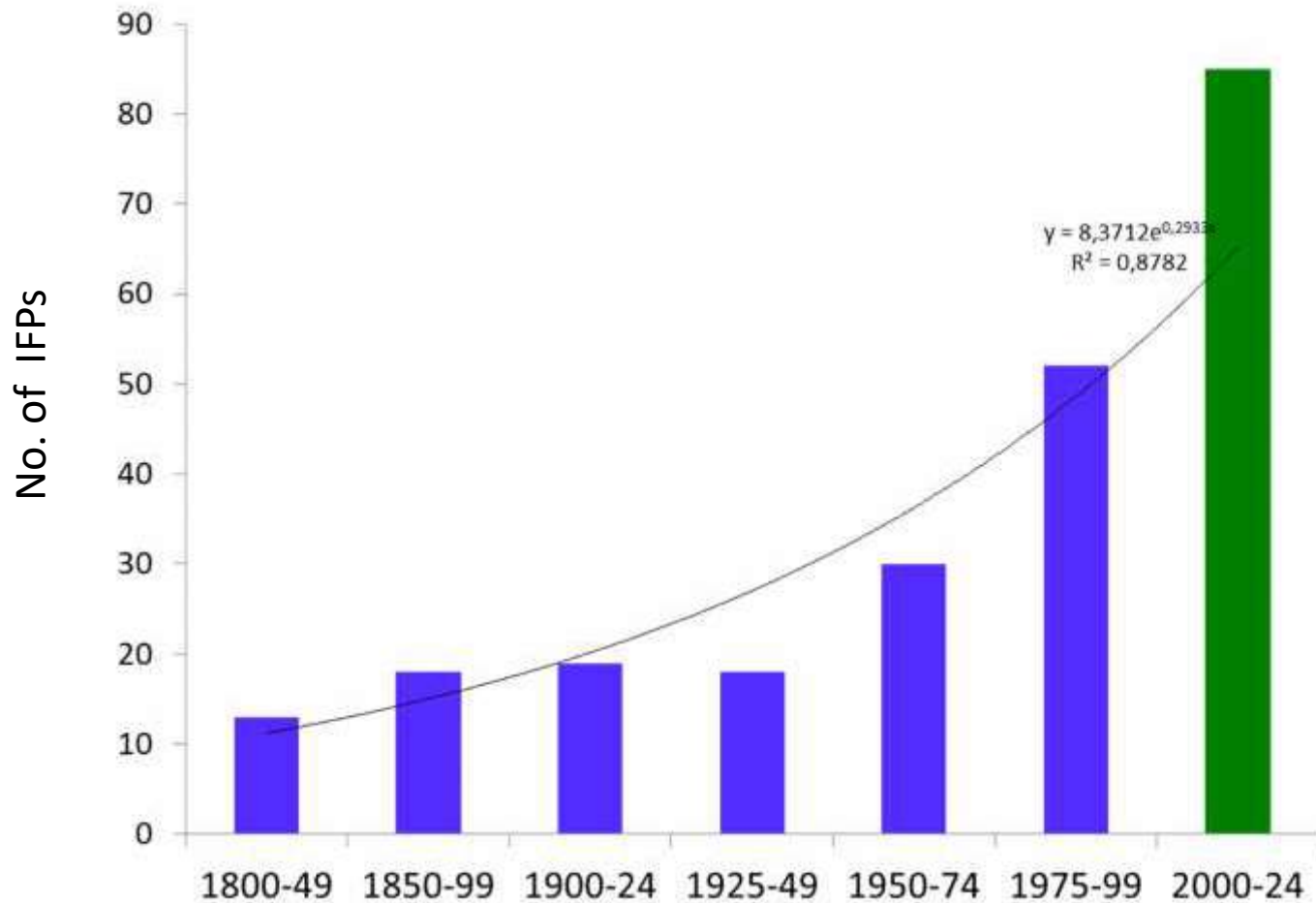
The phenomenon is clear in large countries, like US, where import of living plants for ornamental purposes is an important business. Liebhold et al. (2012) described it by reporting the frequency (number of shipments infested) in shipment of live plants during the period 2003-2010. Europe, even better than US, with a longer history of worldwide trades, is able to show the trend of invasive pests in forestry. According to that, it is interesting to see how the origin of IFP varied in the past in relation to the major EU trade partners (Ghelardini et al. 2017). Both Santini et al. (2013) and Liebhold et al. (2012) agree that living plants are the most suitable pathways for the import of invasive pests and pathogens to Europe and US.

Europe is the only region among those with advanced biosecurity regulation, that is allowing a general authorization for imports of live plants, not requiring import permits (Eschen et al., 2015). A peculiarity in these European phytosanitary law is represented by the contradictory regulation of soil movement, which is a particularly insidious pathway of introduction since soil is an enormous reservoir of living and mostly unknown microorganisms (Vogel et al., 2009). Both the US and the EU restrict the import of soil as such unless authorized (EU, 2000; USDA, 2010), but, contrary to the US, the EU allows importation of plants rooted in soil from outside the EU provided they have been officially declared free from harmful organisms (phytosanitary certificate or plant passport within the EU) and show no sign of infestation or disease (Annex IV in EU, 2000) (Ghelardini et al, 2016).

