Mendel University in Brno

Faculty of Forestry and Wood Technology

Department of Forest Protection and Wildlife Management

Invasive diseases of Pines in South Europe

Diploma thesis

2016 Barbora Buchtová

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ABSTRACT

Invasive disease of Pines in South Europe

Author: Barbora Buchtová

This thesis deals with the issue of invasive pest and diseases invading pine trees in South Europe (Italy, France, Spain and Portugal). Pine trees are one of the largest families spread all over the world, including South Europe, which also has the highest number of invasive diseases.

Information about the most important and most widespread invasive diseases and pests of pine trees in South Europe were identified and compared on several internet databases. This information is detail analyzed in the work. Information include the names of invasive pests and diseases, the year and the pathway of introduction in individual countries, their description, hosts, applied control measures etc. Thesis provides a unified and comprehensive facts about this issue.

The most important and most widespread invasive diseases and pests of pine trees in South Europe are: *Dothistroma septosporum, Lecanostica acicola, Fusarium circinatum, Bursaphelenchus xylophilus* etc.

Key words: Internet databases, Invasive disease and pests, Pines, South Europe

ABSTRAKT

Invazivní choroby borovic v jižní Evropě

Autor: Barbora Buchtová

Diplomová práce se zabývá problematikou invazivních chorob a škůdců napadající borovice v jižní Evropě (Itálie, Francie, Španělsko a Portugalsko). Borovice jsou jedním z nejpočetnějších rodů rozšířených téměř po celém světě včetně jižní Evropy, která se zároveň vyznačuje nejvyšším počtem invazivních chorob.

Informace o nejdůležitějších a nejrozšířenějších invazivních chorobách a škůdcích borovic v jižní Evropě byly zjištěny a porovnány z několika internetových databazí. Tyto informace jsou v práci detailně rozebrány. Zahrnují jména invazivních chorob a škůdců, rok a způsob zavlečení do jednotlivých států, jejich popis, hostitele, aplikovaná ochranná opatření atd. Diplomová práce poskytuje sjednocená a ucelená fakta o této problematice.

Nejvýznamější a nejrozšířenější invazivní choroby a škudci borovic v jižní Evropě jsou: *Dothistroma septosporum, Lecanostica acicola, Fusarium circinatum, Bursaphelenchus xylophilus* atd.

Klíčová slova: Borovice, Internetové databáze, Invazivní choroby a škůdci, Jižní Evropa

CONTENT

1. INTRODUCTION

Nowadays, policies of globalization, especially increasing intercontinental trade, widening of travel possibilities and climate change are the major factors accelerating the introduction and establishment of alien species.

In natural and human-created ecosystems the rapid spread of any damaging organism can result in pest control, forest health, nature protection, public health and even economic issues, especially when an alien invasive species enters the system. The ecological, economic and public health damage caused by species which have become invasive after introduction is growing every year.

Protection against alien invasive species pests is now the biggest problem in pest control. Our aim should be to at least slow the increases in numbers of introduced species and their establishment by the adoption of strict control measures.

According to Brasier (2008) over the millennia, complex and often highly specific plant communities, frequently dominated by trees, have evolved on different continents and in different biogeographical zones within each continent. Some of these communities have changed dramatically under human influence, but many pristine areas have survived and, even where the changes have been great, native species may still feature prominently in the local forests or impart a characteristic appearance to the landscape. Both the diversity of the plant communities and individual species within them fascinated early explorer plant collectors continue to inspire succeeding generations of scientists, botanists and horticulturalists. Elegant gardens and parks, comprising assemblages of exotic and native plants, have been created and rank highly in the cultural heritage of many countries.

As native, locally adapted plant communities evolved, guilds of unique pathogenic microorganisms, viruses and viroids evolved in association with them. Today these organisms often cause little noticeable damage to their host plants, having developed a natural balance through co-evolution. However, major problems may arise if a pathogen escapes – or is introduced – to another region of the world where the native plants have little resistance and the pathogen has eluded its natural enemies. Such events can trigger damaging disease episodes that may also have long-term negative impacts on the environment, economy and cultural heritage. Movement of plants and plant products between biogeographical zones by human activities is now generally accepted to be the primary mode of introduction of exotic pathogens and pests. There is therefore a tension, in terms of risk to the cultural and natural environment, between the conservation and environmental responsibilities of horticulturalists, foresters, garden designers and landscape architects and their desire for novel material or (these days) cheaper plants and instant trees (Brasier, 2008).

Invasive pathogens have been causing damage to native plant communities, woodlands and landscapes on a global scale for over a century (Brasier, 2008).

2. AIM OF THESIS

The aims of thesis are to evaluate the spectrum of main alien and invasive species in Europe. Elaborate review on alien and invasive disease and pests of Pines in the South Europe as a threats for other EU regions. To find out and describe main invasive diseases and pests of pines in South Europe (Other scientific names, common names, taxonomic classification, continent of origin, identification, hosts, biology, symptoms and damage, dispersal and introduction pathways, control measures and distribution). To check measures which are applied against the quarantine disease and pest in EU and to process list of threats (potentially invasive species) for European pines, occurring on outside Europe.

3. THE DISTRIBUTION OF INVASIVE DISEASE AND PESTS IN EUROPE

3.1. Explanation of terms

- Alien disease - species, distributed in an area outside its natural range, will not necessarily cause problems indigenous populations and ecosystems (Jankovský, 2015).

- Invasive disease - the non-native species in a geographically limited area, with an uncontrolled spread and impacts on native populations of organisms that directly displaces competition for natural resources, or damages directly pathogenic effects (Jankovský, 2015).

- Quarantine diseases and pests - the alien species in certain areas, which are applied to the official measures, usually by Phytosanitary authority (Jankovský, 2015).

Over the past 500 yr, the geographic barriers that had maintained an almost static distribution of the world's biota for millions of years have been eroded by human activity, and wild species have consequently moved beyond their natural range (Richardson et al., 2000). Human-driven species expansion has increased tremendously in the last century, as a consequence of the unprecedented growth of international travel and trade, resulting in huge disturbance to ecosystems and severe socio-economic impact (Aukema et al., 2011). In plants, emerging infectious diseases (EIDs) are tightly linked to biological invasions. More than half of the world plant EIDs in 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 (Bandyopadhyay & Frederiksen, 1999; Anderson et al., 2004). Fungal and fungal-like infections have always played a primary role amongst plant EIDs. Disease alerts for plant-infecting fungi in the Program for Monitoring Emerging Diseases (ProMED; http://www.promedmail.org) show a 13-fold increase from 1995 to 2010 (Fisher et al., 2012). In forest trees, alien fungal and fungal-like pathogens are the main cause of EIDs, including such striking examples of virulent outbreaks of anthropogenically introduced fungi as Dutch elm disease and chestnut blight (Anderson et al., 2004; Liebhold et al., 2012).

Invasiveness has been defined in several ways, but in all definitions the crucial factor distinguishing an alien (exotic, nonnative, or nonindigenous) from a native organism is human driven introduction into a new region (Pysek&Richardson, 2006). The definition of 'alien species' given in the Guiding Principles of the Convention on Biological Diversity (2002, CBD Decision VI/23), that is, a species occurring outside of its natural range and dispersal potential, was recently adopted for fungi (Desprez- Loustau et al., 2010). Here we use a slightly modified version of the same definition to better fit forest pathogens. An alien or invasive forest pathogen (IFP) is defined as a species, subspecies, race, or forma specialis which: (1) is introduced into a country where it was previously unknown (for example, it can be either an alien species to Europe spreading in neighbouring countries or a European species extending its range), (2) behaves as an agent of disease, and (3) threatens the biological diversity of native or exotic forest trees and shrubs.

In the theory of invasion ecology, invasiveness has been associated both with biological traits of the invasive species and with environmental and community features in the naturalized range that render an ecosystem prone to invasion and define invasibility (Goodwin et al., 1999; Mitchell&Power, 2003; Alpert et al., 2000). Social and economic factors are crucial for species introduction (Sakai et al., 2005; Guo et al., 2012), whereas biogeographical and ecological factors are important for naturalization, with evolutionary forces being key mediators of invasiveness (Sax, 2001). The species-energy theory suggests that, in regions with higher biomass productivity, host–pathogen system stability and the pathogen-carrying capacity of an ecosystem are higher (Wright, 1983). Host species persistence is higher in areas with varied topographical and edaphic conditions, and large ecosystem diversification (Lonsdale, 1999). The invasibility of a country is likely to be related to its geographical extent and number of ecoregions (Omernik, 2004). The pathogen richness of a territory depends on such climatic variables as annual mean temperature and annual total rainfall which affect the pathogen life-cycle (Whittaker et al., 2001; Guernier et al., 2004; Vacher et al., 2008). Temperature especially is a driver of diversity according to the metabolic theory of ecology (Brown et al., 2004), and temperature-dependent kinetics predicts the association of temperature with generation time, mutation frequency and ultimately species diversification (Rohde, 1992). An assessment of the species features that differentiate successful invaders requires great experimental efforts. For certain species specific traits, a direct link with invasiveness has been established in some biological groups, but finding traits generally and consistently associated with invasiveness has proved to be very difficult (Alpert et al., 2000; Hayes & Barry, 2008). In plant pathogens, invasiveness is affected by strain virulence, host specificity and mode of action as well as by the host's abundance, demography, phytosociology, and variation in susceptibility (Lovett et al., 2006; Schulze-Lefert & Panstruga, 2011). In fungal pathogens of forest trees, a significant effect on invasiveness has been suggested for residence time (i.e. time since first record), lifestyle and phylogenic order (Desprez-Loustau et al., 2010). Recently, traits related to mode of reproduction and dispersal, spore shape and size, optimal temperature for growth, and parasitic specialization have been proposed as useful predictors for distinguishing between invasive and noninvasive forest fungal pathogens (Philibert et al., 2011).

According to (Santini et al., 2013) and results from his research comprises 123 invasive forest pathogens. These invasive pathogens since 1800 were classified as aliens (42%), species of European origin (28%), cryptogenic species (26%), and hybrids (4%). On average, each invasive pathogen was observed in five countries, but there was large variation among species. Thirty-seven species were observed in one country only, whereas four species (*Erysiphe alphitoides* s.l., *Mycosphaerella pini, Rhabdocline pseudotsugae*, and *Phytophthora cambivora*) were found in > 15 countries.

At present, Ascomycota are the most numerous group (70%) of IFPs in Europe, while Oomycota and Basidiomycota represent 21% and 9% of the total, respectively. Invasive pathogens mainly cause tree dieback (37%) or growth reduction (40%), but almost one-fourth of them can cause death of the host. Invasive pathogens have been most frequently found on ornamental trees in parks and gardens (38%) or in forests (36%). A considerable number have also been found on nursery plants (21%), while 5% have been found in orchards and other plantations (Santini et al., 2013).

The large majority of IFPs in Europe are specialists (77%). Most species attack Angiospermae (58%), about one-fourth attack Gymnospermae (26%), and a small group (16%) are polyphagous. Trade and airborne were the most common putative pathways of arrival and diffusion. To our knowledge, all the introductions occurred unintentionally. At present, c. 70% of the species are established in Europe, while 9% are spreading and 19% have been recently recorded for the first time. Only 1% of them have been eradicated through sanitary measures (e.g. *Gibberella circinata* in Italy) or replaced by more aggressive species (e.g. *Ophiostoma ulmi* replaced by *Ophiostoma novo-ulmi*) (Santini et al., 2013).

3.2. Temporal pattern of invasion

The number of IFPs introduced has increased exponentially in the past 200 yr. The time of introduction of a limited number of species (6.5%) could not be established; these species were therefore excluded from further analyses. The rate of introduction of ascomycetes continuously increased until now, basidiomycetes appeared at a constant rate over time and the rate of introduction of oomycetes has increased dramatically since the 1990s (Santini et al., 2013).

Of these IFPs, 27% are European species previously restricted to small areas of the continent, 22% are aliens from temperate North America, and14% are from Asia. The origins of 25% are unknown. Africa, tropical North America and Australasia were minor sources of invasive pathogens for Europe, but their importance has increased over time, especially in the last 30 yr. Spread of endemic species within Europe was the main cause of invasion before the 1940s. The region of origin of alien pathogens was mainly North America from the early 1940s to the 1960s. Hybrids between introduced species were recorded in the 1990s for the first time (Santini et al., 2013).

The exact pathway of introduction was almost unknown for most of the IFPs. However, the most probable pathway was deduced for each IFP based on its biology and host range. Alien pathogens were mainly introduced through living plants (57%) or wood (10%). Less than 10% of the introductions occurred through any of the other pathways. In the last 30 yr, the relative importance of living plant and soil pathways has dramatically increased. IFPs in Europe are agents of cankers (31%), foliar diseases (25%), or root rots and rots (24%). Foliar diseases were common until 1920, whereas after that time canker agents were the most frequent new invaders, and in the last 30 yr the frequency of invasion by agents of root rots and rots has considerably increased (Santini et al., 2013).

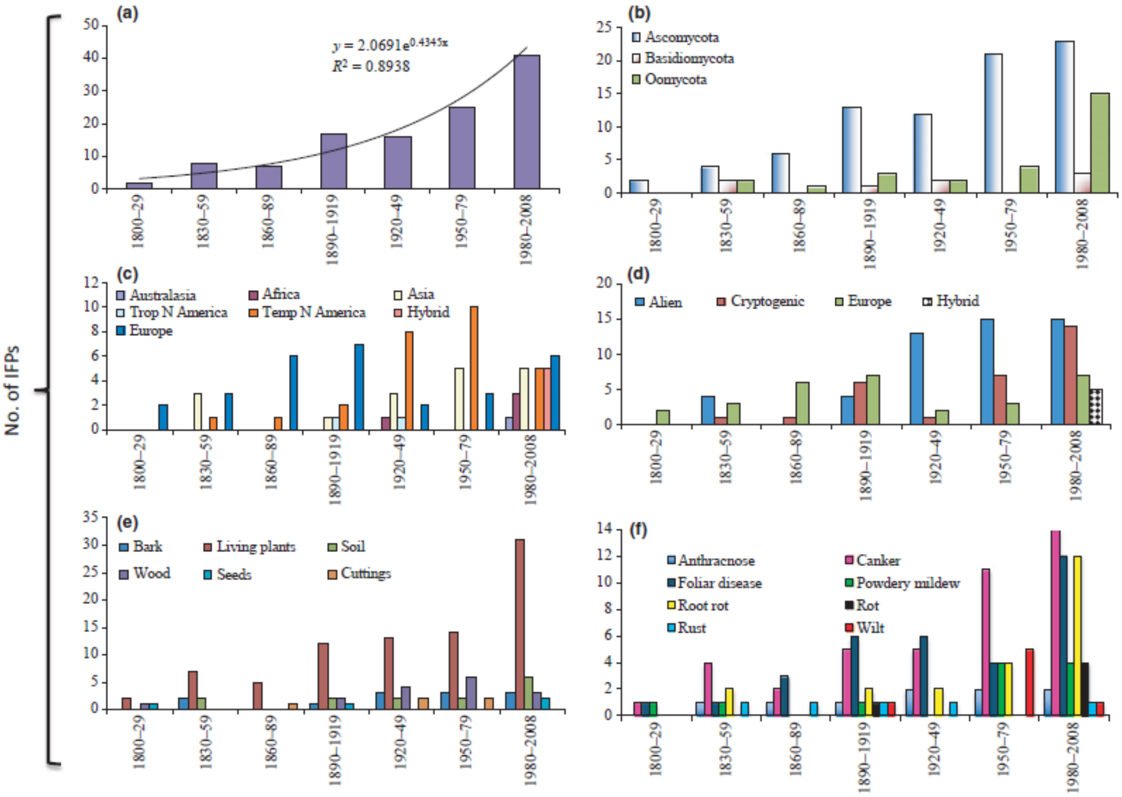

Fig. 1 (a) Total number of alien invasive forest pathogens (IFPs) according to time of arrival in Europe. (b) Taxonomic order of alien IFPs according to time of arrival in Europe. (c) Area of origin of alien IFPs according to time of arrival in Europe. (d) Status of alien pathogens recorded according to arrival in Europe. (e) Most probable substrate on which alien IFPs arrived in Europe, according to time of arrival. (f) Diseases caused by alien pathogens grouped according to time of arrival in Europe (Santini et al., 2013).

3.3. Spectrum of main alien invasive species in Europe

The highest numbers of species (> 40 IFPs since 1800) were found in countries in the central-southern region of Europe (Italy, France, Switzerland, Austria, and Hungary). In Spain, Germany, Slovenia and Sweden, 31–40 species were recorded; in Romania, Slovakia, the Czech Republic, the UK, Norway and Finland, 21–30 species were recorded; and in Latvia, Lithuania, Poland, Belgium and Greece, < 20 IFPs were counted (Santini et al., 2013).

Based on species number and identity, European countries clustered into three macro-groups, illustrating that the incidence of IFPs was related to latitude: Continental (Austria, Belgium, the Czech Republic, Germany, Hungary, Poland, Romania, Slovakia, Slovenia and Switzerland); Atlantic/Mediterranean (France, Greece, Italy, Spain and the UK); and Nordic (Finland, Latvia, Lithuania, Norway, and Sweden) (correspondence analysis). The clustering was significant and explained 16% of the among-groups variance (ANISVA) (Santini et al., 2013).

European countries were divided into two main clusters on the basis of arrival rate (RAc), relative spread rate (RSRc), and prevalence (PIc) of the pathogens in their territory (PCA and hierarchical clustering). The first cluster includes countries with many long-established invasive species (high PIc). Within this cluster, Switzerland, Italy, Austria, Hungary and Slovenia have higher arrival rates and lower spread rates than Germany, Sweden and France. The other main cluster includes countries with relatively low arrival rates and prevalences, but generally high spread rates, indicating more recent invasions. The extreme in this cluster is represented by Poland and Latvia, which experienced a few recent and fast invasive events. The clustering was significant and explained 12% of the among-groups variance (ANISVA) (Santini et al., 2013).

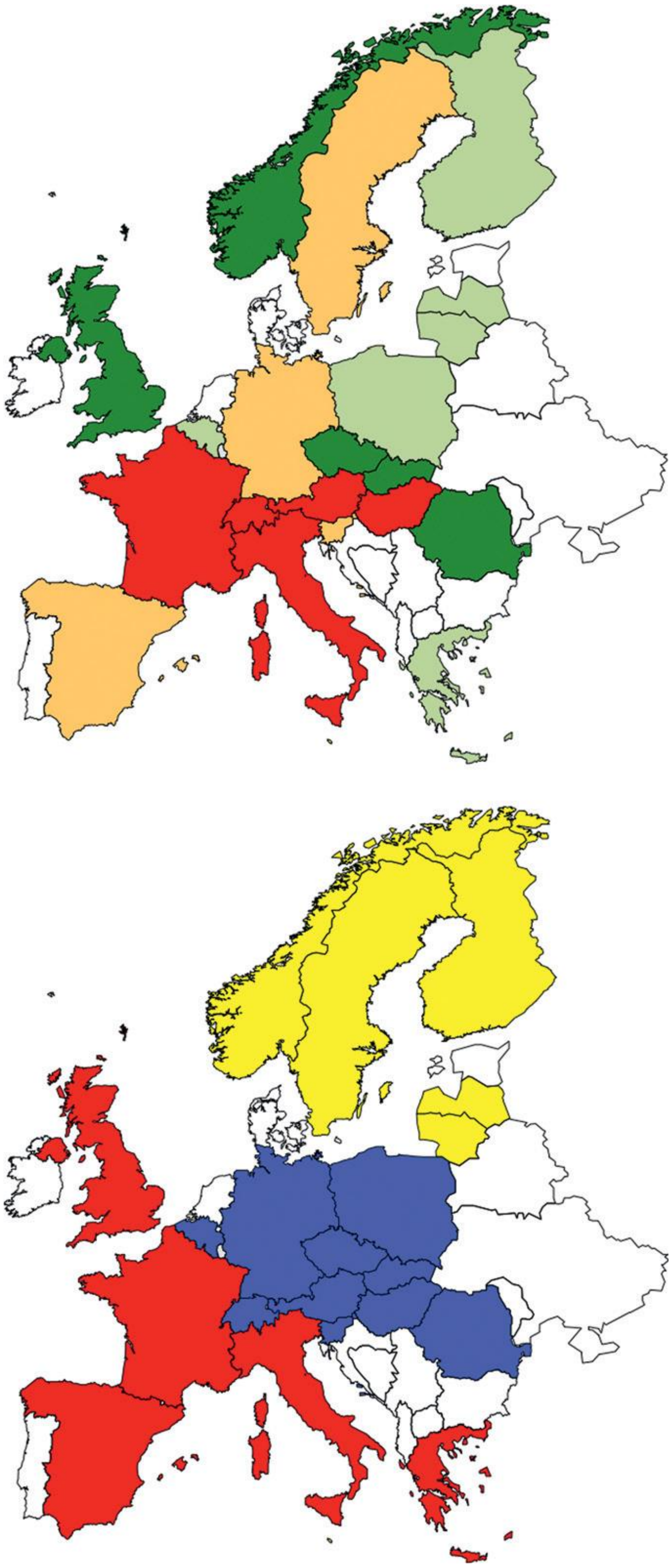

Fig. 2 (a) Numbers of alien invasive forest pathogens (IFPs) in each country. Pale green, 1–20; dark green, 21–30; pale orange, 31–40; red, > 41. (b) Groups of European countries with similar frequencies of IFPs based on correspondence analysis. Similar countries share the same color (Santini et al., 2013).

3.4. Potentially invasive species for European pines

European and Mediterranean Plant Protection Organization (EPPO) - EPPO is an intergovernmental organization responsible for cooperation and harmonization in plant protection within the European and Mediterranean region. Under the International Plant Protection Convention (IPPC), EPPO is the regional plant protection organization (RPPO) for Europe. Founded in 1951, EPPO has grown from 15 original members to today's 50 member countries, including nearly every country in the European and Mediterranean region (EPPO, 2016).

One of the aims of EPPO is to help its member countries to prevent entry or spread of **dangerous pests (plant quarantine)**. The Organization has therefore been given the task of identifying pests which may present a risk, and of making proposals on the phytosanitary measures which can be taken. In recent years, the identification of risk has been formalized, because transparent justifications of phytosanitary measures are required and phytosanitary measures have to be commensurate with the risk. Several EPPO Standards on Pest Risk Analysis (PRA) are now available. To perform these activities, much information on pests presenting a risk to the EPPO region is required and has been collected by the Organization (data sheets, maps, diagnostic protocols and pictures) (EPPO, 2016).