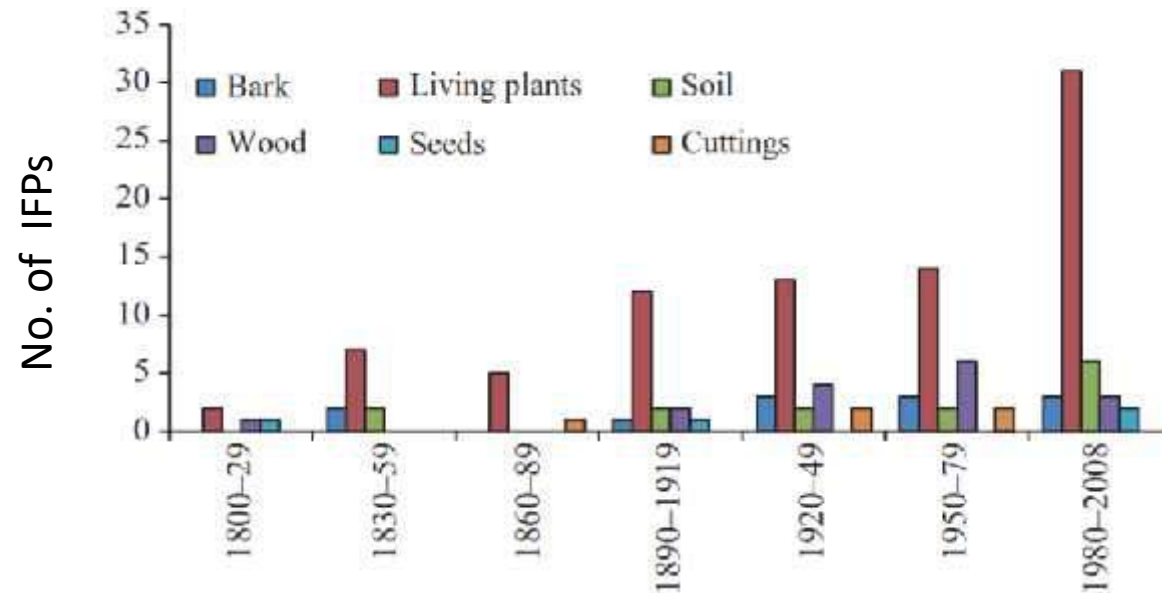
Potted plants in EU are generally imported at an early stage. “Transformed” into a final “ornamental” after a long stay (even some years) in big and specialized nurseries (mainly in Southern Europe) and sold internationally. In this context soil borne pathogens find suitable conditions for their worldwide diffusion.

Santini et al., 2013

Exponential increase in establishment of Invasive Forest Pathogens (IFPs) in Europe



Globalization

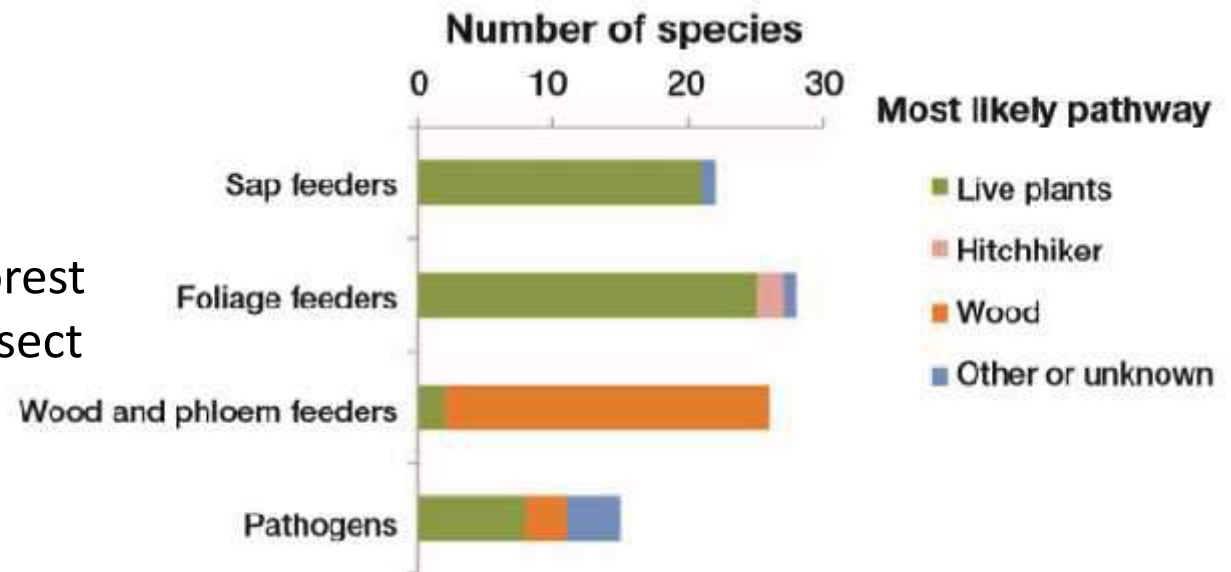


Santini et al., 2013

Most probable substrate on which alien IFPs arrived in Europe, according to time of arrival