EPPO recommends its member countries to regulate the pests listed below as quarantine pests (A1 pests are absent from the EPPO region). The EPPO A1 List is reviewed every year by the Working Party on Phytosanitary Regulations and approved by Council (EPPO, 2016).

EPPO recommends its member countries to regulate the pests listed below as quarantine pests (A2 pests are locally present in the EPPO region). The EPPO A2 List is reviewed every year by the Working Party on Phytosanitary Regulations and approved by Council (EPPO, 2016).

From EPPO A1 List the potentially invasive species for European pines are following:

Fungi:

- *Atropellis pinicola*
- *Atropellis piniphila*
- *Cronartium coleosporioides*
- *Cronartium comandrae*
- *Cronartium comptoniae*
- *Cronartium fusiforme*
- *Cronartium himalayense*
- *Cronartium quercuum*
- *Endocronartium harknessii*
- *Mycosphaerella gibsonii*
- *Ophiostoma wageneri*
- *Phellinus weirii*

Insects:

- *Dendroctonus adjunctus*
- *Dendroctonus brevicomis*
- *Dendroctonus frontalis*
- *Dendroctonus ponderosae*
- *Gnathotrichus sulcatus*
- *Ips calligraphus*
- *Ips confusus*
- *Ips grandicollis*
- *Ips lecontei*
- *Ips pini*
- *Ips plastographus*
- *Monochamus* spp.
- *Pissodes nemorensis*
- *Pissodes strobi*
- *Pissodes terminalis*

3.5. Mediterranean Pines

Pines are important components of many landscapes in Mediterranean region, and have played major roles in the origin of its flora and vegetation. *Pinus* spp., along with other Eurasian and Holarctic elements such as *Acer, Betula, Cercis, Corylus, Fagus, Fraxinus, Quercus, Tilia* and *Ulmus* that are now prominent components of the flora, invaded the Mediterranenan Basin after the advent of Mediterranean type climate about 3,5 million years ago. The biogeography of pines in the region has been greatly influenced by humans. Mediterranean pines and other forest species have, in turn, played a major role in shaping human history in the region, and indeed throughout the world. In no other part of the natural range of *Pinus* has there been such a complex interplay between pines and humans (Richardson, 1998).

The extant pine flora of the Mediterranean Basin comprises 10 *Pinus* species. Included is *P. sylvestris* which, although widespread in the region, is more characteristic of extra-mediterranen Europe. Chloroplast DNA studies show the Mediterranean pines to be divided between a small group of species in subsections *Canarienses* (*P. canariensis*), *Halepenses* (*P. brutia* and *P. halepensis*) and *Pineae* (*P. Pinea*), which correspond to almost all of group of Mediterranean shore and island pines; and a separate, larger group comprising part of subsection *Pinus* (*P. heldreichii, P. mugo, P.nigra, P. pinaster, P. sylvestris* and *P. uncinata*) which fall into group of mountain pines from areas surrounding the Mediterranean. The chloroplast DNA restriction site tree suggest that the subsections *Canarienses, Halepenses* and *Pineae* form a well-supported clade separate from subsection *Pinus*. Pines of the subgenus *Strobus*, which comprise more than a third of species in the genus, are not represented in the region, although taxa in this group (*P. juarezensis, P. monophylla*) do occupy Mediterranean-type climates in North America. *Pinus peuce* has a very localized occurrence in the Balkan mountains, but does not occur in the Mediterranean-climate part of this range (Richardson, 1998).

The area of forests in the Mediterranean Basin and adjoining areas has fluctuated dramatically over many centruries, especially in the last two centuries. Given these circumstances, and many large-scale afforestation programmes in many parts of the region, it is difficult to give precise assessment of the area covered by each *Pinus* species in the Mediterranean Basin. Taking into account, we suggest that *P. brutia* and *P.*

halepensis now cover 6,8 x 10^6 ha, *P. nigra* (sensu lato) 3,5 x 10^6 ha, *P. pinaster* 1,3 x 10^6 ha, *P. pinea* 320 000 ha and other *Pinus* species 300 000 ha, giving a total of almost 13 x 10^6 ha. Although pine forests cover only 5% of the total area of the Mediterranean Basin, they comprise about 25% of the forested area. In North Africa and in Anatolia 75% of the forested area comprises pine forests, and the proportion is probably higher in central and northern Taurus. In the northwestern part of the Basin, although pines are less dominant, pine forests are nonetheless important features of the landscapes, particularly in Provence, eastern Spain, Corsica, and southern Greece. Pines have been widely used and planted by human inhabitants of the Mediterranean Basin since prehistoric times (Richardson, 1998).

3.6. Threats to the Mediterranean Forest

Both the native forest systems and the plantation forest systems that are common in many of the Mediterranena climate zones are subject to the threats of environmental change and human activities. They are also subject to the introduction of exotic insects and pathogens. Many of the plantation forests are established using exotic conifer and angiosperm tree species. The exotic species may have an advantage in the adventive environment because they do not have the community of adapted herbivores they would have in the native range. For example, eucalypts and Monterey pine (*Pinus radiata*) are good examples of trees that have flourished in plantations in adventive environments. However, with the increasing international movement of goods and people, there has been a globalization/homogenization of communities of key insect pest and diseases on plantation species. Unfortuantely, some of these exotic pests and diseases have shifted on to closely related native forest trees which can cause signigicant problems in natural forest communities. Consequently, the pest communities in the native forests have expanded to include both native and introduced herbivores that must be managed (Timothy D. Paine, François Lieutier, 2016).

The insect and disease issues are often specific to the Mediterranean forest systems rather than shared with the temperate forests. As noted above, the plant communities are different between temperate and Mediterranean forest communities. The insect and disease communities are either host specific or have different environmental tolerances that limit their distributions to specific habitats. This may be particularly important in the leght of time that insects are active throughout the year as well as whether they are active during the cool winter months and aestivate in the summer to avoid the high summer temperatures. *Thaumetopoea pityocampa*, the pine processionary moth feeds in the winter months and undergoes a summer diapause with pupae spending the hot dry period underground. Similarly, *Tomicus destruens* attack trees in the fall and the larvae feed under the bark in the winter (Timothy D. Paine, François Lieutier, 2016).

The above mentioned introduced *Pinus radiata* in Mediterranean Basin is attacked by invasive disease called *Fusarium circinatum* (*Gibberella circinata*). It has been recorded in radiata pine stands in Italy, Spain and South Africa and in nurseries in Spain, South Africa and Chile. Pine pitch canker, which is found on a wide range of pine species and Douglas fir, is considered an indigenous disease in the United States, where it has been affecting native southern pine stands since 1946. It occasionally causes epidemics there that result in malformation and a loss of growth and occasional tree death. Radiata pine shows less resistance to this disease than most other pines, but like other pine species there is a large genetic diversity from which to breed resistance (Timothy D. Paine, François Lieutier, 2016).

4. MATERIALS AND METHODS

The methodology of work lies in collecting and consolidating of data related to invasive pests and diseases in South Europe. Data was obtained primarily from the internet database, scientific articles dealing with the issue of invasive diseases/pests and oral consultations with students who came from countries in South Europe. Each database contains a different kind of information. This information is broken down and unified in the following outline:

1) List of major invasive pests and diseases of pines in South Europe
2) Description of invasive disease or pests of pines in South Europe – including:
    - Other scientific names
    - Common names
    - Taxonomic classification
    - Continent of origin
    - Identification
    - Hosts
    - Biology
    - Symptoms and damage
    - Dispersal and introduction pathways
    - Economic impact
    - Control measures

In addition, the outline includes specific pictures of symptoms and damage that disease or pest causes and also includes graphs displaying the year of introduction of the disease or pest in individual countries of South Europe created in Excel and maps of distribution obtained from internet databases.

As I said above, data were collected by of the following databases:

EPPO Global Database (https://gd.eppo.int/), Delivering Alien Invasive Species Inventories for Europe (http://www.europe-aliens.org/), INVASIVE.ORG (http://www.invasive.org/), Invasive Species Specialist Group (http://www.iucngisd.org/gisd/), Phytosanitary Alert System (http://www.pestalert.org/).

5. RESULTS

Of all these cited databases it shows that the most widespread and most important invasive diseases and pests of pines are:

- *Mycosphaerella pini*
- *Bursaphelenchus xylophilus*
- *Gibberella circinata*
- *Mycosphaerella dearnessii*
- *Thaumetopoea pityocampa*
- *Sphaeropsis sapinea*
- *Gremmeniella abietina*
- *Heterobasidion irregulare*

5.1. *Mycosphaerella pini* Rostrup (1957)

Synonyms: *Scirrhia pini* Funk & A.K. Parker
Anamorph: *Dothistroma septospora* (G. Doroguine) Morelet
Synonyms: *Dothistroma pini* Hulbary
Cytosporina septospora G. Doroguine

Phylum, Oder, Family: *Ascomycota: Capnodiales: Mycosphaerellaceae*

Common names: pines needle blight; dothistroma needle blight, needle fungus, red band needle blight

Mycosphaerella pini is a fungus that infects and kills the needles of *Pinus* spp. resulting in significant defoliation, stunted growth and eventually death of host trees. It is a major pest in both naturally regenerating and planted forests and probably the most important foliage disease of exotic pines. Susceptibility among pine species does vary. The widely planted *P. radiata* is particularly susceptible and many forests planted with this species in the Southern Hemisphere, particularly in East Africa, New Zealand and Chile, have been devastated by this needle blight. This pathogen has forced managers in some areas to abandon the planting of *P. radiata* and depend more on other tree species (EPPO/CABI, 1997).

Continent of origin

M. pini is indigenous in the cloud forests of Central America (EPPO/CABI, 1997).

Identification

Acervuli initially white, innate, subepidermal becoming erumpent, black, stromatic and cupulate or loculate (pseudopycnidial), variable in size, see above. Conidia hyaline, smooth, thin-walled, with one to five (or up to seven) septa, short-clavate to long-filiform, (8-)10-32(-40) x 1.8-3 µm, with a rounded apex and truncate base. Spermogonia as described for *M. dearnessii*. Ascostromata densely aggregated in red bands, otherwise similar to *M. dearnessii*. Ascospores slightly longer but essentially similar to *M. dearnessii* (EPPO/CABI, 1997).

Hosts

The principal hosts are *Pinus* spp., and an extensive list has been compiled by Gibson (1979), who also included *Pseudotsuga menziesii* and *Larix decidua*. The most susceptible species of importance in the EPPO region are: *P. canariensis, P. contorta, P. halepensis, P. muricata, P. nigra, P. pinea, P. ponderosa, P. radiata, P. sylvestris, P. thunbergii.* Many of the Central American pine species are resistant or immune. *P. nigra* has proved to be particularly susceptible in Europe (south Germany), whilst *P. sylvestris* shows little infection even when exposed to severely blighted *P. nigra* (Lang & Karadzic, 1987). Lang (1987) also reported it for the first time on *Picea abies*.