Liebhold et al., 2012

Most likely pathways for forest pathogens and different insect guilds (USA)



Globalization



Globalization

Phytophthora in particular, which has been already mentioned before regarding the jarrah dieback, it is one of the best at hiding. Organisms that travel around the world inside plants without causing symptoms on the hosts (cryptic diseases) are called: “plant hitchhikers”.

The genus *Phytophthora* comprises oomycete microbes, many of which are potentially invasive and lethal soil-borne pathogens. It is widely known for having caused some of the most destructive crop and forest epidemics ever documented, such as the Irish potato famine in which more than one million people died, sudden oak death in the USA, and the Jarrah dieback in Australia. Many species of the genus are strictly linked to soil for dispersal and well adapted to live in water and spread from plant to plant via mobile zoospores. Many *Phytophthora* species are able to survive in the soil for long periods in unfavorable conditions, in the form of resting chlamydospores. Several researchers have demonstrated that the diffusion of *Phytophthora* is linked to the vicinity of nurseries, a common factor in many areas of the world. In a large study conducted across European nurseries, [Jung et al. \(2016\)](#) found Forty-nine *Phytophthora* taxa in 670 nurseries; within these nurseries, 1614 of 1992 nursery stands (81.0%) were infested, although most affected plants appeared healthy.

In the first article that I published ([Migliorini et al.,2015](#)) we described how *Phytophthora* is able to mask its presence in asymptomatic nursery plants. Asymptomatic and symptomatic potted plants were collected in equal numbers from 2 large nurseries in central Italy in a specific area where concentration of nurseries is very high: 1500 nursery enterprises covering 5000 ha. Most of the production (83%) is dedicated to woody ornamentals, more than 5% of the total European nursery production. Presence of *Phytophthora* was checked in soils and roots using two methods: traditional isolation technique of the living organism and molecular tools (quantitative PCR). This second was necessary to reinforce the resolution of the first because *Phytophthora*, thanks to its skills as cryptic pathogen, might be present in the host in extremely low quantities and in a quiescent state, thus isolation methods which are efficient to detect fungi or other microorganisms in an active state of the life cycle, might not be good enough. *Phytophthora* was detected by qPCR in 87% of the tested pots and in 70% of the asymptomatic potted plants. Potted plants in soil carried several *Phytophthora* species without showing any external symptoms.

The potential of symptomless potted plants for carrying invasive soilborne plant pathogens.

Migliorini et al., 2015

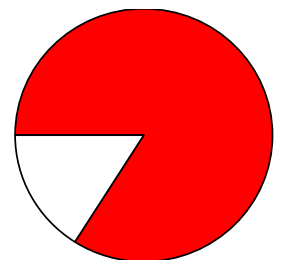
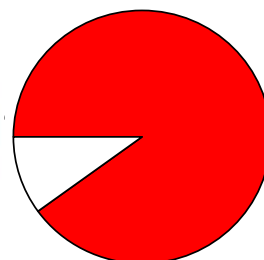
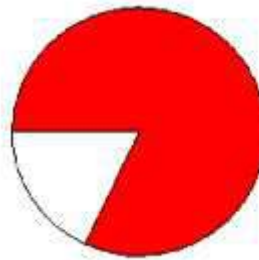
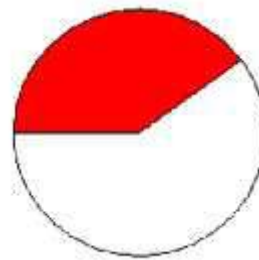
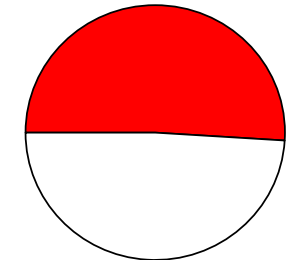
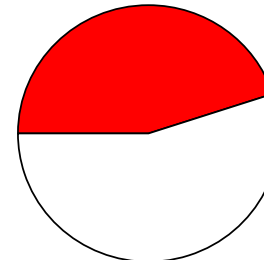
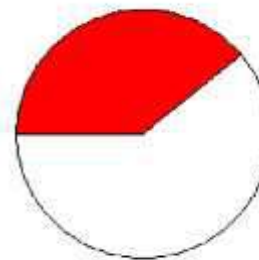
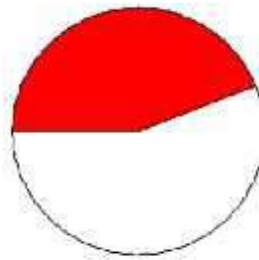


Soil

Roots

Symptomatic

Asymptomatic



Globalization

I had the chance to also investigate the international movement of plant pathogens during my PostDoc project as well. With the commercial name of PROTEAS, several ornamental varieties are currently cultivated for the cut flower industry. Mainly are hybrids or selection of ZA species. Bigger exporters are Au, ZA. Big importers are Japan, USA, Europe.

Proteaceae is a large Southern hemisphere family. Australia and South Africa are the richest countries in terms of biodiversity of the flora. Kwongan and Fynbos, which are the names of the Australian and South African natural bush formations, are floristically dominated by this family.



Globalization

Proteaceae

Westen Australia 697 species



Globalization

South Africa 332 species

South America 90

New Guinea 80

New Caledonia 45

Serious damage is caused by soil borne pathogens as *Fusarium* and *Phytophthora*, the later responsible sometimes of rapid dieback phenomena across entire plots of the plantations. Cluster roots, peculiar roots of Proteaceae, are considered a highly vulnerable point of entrance for *Phytophthora*.

Crown fungal diseases have a strong influence on Protea production too. Damage and, in some cases, plant mortality are related to canker and stem blight agents, at the same time leaf blight agents and fungi of flowers, even if they are not the primary risk for plantations stability, might compromise the final yield of cuttings designated to the market. Samples collection occurred in South Africa, Australia and Europe, both in plantations and nature (excluding Europe where they are not in nature). The main aim was to characterize differences in pathogens distribution between cultivated and natural conditions. A second scope was to understand if fungal species from South Africa were exported to EU 20 years ago, when Portugal Protea farmers used propagation material from the Cape.

Using a metagenomics approach, preliminary results demonstrated that fungal species previously described only in the Southern Hemisphere have been identified in Portugal, suggesting that the past import of Proteaceae propagation material has been responsible for the introduction of non-native microorganisms (data not published yet).

Damages by *Phytophthora cinnamomi* on *Leucadendron* plants



Mycorrhizal species are going through a growing consideration in the research sector that concerns invasions biology (Dickie et al., 2016; 2017; Burgess et al., 2016). *Amanita muscaria*, associated with conifers and angiosperms in the North Hemisphere, has become invasive in Australian forests. This species forms symbiotic association with *Nothofagus cunninghamii* (Fagaceae) and probably *Eucalyptus globulus* (Myrtaceae) (despite numerous but unconfirmed field reports, the association with *E. globulus* has been proved only *in vitro* conditions) (Dunk and Keane, 2012). The congeneric species *Amanita phalloides* moved from Europe to N America, establishing symbiotic association with Pines, *Picea*, *Abies*, *Cedrus*, *Fagus*, *Quercus* (Nunez and Dickie, 2014). Royal Melbourne Botanical Gardens, where *A. phalloides* often fructifies under some of the big planted trees, is currently undertaking a management/education activity about the diffusion of the *Dead cap fungus* in Victoria.

The first report of *A. muscaria* in WA is from 2010 (Robinson, 2010), when few sporocarps were collected under a European Birch tree and taxonomically assessed (It happened in 2009, published in 2010). To the best of my knowledge there have not been further scientific reports about a later diffusion in the area, however, as all locals know, and as I experienced, *A. muscaria* is now spread under European broadleaves species in many other locations of SWWA. My personal hypothesis is that Truffles industry of WA, due to the use of European plant species in plantations, is endangered. If *A. muscaria*, whose fruitification looks extremely tough to me under observed chestnuts and oaks WA stands, is able to replace truffles association in the farms, the financial damage for local farmers will be a reality and the lack of action aimed to eradicate the invasive species at the time of the first report will represent a failure in the biosecurity policy of WA.