Biology

Conidia are exuded in a white or pale-pink, mucilaginous mass during light rain or misty conditions. After release, these germinate in free water between 8 and 25°C, with an optimum at 18°C (Ivory, 1967). Gilmour (1981) recorded no infection below 7°C nor when leaves remained wet for less than 10 h. The incubation period is similar to that reported for *M. dearnessii* (1-4 months), although Karadzic (1989) put this at 4-6 months under Yugoslavian conditions, with the critical infection period occurring from May to June and symptoms appearing in October-November. Serious needle blight is likely to occur following protracted periods of high humidity and temperatures within the range 15-20°C (Gibson, 1979). *M. pini* is indigenous in the cloud forests of Central America (Honduras, Guatemala) at altitudes of 1600-2200 m (Evans, 1984). In these habitats the pathogen is common but never seriously damaging; the teleomorph forms freely on attached and fallen needles and seems to play an important role in the life-cycle. In Africa, South America and Oceania, only the anamorph has been reported (Gibson, 1979; Evans, 1984).

Symptoms and damage

As for *M. dearnessii*, the disease first appears on older needles as yellow spots. Generally, however, a profuse reddening develops, and a red pigment may be present around the fructifications. On highly susceptible hosts, red bands containing dense aggregations of stromata are freely formed whilst on other hosts the infected needles appear uniformly reddened or scorched. Reddening of needles has occasionally been observed on *P. radiata* infected with *M. dearnessii* (Evans, 1984); characteristically, however, its fructifications are rarely grouped, being dispersed linearly along the needles. As the disease develops, needle necrosis and subsequent needle cast spreads from the branch bases into the younger foliage. A chronic state may then be reached with the lower parts of the branches denuded and the distal parts bearing isolated groups of diseased needles, often accompanied by the development of epicormic shoots on the stem and major branches.

Fig. 3 Attack of *Mycosphaerella pini* (*Dothistroma septospora*) on *Pinus mugo* (EPPO, 2002)

Dispersal and introduction pathways

Similar to *M. dearnessii,* but the hyaline conidia are less adapted to exposure and thus less likely to be transported by methods other than rain-splash. Mist and low cloud may be involved in long-distance dispersal (Gibson, 1972). The rapid intercontinental spread of *M. pini* was the result of man's movement of live plants or contaminated seed stocks (Gibson, 1974). It was probably introduced into southern Germany on infected *P. nigra* (Butin & Richter, 1983).

Economic impact

M. pini causes loss to timber production in susceptible species, notably *P. radiata*, through reduction in growth rate following defoliation. The severity of damage led to the abandonment of *P. radiata* as a major softwood species in many parts of Africa (Gibson, 1979).

Defoliation of more than 25% has a significant effect on diameter increment whilst 50% needle cast reduces this by a half. Repeated attacks lead to tree death. In New Zealand similar losses have been recorded (Pas, 1981), while in Chile a reduction in diameter increment of almost 75% was recorded in 7-year-old *P. radiata*, 1 year after 80% defoliation (Gibson, 1974). *M. pini* has been in the EPPO region for at least 80 years (Evans, 1984) and has been reported sporadically since, but has not had a significant impact on pine cultivation, except perhaps on *P. radiata* in Spain. A combination of low temperature and low humidity may restrict development of this essentially subtropical fungus, although it could be locally important on susceptible hosts in humid Mediterranean regions.

Control measures

M. pini has been successfully controlled through the use of copper fungicides in New Zealand, where aerial spraying with cuprous oxide or copper oxychloride at 2.24-3 kg active copper per ha is routine practice. Pruning has been recommended to reduce infection in *P. radiata* plantations in Australia (Marks & Smith, 1987).

Distribution and years of first finding disease or pest in individual countries

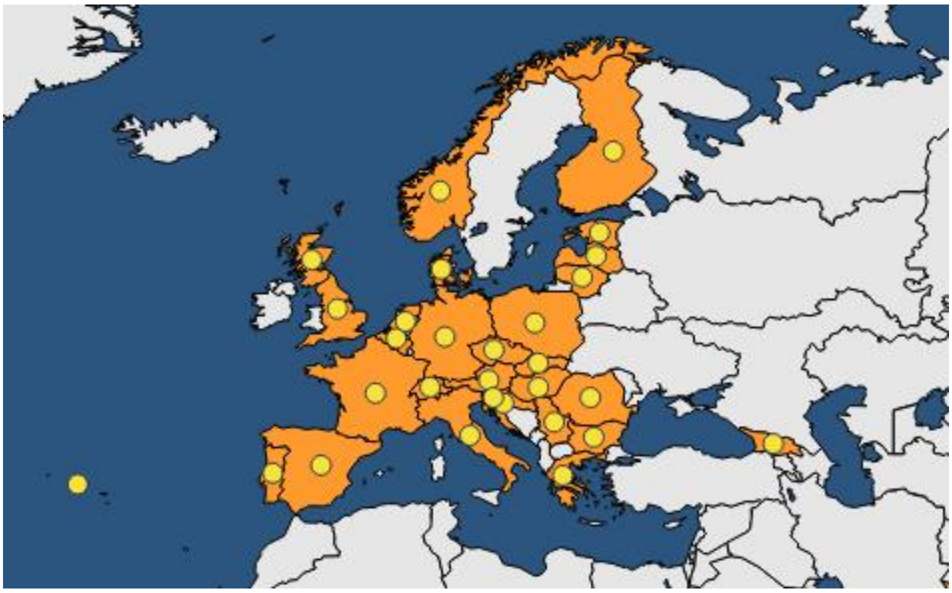

Fig. 4 Distribution of *Mycosphaerella pini* in Europe (EPPO, 2016)

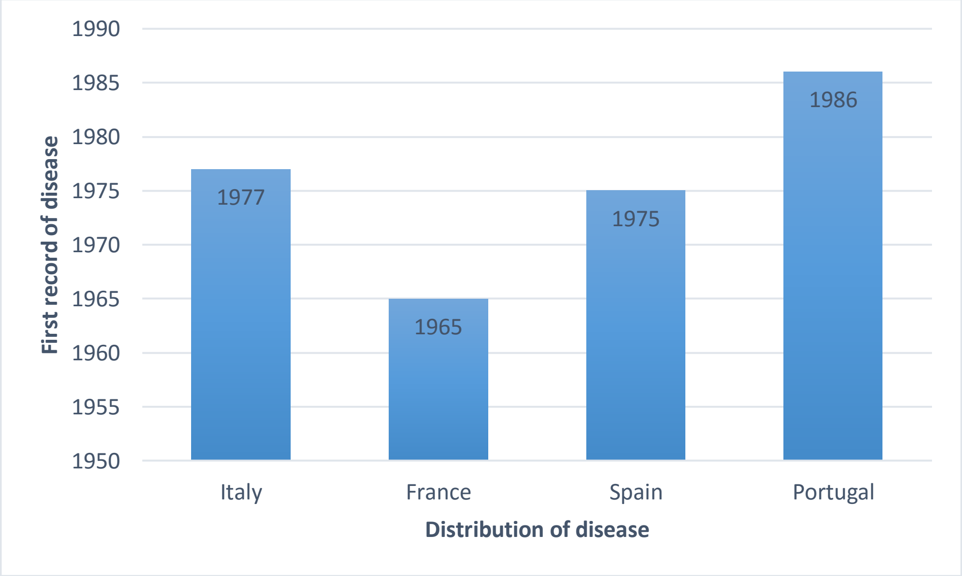

Fig. 5 Years (EPPO, 2002) of first record of disease or pest in individual countries

5.2. *Bursaphelenchus xylophilus* (Steiner & Buhrer) Nickle

Synonyms: *Aphelenchoides xylophilus* Steiner & Buhrer
Bursaphelenchus lignicolus Mamiya & Kiyohara

Taxonomic position: *Nematoda: Aphelenchoididae*

Common names: Pine wood nematode, pine wilt disease

Bursaphelenchus xylophilus, the pine wilt nematode, is the causal agent of pine wilt disease. Native to North America where it is not considered a serious pest, the nematode is a major threat to Asian and European pine forests and has resulted in extensive tree mortality in countries where it has been introduced (EPPO/CABI, 1997).

Continent of origin

B. xylophilus originated in North America (EPPO/CABI, 1997).

Identification

B. xylophilus shows the general characters of *Bursaphelenchus* spp.: lips high and offset; weakly developed stylet with reduced basal knobs; median bulb well developed; dorsal oesophageal gland opening inside median bulb. In the female, the post-uterine sac is long. In the male, the tail is curved ventrally, conoid and has a pointed terminus. A small bursa is situated terminally. The spicules are well developed, with a prominent rostrum (EPPO/CABI, 1997).

B. xylophilus can be distinguished by the simultaneous presence of the following three characters: in the male the spicules are flattened into a disc-like structure (the cucullus) at their distal extremity. In the female the anterior vulval lip is a distinct overlapping flap and the posterior end of the body is rounded in nearly all individuals. This last character separates *B. xylophilus* from *B. mucronatus*, a non-pathogenic species in which the female has a mucronate posterior end. However morphological differentiation between *B.*

mucronatus and populations of *B. xylophilus* with mucronate tails in North America is very difficult (EPPO/CABI, 1997).

Before any symptoms appear in trees suspected of being infested, the reduction of oleoresin production can be detected by making a hole of 10-15 mm in diameter through the bark and cambium (Oda, 1967). Nematodes can be extracted from trees showing symptoms by taking trunk cores and then soaking the cores in water for several days; the nematodes will emerge from the wood into the water. Nematodes can be extracted from small chips of infested wood by use of the standard nematode extraction technique (the Baermann funnel) (EPPO/CABI, 1997).

Hosts

B. xylophilus is found mainly on *Pinus* spp. Apparently, the dead wood of all species of *Pinus* can act as a substrate for the development of *B. xylophilus*. However, only a limited number of species is susceptible to attack as living trees; the Far Eastern species *P. bungeana, P. densiflora, P. luchuensis, P. massoniana* and *P.thunbergii* (in their native habitats), and the European species *P. nigra* and *P. sylvestris* (planted in North America) and *P. pinaster* (planted in China) are the only species known to be killed by pine wilt disease as mature trees in the field. Many other species have been found to be damaged or killed by the nematode but only under experimental conditions (mainly as seedlings in glasshouses) (EPPO/CABI, 1997).

Other conifers can also act as hosts (primarily *Larix*, *Abies* and *Picea*) but reports of damage are rare. Isolated cases of death of *Picea* and *Pseudotsuga* due to this nematode have been reported in the USA (Malek & Appleby, 1984).

Within the EPPO region, *P. sylvestris* would be the species of *Pinus* most at risk in northern and central areas, whereas *P. nigra* and *P. pinaster* would be threatened in central and southern areas (EPPO/CABI, 1997).

Biology

B. xylophilus is known to have two different modes in its life cycle, a propagative mode and a dispersal mode (Wingfield, 1983). In both cases, the nematodes are transmitted from one host to the next by species of *Monochamus*. In the propagative life cycle, fourth-stage larvae of the nematodes are transmitted to recently dead or dying trees during oviposition by the female vector. The nematodes leave the beetle and enter the tree through the hole in the bark cut by the vector to lay its eggs. Within the wood the nematodes feed on the hyphae of fungi (usually *Ceratocystis* spp.) also transmitted to the wood by ovipositing beetles. Immediately on entering the wood the larval nematodes moult to adult and begin laying eggs. The population is composed of males, females and four larval stages in this propagative stage of rapid multiplication (EPPO/CABI, 1997).