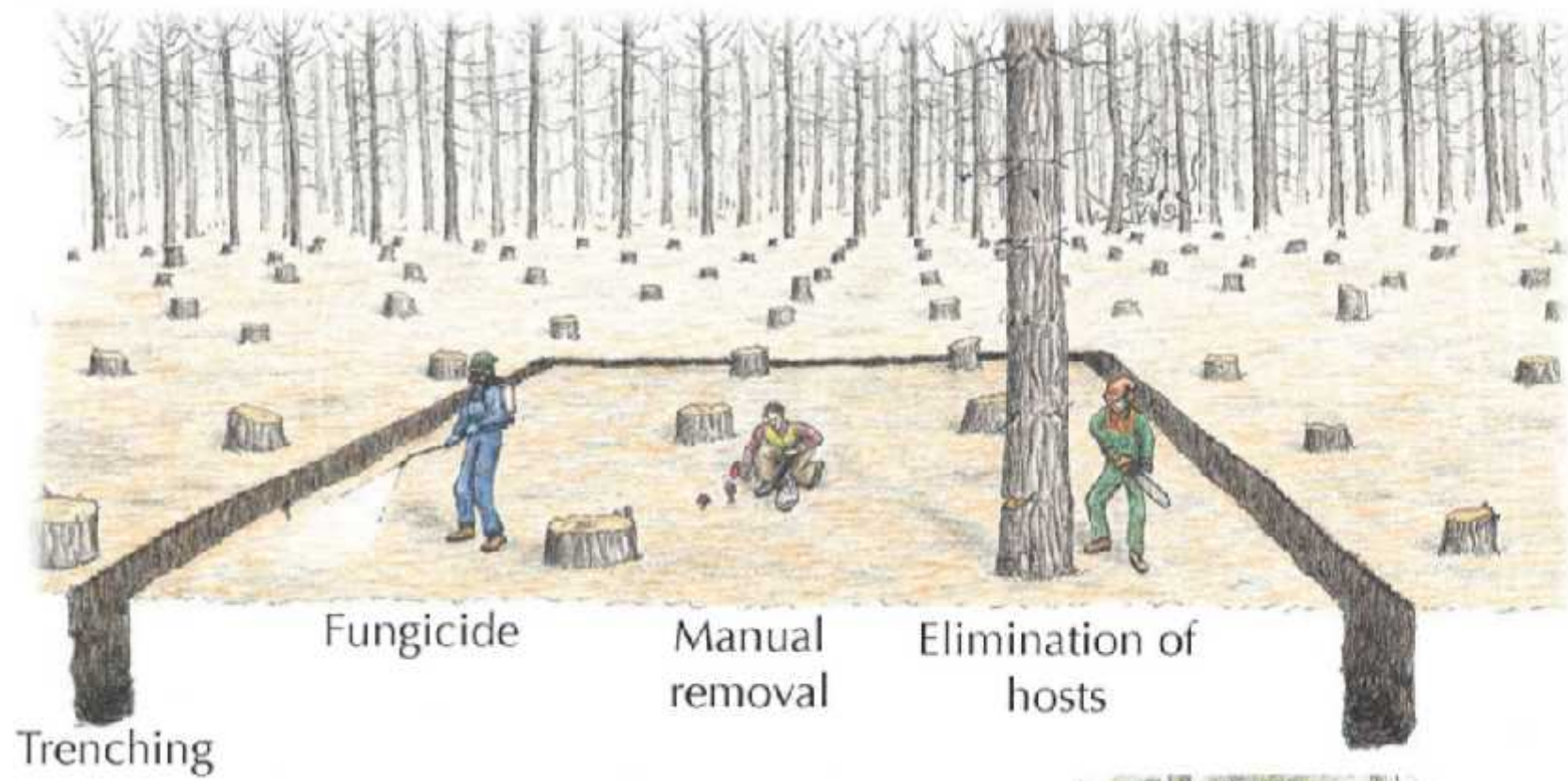
Management of invasive ectomycorrhizal fungi have been discussed in Dickie et al. (2016). Authors suggested host removal, sporocarps removal, use of fungicides and trenching. Sporocarps removal and trenching look to be the only adaptable choices for truffle farms. I would add Fumigation. A protocol including host destruction, fungicides, fumigation and physical root barriers was successfully applied for eradicating *P. cinnamomi* from spot infestations in Western Australia and Tasmania (Dunstan et al. 2010), where no viable pathogen was detected 6 to 9 months after the end of treatments.



Amanita muscaria. Native to Northern Hemisphere. First detected in SW WA in 2010. A potential threat to our truffle industry.

Dickie et al., 2016

Towards management of invasive ectomycorrhizal fungi



Human disturbance

Human disturbance

So, if plant pathology is operating in a changing context, where past and present trades of living plants are the main reason of new plant diseases spread and the recent changing of climatic conditions is a predisposing factor of plant susceptibility, there has been very limited experimental research studying the effects of combined multiple factors of influence at the stand level. Interdisciplinary studies across different spatio-temporal scales are required to address the challenge of assessing forest health (Paap et al., 2017a and articles reported in it). In other words some disease outbreaks can be properly assessed and managed only if the experimental investigation is focused on multiple factors like biotic and abiotic stress together with elements about past and present history of the area. A growing number of experimental studies is introducing Human disturbance as an additional, crucial co-driver of plant ecosystems health.

A case of study that has a particular affinity with this concept is the marri canker in SWWA.

Corymbia calophylla ((R. Br. ex Lindl.) K.D. Hill & L.A.S. Johnson) is a tall bloodwood tree endemic to SWWA with a restricted range. The first stem cankers *Quambalaria coyrecup* of marri were recorded in 1939–1940 (Paap et al., 2017a and b). The pathogen, which is now extended across almost the entire range of marri, was intensively studied at CPSM of Murdoch University, where I am currently hosted.



Image by Trudy Paap
WA

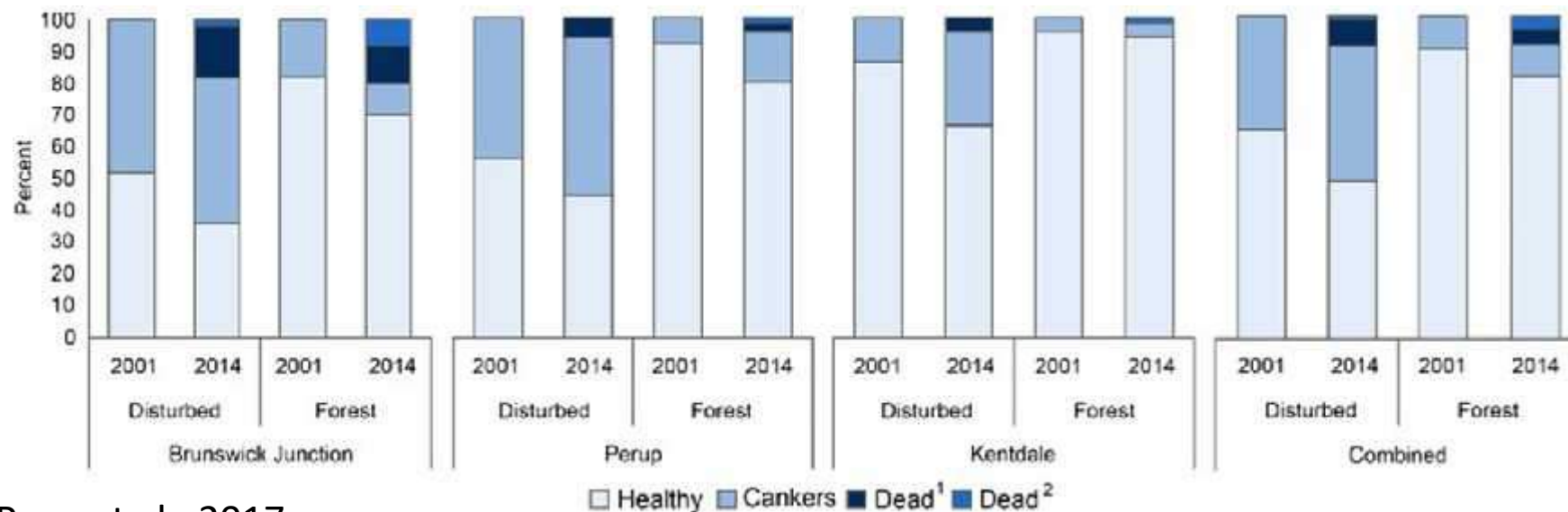
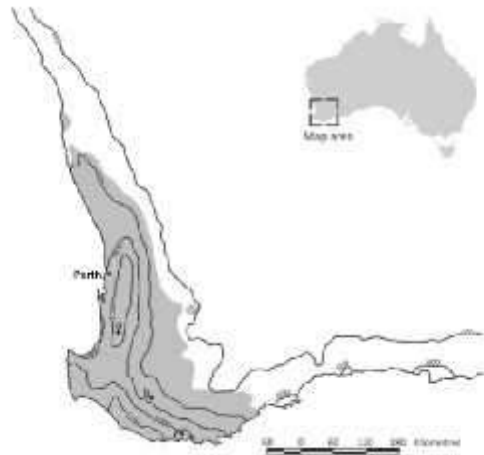
Human disturbance (land use)

Corymbia calophylla
(marri tree)

affected by

Quambalaria coyrecup

Paap et al. (2017a) evaluated the health status of *Corymbia calophylla* trees at six sites in the SWWA in 2001 and 2014. They found out that canker incidence was related to region (location) and local disturbance of the stand. Similarly, in a second larger study, which included more than 50 areas across the entire marri range, the influence of other predisposing factors in the probability of canker incidence was evaluated, finding that: canker incidence was significantly higher in wetter and cooler areas of the marri distribution; presence of pathogenic *Phytophthora* spp. equally increased canker incidence; and again, in areas with high proportions of non-native vegetation in proximity of the studied stands canker effect was stronger, as well as high density of the Marri trees in a possible “host density threshold” effect .



Paap et al., 2017.