At a certain time after the initial invasion by the nematodes, the population ceases to multiply and begins to decline. A different type of third-stage larva is produced; this is called the "dispersal third-stage larva" (Mamiya, 1983), although it is more correctly a survival stage, being capable of resisting adverse conditions. It is likely that the onset of the dispersal mode is in reaction to a reduction in the availability of food, when the fungus has fully exploited the wood. The "dispersal" larvae gather in the wood surrounding the pupal chamber of the *Monochamus* vector, possibly under the influence of substances diffusing from the developing pupa. Close to the time of emergence of the beetle, the nematodes moult into the special fourth-stage larvae, called the "dauer larvae". Fungal hyphae also develop around the pupation chambers. The fungus forms long-necked perithecia projecting into the chamber, and the nematodes gather at the tips of the perithecia. When the young adult beetle emerges, it brushes against the perithecial necks, picking up the nematodes which settle below the elytra and, in particular, in the tracheae. The immature adult beetle then flies from the wood carrying nematodes. (EPPO/CABI, 1997).

The life cycle could be considered to be the "normal" life cycle of *B. xylophilus* and is similar to that of most other *Bursaphelenchu*s spp. that have phoretic relationships with forest beetles. In North America, it is presumably the most common condition (Wingfield, 1983). On the other hand, in Asia, and also in North America wherever the nematode comes into contact with non-native or susceptible species of *Pinus*, a different type of transmission to tree hosts predominates. Under these conditions, the nematodes are transmitted from young adult beetles shortly after emergence from their pupal chambers, when they fly to feed on young *Pinus* shoots. The nematodes enter the shoots through the feeding wounds. Why this form of transmission occurs only on certain *Pinus* species is not fully understood, but it is presumably because *Pinus* species native to the area where *B. xylophilus* occurs have developed physical or biochemical barriers to prevent direct invasion to healthy tissues (EPPO/CABI, 1997).

In the young *Pinus* shoots, *B. xylophilus* then multiplies in the resin canals, attacking their epithelial cells. About 3 weeks later, the tree shows first symptoms of 'drying out', in the form of reduced oleoresin exudation. The nematodes can now move freely throughout the dying tree. As a consequence of the reduction of its defence mechanisms (e.g. reduced oleoresin), the tree becomes attractive to adult insects which gather on the trunks to mate. At this stage, intensified wilting and yellowing of the needles is seen. The tree dies 30-40 days after infection, and may then contain millions of nematodes throughout the trunk, branches and roots. The remainder of the life cycle is similar to that described for transmission during oviposition, as the nematodes locate the pupa of *Monochamus* just prior to emergence (EPPO/CABI, 1997).

In the laboratory, *B. xylophilus* can be maintained on fungal cultures. It reproduces in 12 days at 15°C, 6 days at 20°C and 3 days at 30°C. Egg-laying starts on the 4th day after hatching, and the eggs hatch in 26-32 h at 25°C. The temperature threshold for development is 9.5°C (EPPO/CABI, 1997).

Symptoms and damage

The first indication of the presence of nematodes in the tree is a reduction of oleoresin production. Transpiration from the leaves decreases and later stops completely. The first obvious external symptom is the yellowing and wilting of the needles, leading to eventual death of the tree (Mamiya, 1983). The wilting may first appear on only one branch ("flag") although the whole tree may later show symptoms (Malek & Appleby, 1984). Note that "flagging" can also result from *Monochamus* feeding on the shoots. (EPPO/CABI, 1997).

Fig. 6 *Bursaphelenchus xylophilus* (pine wilt nematode) damage (Forestryimages, 2016)

Dispersal and introduction pathways

Within the wood tissues the nematodes can move actively and can leave one piece of wood to move into an adjoining piece. Without their vectors, however, they are incapable of moving from one host tree to another. Adults of the vector beetles can fly actively and a peak of flight activity is reached about 5 days after emergence. Beetles have been recorded as capable of flying for up to 3.3 km, but, in most cases, dispersal is only for a few hundred metres (Kobayashi et al., 1984).

Infested wood is the most probable means of international transport of *B. xylophilus*, and the species has been intercepted on a number of occasions on sawn wood, round wood and wood chips imported into the EPPO region from the USA and Canada (EPPO/CABI, 1997).

The most likely pathway of introduction of *B. xylophilus* is when imported together with vector insects which may carry the nematodes to coniferous trees. Such insects can only survive if the wood has a sufficient moisture content, greater than that needed by the nematode. The larger the pieces of timber, the longer insects are liable to survive, and therefore round wood and sawn wood present a greater risk than wood chips. Wood chips can have a high moisture content, allowing ready nematode survival, but the processing undergone in their preparation reduces the possibility of vectors surviving (EPPO/CABI, 1997).

Whether introduced with or without a vector insect, it is still necessary for long-term establishment for the nematode to find a means of coming into contact with a native vector, and this can probably only be achieved if the nematode first invades wood which contains larvae or pupae of a potential vector. Nematodes can move very actively from wood chips or sawdust, and the connection with the vector could be made if such material were to come into contact with tree stumps or cut logs; within the wood processing industry, the same means of transport is sometimes used for collecting both imported and local wood material (McNamara & Støen, 1988).

Economic impact

Pine wilt disease was first reported in Japan in 1913 in the Nagasaki region, but the causal agent was only identified as *B. xylophilus* in 1972 (Mamiya & Kiyohara, 1972). The symptoms were first attributed to wood-boring insects, which are found abundantly on infected trees, but it was then found that first symptoms precede attack by the insects. The disease then began to spread northwards causing very severe losses throughout the country. Over a million m3 of wood were being lost per year at the end of the 1940s, but a campaign for destroying infected trees then brought this figure below 500 000 m3 per year (still a substantial loss). However, since industrialization has reduced the availability of manpower for the forests, and since wood has been replaced by oil as a fuel, infected trees are again remaining standing as reservoirs of the nematode. In consequence, the loss curve turned sharply upwards from 1970 and now even exceeds 2 million m3 per year. Almost all of the Japanese archipelago is affected, from the Ryukyu Islands in the far south, where *P. luchuensis* is very susceptible, to the northern part of the island of Honshu, with much colder climates where the mean annual temperature is 10-12°C. It seems probable that this northward spread is due to heavy population pressure from the south. Only the most northern island of Hokkaido is still not affected. However, it is clear that serious pine wilt disease is associated with higher temperature and occurs only where the mean summer temperatures exceed 20°C (Rutherford et al., 1990).

In 1979, *B. xylophilus* was associated with death of *Pinus* in Missouri (USA), primarily of *P. sylvestris* growing in amenity plantings (Malek & Appleby, 1984), and, in North America in general, losses arise almost exclusively among exotic species and in artificial forest ecosystems like ornamental conifer plantings, wind-breaks and Christmas tree plantations. *B. xylophilus* is widespread in natural coniferous forests but significant losses are not recorded (EPPO/CABI, 1997).

Control measures

So far it has proved impossible to control *B. xylophilus* once introduced into a tree. Therefore, control of pine wilt disease in Japan has concentrated on a combination of cultural practices, in removing dead or dying trees from the forest to prevent their use as a source of further infection, and the control of the vector beetles by insecticidal treatment. The Japanese government has spent large amounts of money on extensive control programmes involving aerial spraying and removal of diseased trees (Ikeda, 1984). In the case of individual trees with a particular significance (e.g. religious), infection can be prevented by a prophylactic chemical treatment. Research is continuing to try to find alternative means of control, such as biological control agents for both nematodes and vectors, insect attractants, breeding of resistant *Pinus* clones, and inducing resistance by inoculation of non-pathogenic strains of *B. xylophilus* (EPPO/CABI, 1997).

EPPO's recommendations to prevent the introduction of *B. xylophilus* and its vectors cover plants and wood of all conifers, apart from *Thuja plicata*, from countries where the nematode occurs. It is recommended that coniferous plants should be prohibited but that countries may choose whether to prohibit wood. If not prohibited, wood must have been heat treated to a core temperature of 56°C for 30 minutes. In the case of packing wood (crates, dunnage etc.), kiln drying could be accepted instead, whereas for particle wood, the alternative of fumigation is also acceptable (EPPO/CABI, 1997).

Several quarantine treatments for wood chips have been proposed, such as steam/heat treatment or fumigation in transit with phosphine (Kinn, 1986). Such treatment can be expensive in relation to the value of the commodity. The main risk of infection of cut timber is in the period between felling and removal from the forest. Cut logs can be protected from oviposition (and thus from introduction of nematodes) by chemical treatment but such treatment is more effective in killing the insect larvae already present under the bark; in the latter case, the treatment is too late to prevent nematode infection. Other means of reducing the risk of attack are to cover logs after felling, to leave trap logs exposed nearby and to ensure that the felling is conducted outside the flight period of the beetles (Dominik, 1981; Raske, 1973).

The only known effective treatment for wood already infected with *B. xylophilus* and its vectors appears to be heat treatment, in which all parts of the wood reach a temperature of 56°C for at least 30 min; commercial kiln practices normally achieve this. Inspection of timber does not always reveal the presence of insect larvae or pupae, which can be hidden within internal galleries (EPPO/CABI, 1997).

Distribution and years of first finding disease or pest in individual countries

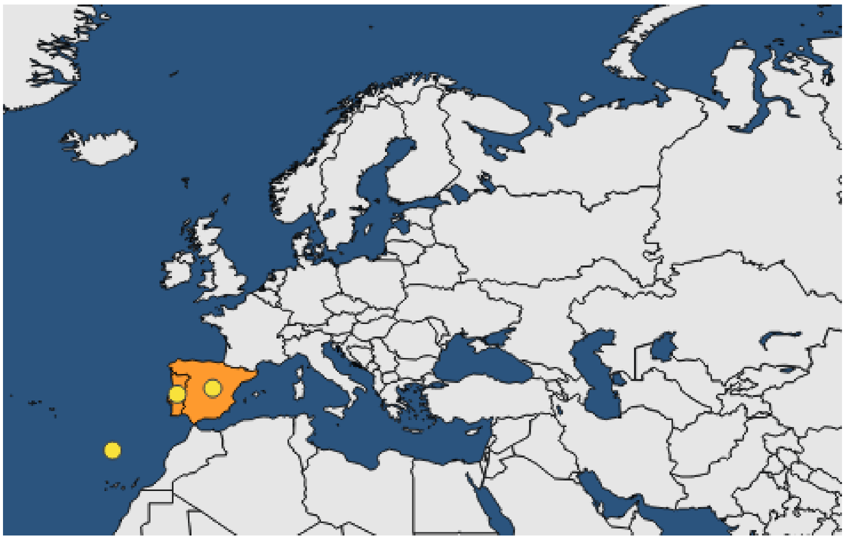

Fig. 7 Distribution of *Bursaphelenchus xylophilus* in Europe (EPPO, 2016)