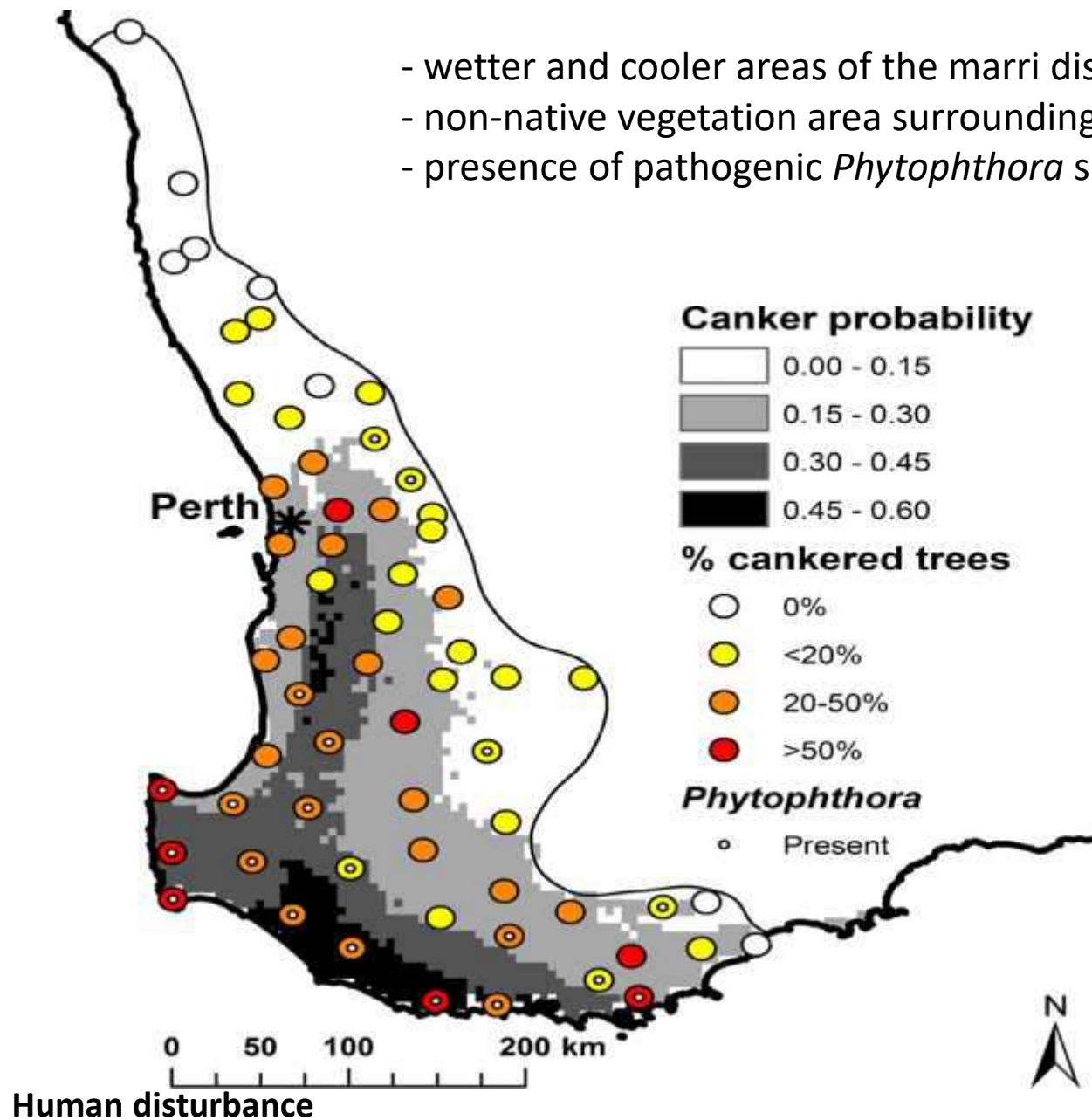
Health status of *Corymbia calophylla* trees at six sites in the southwest of Western Australia in 2001 and 2014. Fifty trees were assessed per site. ¹Death caused by canker; ²death by cause other than canker.