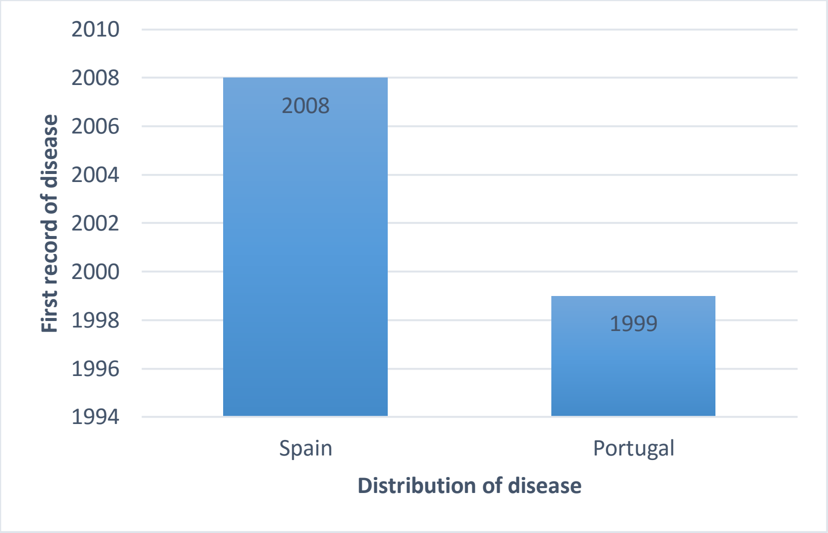

Fig. 8 Years (EPPO, 2002) of first record of disease or pest in individual countries

5.3. *Gibberella circinata* Nirenberg & O'Donnell

Anamorph: *Fusarium circinatum* Nirenberg & O'Donnell

Other scientific names: *Fusarium subglutinans* f. sp. *pini* Hepting
Fusarium lateritium f. sp. *pini* Hepting

Phytosanitary categorization: EPPO A2 action list no. 306

Taxonomic position: *Fungi: Ascomycota: Hypocreales: Nectriaceae*

Common names: pitch canker of pine

Continent of origin

The origin and spread of *G. circinata* seems obscure. Older records from various parts of the world may be based on inadequate identification. Outside America, records in Japan and South Africa are considered to result from introduction. The fungus is probably native in North America, but some US states (and Mexico) record its introduction (EPPO/CABI, 1997).

Identification

In culture, *G. circinata* produces macro- and microconidia (Nirenberg & O'Donnell, 1998). Macroconidia are typically 3-septate, with slightly curved walls, 32–48 × 3.3–3.8 µm, resembling those of numerous other anamorphs in the form-genus *Fusarium*. Microconidia, typically single-celled, ovoid (or nearly oval or allantoid), are borne in false heads on aerial polyphialides. The proliferation of microconidiophores, coupled with a slight twisting of the aerial mycelium on which they are borne, gives a distinctive colony morphology. Aerial mycelium is white, or slightly violet. Colonies are frequently sectored. These characters do not clearly separate *G. circinata* from other fungi with anamorphs of the *Fusarium subglutinans* group (EPPO/CABI, 1997).

Perithecia are also readily produced in culture: dark purple to black, ovoid to obpyriform, 332–396–453 µm high and 288–337–358 µm wide (Britz et al., 2002), cylindrical asci 88–100 × 7.5–8.5 µm, released by oozing; ascospores 8, 1-septate, ellipsoidal to fusiform. This description is close to that of many related species (EPPO/CABI, 1997).

Identification relies on the presence of characteristic symptoms (amber-coloured, resin-soaked appearance of tissue beneath the bark) and isolation and culturing of the fungus. Correll et al. (1991) describe a suitable selective medium. A fungus isolated from typically symptomatic material of infected pine and matching the above description should be *G. circinata*. Final confirmation can be obtained by re-inoculation to pine (Gordon et al., 1998a).

Hosts

G. circinata infects only *Pinus spp*. In North America, its main native hosts are *Pinus elliottii, Pinus palustris, Pinus patula, Pinus radiata, Pinus taeda, Pinus virginiana*. It has also been recorded on over 30 other *Pinus spp*., including the European and Mediterranean species *Pinus halepensis, Pinus pinaster* and *Pinus sylvestris*, various North American species planted in Europe such as *Pinus contorta* and *Pinus strobus*, and various Asian species (e.g. *Pinus densiflora, Pinus thunbergii*). There is an isolated record on *Pseudotsuga menziesii*, not apparently associated with any damage (EPPO/CABI, 1997).

Biology

G. circinata infects the branches of pine, causing a bark canker. Since perithecia have not been observed in nature, it is presumed that ascospores are not of great importance for infection of the host. Most infection is by macroconidia and/or microconidia, carried by wind or insects. Bark-feeding insects (e.g. *Pityophthorus, Ips, Conophthorus*) commonly breed in affected branches and emerging adults commonly carry the pathogen. These insects may also provide a wound suitable for infection (Storer et al., 1997).

Moisture is required for an infection to occur, and infections appear to be associated with locations or seasons where atmospheric moisture is readily available and temperatures are relatively warm, such as in the south-eastern USA during summer thunderstorms (Dwinell et al., 1985). In California, the disease is most severe in close proximity to the coast. The distribution of the disease also suggests that cooler temperatures are restrictive (Gordon et al., 2001). At moderate temperatures, the pathogen can survive for 1 year or more in infected wood (EPPO/CABI, 1997).

G. circinata can infest pine seeds internally or be present as a superficial contaminant (Barrows-Broaddus & Dwinell, 1985; Storer et al., 1998), but it is not known how this infestation occurs. Seed-borne inoculum can infect and kill pine seedlings (EPPO/CABI, 1997).

Symptoms and damage

G. circinata may be seed-borne, and pine seedlings may be attacked by the fungus in infected seeds, which typically rots the hypocotyl at or near the soil-line so that the seedling collapses. Seedlings may also be infected by soil-borne inoculum. In either case, the symptoms are not particularly distinctive, differing little from those caused by other damping-off pathogens. Root infections are most often observed on seedlings in nurseries or Christmas tree farms, but can also occur on exposed roots of larger trees in landscape plantings. In Christmas tree farms, the pathogen may extensively colonize the root system, causing a brown discoloration and disintegration of the cortex. Above-ground symptoms are generally not apparent until the pathogen has reached the root crown and girdled the stem. This results in a uniform loss of colour in the foliage, which fades first to a dull green, then yellow and finally brown. Removal of the bark on the main stem near the soil-line may reveal resin-soaked tissue with a honey-brown to dark-brown discoloration (pitching) (EPPO/CABI, 1997).

Branches and stems of pine trees of any age may also be infected. Infection usually begins as a canker and dieback of small branches. Needles wilt above the infection site (becoming chlorotic, then red and brown) and resin accumulates on the branch surface. Repetition of these symptoms throughout the canopy may lead to extensive dieback. The trunk and larger branches may in due course be infected, producing copious amounts of resin and accelerating the decline of the tree. Girdling of the main stem may lead to death of the tree (EPPO/CABI, 1997).

Fig. 9 *Gibberella circinata* (pitch canker) symptoms (Forestryimages, 2016)

Dispersal and introduction pathways

G. circinata is spread locally by wind and insects, but its rate of spread in newly infested areas does not appear to be very high. Over long distances, it can be carried by consignments of pine seeds, or by plants for planting of pine. In principle, it could be carried by infected wood, but this is most likely for particle wood made from small branches and their bark, in which spores of the fungus can survive. Round wood and sawn wood, especially if debarked, are less likely to carry the fungus. In view of the substantial trade in pine wood, and the limited distribution of the fungus, it seems unlikely that this has been a significant pathway in practice (EPPO/CABI, 1997).

Economic impact

G. circinata is a chronic problem in the south-eastern USA, where it affects production in plantations, nurseries (Barnard & Blakeslee, 1980) and seed orchards (Dwinell et al., 1981; Dwinell et al., 1985), but does not significant impact on native forests. It regularly adds to the cost of production but does not result in large financial losses in most years. Most southern pines are affected to some extent, including *P. taeda*, which typically sustains only minor damage and *P. elliottii*, which can be more severely affected (major epidemics in Florida in the 1970s, with an estimated loss of between 13.6 and 30.7 million cubic feet annually in the period from 1974 through 1979; Dwinell et al., 1985). However, the use of less susceptible genotypes and changes in silvicultural techniques have greatly reduced the impact since that time (EPPO/CABI, 1997).

Since *G. circinata* was introduced into California in 1986, it has caused damage and mortality of *P. radiata* in urban plantings and in native forests. Costs of tree removal and replacement may eventually amount to several million USD in severely affected areas (Templeton et al., 1997). Other *Pinus* spp. are also affected. Since its introduction into South Africa, *G. circinata* has caused serious problems in seedling nurseries (Viljoen et al., 1994, 1995). In Chile, it occurs in nurseries, but introduction is too recent for the impact to be clear (EPPO/CABI, 1997).

Control measures

In south-eastern USA, the *G. circinata* problem is addressed by controlling the disease as far as possible in well managed seed nurseries, using less susceptible planting material, and preventing the spread of inoculum from infested areas by sanitary precautions (Dwinell et al., 1985). Chemical and biological control methods are ineffective or uneconomic, and have at present no particular role to play (except possibly seed treatment with fungicides). Nurseries and Christmas tree farms should be carefully sited. Clean, preferably local, seeds should be used. Wounding and over fertilization should be avoided. In general, good hygiene should be maintained, and precautions taken for movement of equipment and soil. In plantations, infected material (logs, firewood) should not be moved: chipping or debarking may be used to reduce the risk that the pathogen is spread by insects. Insecticide use to limit spread by insects is not environmentally appropriate (EPPO/CABI, 1997).

Large-scale studies of American *Pinus* spp. (Hodge & Dvorak, 2000) have shown considerable differences between species in susceptibility. *P. radiata* was very susceptible, while pines of subsection Oocarpa were extremely resistant. Within *P. radiata,* variation in susceptibility has been observed in California populations of both planted and naturally regenerated trees (Storer et al., 1999, 2002), and similar variation is found among species from southern USA: *P. elliottii* (Dwinell & Phelps, 1977) *P. taeda* and *P. virginiana* (Kelley & Williams, 1982; Kuhlman et al., 1982; Barrows-Broaddus & Dwinell, 1984).

If individual valuable amenity trees are affected, pruning with appropriate hygienic precautions can restore the value of the tree. In the case of isolated infected trees in an otherwise pest-free area, it may be more appropriate to remove and destroy the tree. In general, in affected areas, it is preferable to use trees other than *Pinus*, or less susceptible *Pinus* spp., in amenity plantings. For example, in California, several exotic pine species that are suitable for a Mediterranean climate are less susceptible than the native species (Gordon et al., 1998a, b).

G. circinata has shown its capacity to spread to new areas (California, Mexico, South Africa, and Chile). It could readily be further spread by international movement of infected *Pinus* seeds. Unconfirmed records in the EPPO region may indeed be associated with the import of infected seeds, from which the disease did not establish. The areas to which it has spread have Mediterranean-type climates, so that, within the EPPO region, the Mediterranean area is clearly at risk since *Pinus* spp. are widely planted there. The disease probably presents the greatest danger to forest nurseries. Damage to plantations or native forests seems more likely to arise in a warmer and more humid climate than exists anywhere in the EPPO region (EPPO/CABI, 1997).

G. circinata was added in 2002 to the EPPO A1 action list of pests, and endangered EPPO member countries are thus recommended to regulate it as a quarantine pest. Seeds of *Pinus* spp. imported from countries where *G. circinata* is present should be free from the pest. Seed-testing methods are presented by Anderson (1986) and Correll et al. (1991). There is a certain risk of introduction with soil but, in general, most EPPO countries prohibit the import of soil, and restrict the import of plants with soil (OEPP/EPPO, 1994), from other continents. These measures should be effective against *G. circinata*. Host plants for planting should be free from the pest (EPPO/CABI, 1997).

Distribution and years of first finding disease or pest in individual countries

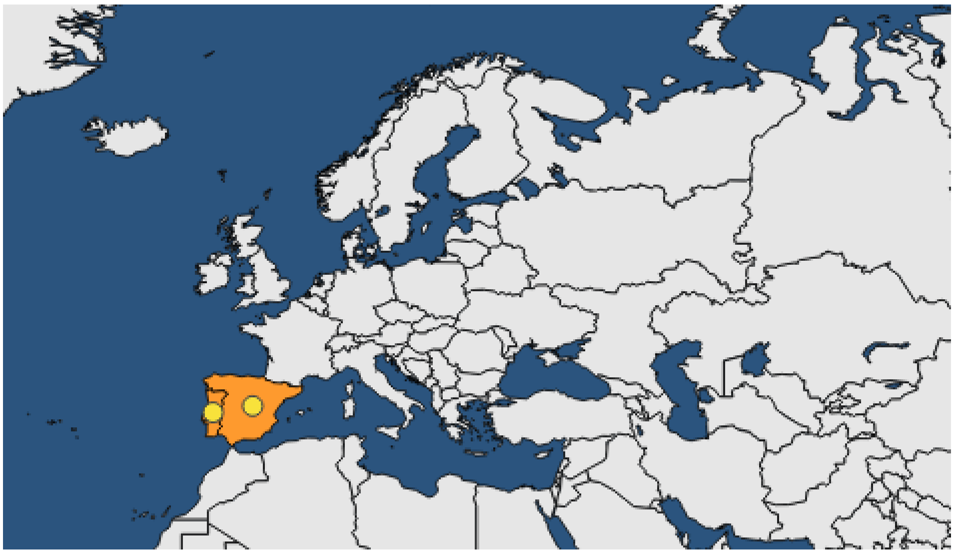

Fig. 10 Distribution of *Gibberella circinata* in Europe (EPPO, 2016)

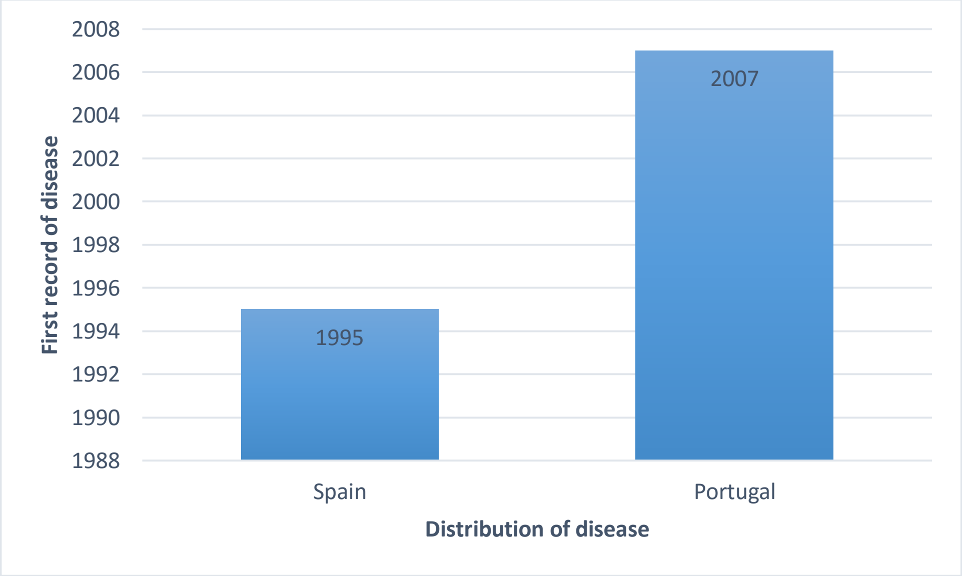

Fig. 11 Years (EPPO, 2002) of first record of disease or pest in individual countries

5.4. *Mycosphaerella dearnessii* M.E. Barr

Synonyms: *Scirrhia acicola* (Dearness) Siggers
Systremma acicola (Dearness) F.A. Wolf & Barbour
Anamorph: *Lecanosticta acicola* (Thümen) H. Sydow
Synonyms: *Lecanosticta pini* H. Sydow
Septoria acicola (Thümen) Saccardo

EPPO A2 list: No. 22

Taxonomic position: *Fungi: Ascomycetes: Dothideales*

Common names: Brown spot needle blight

Continent of origin

The fungus appears to be of American origin and has spread to other continents (EPPO/CABI, 1997).

Identification

Acervuli olive to dark-green, subepidermal, innate, becoming erumpent and stromatic, elliptical to elongate, arranged parallel to the long axis of the needle, 100-600(-750) x 80-120 µm, opening by a longitudinal slit. Excessive stromatal development results in loculate acervuli, often misinterpreted as pycnidia. Conidia extremely variable in form, subhyaline to dark-brown, echinulate to verrucose or tuberculate, thick-walled, straight to curved, with one to five septa, fusiform to cylindrical, (10-)12-45(-55) x 2-4.5 µm, with a rounded apex and truncate base. Spermogonia of the *Asteromella* synanamorph present in uniloculate or multiloculate stromata; spermatia subhyaline to pale-green, rod-shaped, 2-4 x 0.8-1.3 µm. Ascostromata scattered, linear, innate, subepidermal, becoming strongly erumpent, black, invariably multiloculate (two to 18 locules), 400-850(-1200) x 120-250 µm. Ascospores hyaline, smooth, one-septate, usually four-guttulate, oblong to cuneate, 7.5-14 x 2-3.5 µm, bluntly rounded at one end, tapering and fusiform at other (EPPO/CABI, 1997).

Hosts

Potentially all species of *Pinus* are hosts. Of most importance in the EPPO region are: *P. contorta, P. halepensis, P. muricata, P. palustris, P. pinaster, P. pinea, P. radiata, P. strobus, P.* sylvestris and *P. taeda*. Certain species, such as *P. banksiana*, have been shown to be highly resistant (Skilling & Nicholls, 1974), whilst traces of infection were noted on *Picea glauca* artificially exposed to a heavy spore inoculum (EPPO/CABI, 1997).

Biology

In northern USA, rainfall and temperature are the critical factors for spore dispersal and infection, which occur from June to September (Skilling & Nicholls, 1974). Spores are released only during rainy weather and never at low temperatures (near 2°C). The major infection period is from late June to early July and moisture on the needle surface is necessary for spore germination. The conidia produce appressoria and penetration occurs via stomata. The incubation period is variable depending on host type and age: from 1-2 months on young needles to 4-7 months on older foliage. Acervuli develop and mature in late August and, although conidia are released in September, infection is restricted, probably due to increased needle resistance. The disease cycle renews the following summer when the overwintering fruiting bodies release conidia as temperature and rainfall increase. However, in warmer, less seasonal climates in Central America, the conidial cirri remain on the needle for many months and it is significant that the conidia in lowland tropical areas are considerably more robust (large, thick-walled, heavily pigmented and ornamented) than those found in high-altitude, cloud-forest localities (Evans, 1984). It is uncertain whether this variation is determined environmentally or genetically (EPPO/CABI, 1997).

Acervuli and ascostromata also develop and mature on cast needles and constitute an important source of interseasonal survival (EPPO/CABI, 1997).

Symptomps and damage

On *Pinus sylvestris* in the USA, symptoms initially appear in August-September on older needles in the form of yellow, resin-soaked spots, approximately 3 mm in diameter, which later become dark-brown in the centre with a prominent yellowish-orange border. These lesions coalesce and infected needles typically die back; eventually the whole needle turns brown and falls prematurely in late autumn to early winter. In lightly infected plantations, only the 2- and 3-year-old needles are cast, but as infection increases in severity, the current-year needles may also be shed. Over several years, this may result in branch and tree death. These symptoms can be confused with those of other needle pathogens, including *M. pini* and several *Lophodermium* and *Ploioderma* species. Final confirmation can only be made when the conidia mature (EPPO/CABI, 1997).

Fig. 12 Attack of *Mycosphaerella dearnessii* (*Lecanosticta acicola*) on *Pinus mugo* (EPPO, 2002)

Dispersal and introduction pathways

Under moist conditions, the conidia exude from the acervulus in a mucilaginous, green, wedge-shaped cirrus and are dispersed by rain-splash, this being the main means of tree-to-tree dispersal. The sticky conidia can also be spread by insects and on forestry equipment, especially shearing tools (Skilling & Nicholls, 1974), allowing inter-plantation dissemination. Wind-borne ascospores, produced abundantly in southern USA

(Kais, 1971), also allow long-distance dispersal, but they are never formed in the northern states (Skilling & Nicolls, 1974). Long-distance movement is most likely to be on infected nursery stock and this is probably how the pathogen spread northwards from the southern USA (Skilling & Nicholls, 1974). Intercontinental movement is possible in seed lots contaminated with needle debris (EPPO/CABI, 1997).

Economic impact

In North America, *M. dearnessii* is an important pine foliage disease, particularly of *P. palustris* in south-eastern USA, causing severe growth checks to seedlings and young trees (Gibson, 1979); it is the main limiting factor to the establishment of this species throughout its natural range. Skilling & Nicholls (1974) report its spread and increasing damage to Christmas tree plantations (*P. sylvestris*) in northern USA (Wisconsin, Minnesota), making the affected trees unsaleable. Since the market value for this crop in 1974 was put at 70 million USD, the economic losses may be considerable (EPPO/CABI, 1997).

In Central America the pathogen is endemic and omnipresent in native pine forests (*P. caribaea, P. oocarpa, P. maximinoi, P. patula*) from sea level to cloud forest (2000 m altitude) but is never associated with a serious needle blight condition (Evans, 1984). Gibson (1979), on the evidence of its spread and distribution in the USA, considered *M. dearnessii* to be highly adaptable to new hosts and environments and therefore a major threat outside North America. This was corroborated by the finding of severely damaged *P. radiata* in the Altiplano of Colombia (Gibson, 1980).

Control measures

Cultural control is possible by controlled burning to destroy infected litter on the ground. Fungicide applications of chlorothalonil and Bordeaux mixture to nursery stock and young plantations, critically when the newly emerging needles are about half their total length, have been recommended (Skilling & Nicholls, 1974). When inoculum levels are high, a second spray 3-4 weeks later is advised and Kais (1975) reported that a schedule of four to seven treatments over a 6-month period during the height of the growing season in the USA (May-October) is necessary for short-term control in nurseries. Good control has also been noted with benomyl and maneb; Kais et al. (1986) used a 5% benomyl root treatment before planting.

EPPO recommends (OEPP/EPPO, 1990) that planting material of *Pinus* should come from an area free from *M. dearnessii*, and in addition that the place of production should have been found free. This requirement, appropriate for an A2 pest, was partly conditioned by the suggestion that *M. dearnessii* was more widespread in the EPPO region than previously thought. If the fungus is really restricted to a small area in Yugoslavia, more severe measures could be appropriate and will be discussed within EPPO. If *M. pini* is to be regulated at all, the existing measures for *M. dearnessii* would seem sufficient (EPPO/CABI, 1997).