Human disturbance

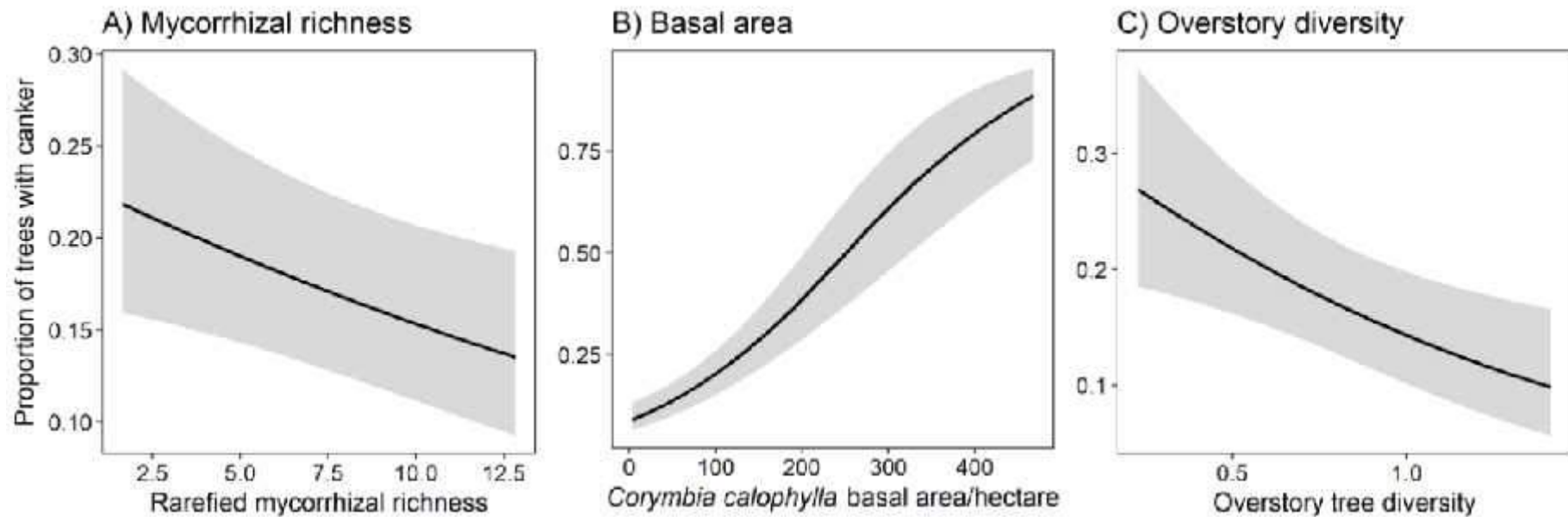
An ex-colleague from Murdoch Uni., Sarah Sapsford, now PostDoc at the University of Canterbury (NZ), dedicated her PhD Thesis (2017) to this argument, providing many other interesting data (Sapsford, 2017; Sapsford et al., 2017). Her project crossed the articles previously cited for a good portion. She worked on 17 of the over 60 sampling locations shown on the SWWA map in the previous slides. In each location sampling was done across a disturbance gradient: disturbed edge (i.e., remnant stand of *C. calophylla* bordering cleared land and a road), forest edge and 200 m into intact forest. The overall proportion of cankered trees resulted clearly dependent on the grade of disturbance. She found a relationship to proportion of trees with canker (canker incidence) and very important biotic and abiotic variables: Mycorrhizal richness, plant basal area, and reduced overstory diversity.

Canker incidence increased by

- wetter and cooler areas of the marri distribution
- non-native vegetation area surrounding the studied stands
- presence of pathogenic *Phytophthora* spp.



Paap et al. 2017



Sarah Sapsford, PhD Thesis (2017)

Relationship among proportion of trees with canker (canker incidence) and the top biotic predictor variables

Human disturbance

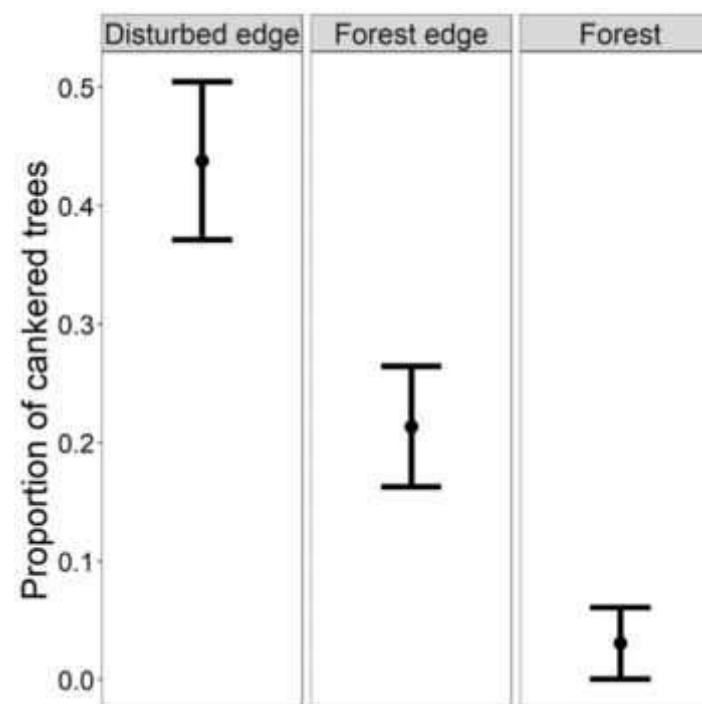


Sarah Sapsford, PhD Thesis (2017)

**Factors predisposing *Corymbia calophylla*
trees to canker disease caused by
*Quambalaria coyrecup***

Murdoch University

Human disturbance



She found that the mycorrhizal taxonomical richness varied along the disturbance gradient, with similar results about arbuscular and ectomycorrhizal communities.

Studies like this one are very rare in plant pathology. The approach is hard to do and to understand the reasons of diseases outbreaks by the consideration of different casual agents (biotic and abiotic) is expensive and definitely time demanding, but results of the investigation are often very clear and helpful. This is way I found this experimental investigation on Marri canker particularly interesting for this presentation.

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