Distribution and years of first finding disease or pest in individual countries

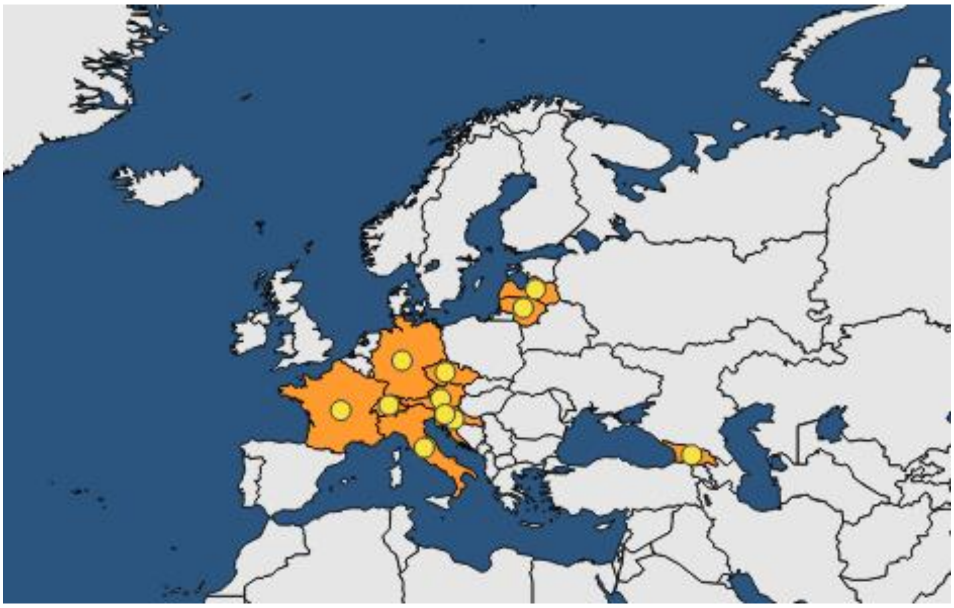

Fig. 13 Distribution of *Mycosphaerella dearnessii* (*Lecanosticta acicola*) in Europe (EPPO, 2016)

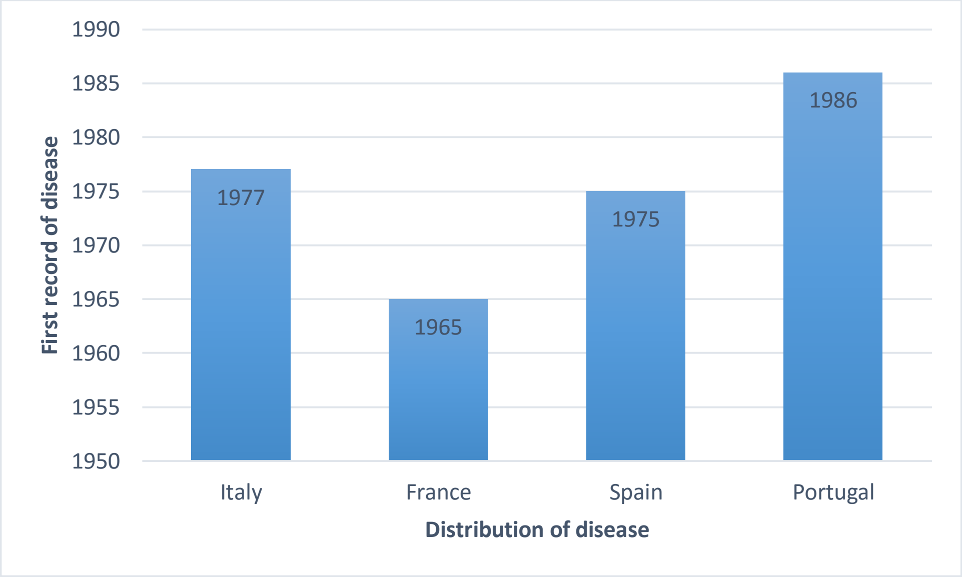

Fig. 14 Years (EPPO, 2002) of first record of disease or pest in individual countries

5.5. *Thaumetopoea pityocampa* Denis & Schiffermüller

Other scientific names: *Bombyx pityocampa* Denis & Schiffermüller; *Cnethocampa pityocampa*; *Thaumetopoea wilkinsoni* Tams

Taxonomic position: *Insecta: Lepidoptera: Thaumetopoeidae*

Common names: pine processionary caterpillar

Thaumetopoea pityocampa Denis & Schiffermüller, 1775 is considered the most destructive forest insect pest throughout the Mediterranean Basin. It is a tent-making caterpillar that feeds gregariously and defoliates various species of pine and cedar. Note the taxonomic status of this pest is under review. In Cyprus for example, *Thaumetopoea wilkinsoni* is the preferred scientific name though it is considered an eastern Mediterranean form (race) of *Thaumetopoea pityocampa* (EPPO/CABI, 1997).

Continent of origin

Native: Africa (North), Europe (southern), Near East. This pest is found in almost all the countries around the Mediterranean Sea with the exception of Egypt and Libyan Arab Jamahiriya (EPPO/CABI, 1997).

Identification

Eggs - the typical cylindrical egg masses range in length from 4 to 5 cm. They are covered with the scales of the female anal tuft, which mimics the pine shoots (EPPO/CABI, 1997).

Larva - the larvae develop through five instars, recognized by differences in head capsule size. The average head width of the 5th-instar caterpillar is 4.8 mm for the male and 3.4 mm for the female. The full-grown caterpillar is about 40 mm in length. The head capsule is black. The body of the 1st-instar caterpillar is dull apple-green. After the second moult, the caterpillar assumes its definitive appearance and the reddish dorsal urticating hair patches on each body segment appear arranged in pairs. The integument and hairs that clothe the body vary considerably with different provenances. In general, the integument is darker in colder areas and varies from dull bluish-grey to black. The pleural hairs vary from white to dark-yellow; the dorsal hairs range from yellow to dull orange (EPPO/CABI, 1997).

Pupa - pupation takes place in the soil in an oval, ochreous-white silken cocoon. The obtect pupae are about 20 mm in length, oval, and of a pale brownish-yellow colour that later changes to dark reddish-brown (EPPO/CABI, 1997).

Adult – the female moth has a wing-span of 36-49 mm. The wing-span of the male is 31-39 mm. The antennae are filiform in females and pectinate in males. Both have a hairy thorax. The abdomen is stout and its last segments are covered with a tuft of large scales; the abdomen of the male is brushy and sharp. The forewings are dull ashen-grey; the veins, margins and three transverse bands are darker. The hindwings are white, grey-fringed, with a characteristic dark spot in the anal region (EPPO/CABI, 1997).

Hosts

All species of *Pinus* and *Cedrus* and occasionally *Larix decidua* are attacked. Different species vary in susceptibility, partly because of physical factors such as needle morphology and dimensions, which determine suitability for oviposition (Demolin, 1969a). The following list places species in decreasing order of susceptibility: *Pinus nigra* var. *austriaca, Pinus sylvestris, Pinus pinaster, Pinus pinea, Pinus canariensis, Pinus halepensis, Cedrus atlantica, Larix decidua.* The host plant also influences larval development. Survival is greater on *P. sylvestris* and *P. nigra* var. *austriaca* than on *P. pinaster* and *P. halepensis*. In field trials in the Thessalonika area of northern Greece, larvae developed faster on *P. radiata* than on *P. pinea* (Avtzis, 1986). Such differences must not be assumed to apply outside the regions where they were observed. For example, *P. pinaster* is not much attacked in Corsica, southern France or Spain but suffers significant damage in Les Landes (France). *Cedrus* is undamaged in the Mont Ventoux area (France), but carries high population levels in North Africa (Geri, 1980).

Biology

The life cycle of *T. pityocampa* is normally annual but may extend over 2 years at high altitude or in northern latitudes for part or the whole of the population. The life cycle has two phases, the adult, egg and caterpillar being aerial and the pupa hypogeal (EPPO/CABI, 1997).

Development lasts 6 months under the most favourable conditions, but the 4th and 5th instars may be prolonged in the winter. The pupal stage can be prolonged considerably by diapause which adjusts, at a given location and within certain limits, to ensure constant adult emergence dates each year. Effects of altitude and latitude are discussed by Demolin (1969b), explaining the variation in behaviour at different sites.

Daily average sunshine plays an important role in defining the northern limit of distribution. Androic (1957) proposed the isohelia of 2000 h for the northern border; this is a good aproximation but varies with other climatic factors. Adult emergence dates are earlier at northern latitudes and at higher altitudes. In general, the emergence period lasts less than 1 month for vigorous populations and 1.5 months for weakened populations in regression. In most ecological conditions, the adults fly in July (EPPO/CABI, 1997).

A few hours after emergence and mating, the females oviposit on the nearest pines. They can, however, fly several kilometres, and quickly extend outbreaks over large areas. The eggs are laid in cylindrical masses in a helicoid arrangement around pairs of needles. A large proportion of the egg masses are generally laid on the peripheral shoots of the crown and contain 70-300 eggs, according to the feeding conditions of the caterpillars (Geri, 1980).

After 30-45 days the young larvae bore an opening in the chorion that can be recognized easily. They aggregate in colonies and spin silken nests which enlarge until the 4th instar when the definitive winter nest is built. In general, this is situated at the branch tips in the upper part of the crown. The caterpillars change colour at each moult and at the 3th instar urticating hair patches appear (Demolin, 1963). If the autumn is warm and sunny, the caterpillar can reach the 5th instar in early winter (EPPO/CABI, 1997).

The pupation 'processions', which occur in late winter and early spring, are a spectacular expression of the social behaviour. The caterpillar at the head of the procession is commonly a future female, leading the colony in a file searching for a suitable site to tunnel underground and pupate in the soil. The processions occur at temperatures of 10-22°C; at lower temperatures the colonies regroup and at higher temperatures they bury themselves wherever soil texture allows. Consequently, the cooler the soil, the more extensive is the spread of pupation sites at forest edges. At higher temperatures, the procession moves towards trunk bases in the shade of trees and may even bury itself close to the base of the original tree (Demolin, 1969c). A colony was observed to travel 37 m in 2 days in a cold mountainous area of Spain, the first 35 m being covered during the first day (Robredo, 1963).

Pupation takes place at a depth of about 10 cm and the pupae enter diapause, which always breaks 1 month before adult emergence. Some pupae or the whole colony may not yield adults in the year of pupation, the diapause period extending until the following year or longer (EPPO/CABI, 1997).

Symptoms and damage

On pines, it is easy to detect the presence of *T. pityocampa* by the cylindrical egg masses laid on the low branches of trees and by the early damage caused by the 1stand 2nd-instar caterpillars. They feed on the needles of twigs close to the silken nest; these partially eaten twigs remain on the tree with their brown and yellowing needles. During the winter, defoliation increases and the white nests stand out plainly (EPPO/CABI, 1997).

Fig. 15 Pine processionary moth *Thaumetopoea pityocampa* (Forestryimages, 2016)

Dispersal and introduction pathways

Females of *T. pityocampa* are able to fly some kilometres and the pupation processions may cover up to 37 m. Pupae may be transported with plants in attached growing medium which may be infested by buried insect pupae. Any plant cultivated near infested trees could harbour pupae (EPPO/CABI, 1997).

Economic impact

In the Mediterranean region, *T. pityocampa* is considered one of the most important forest pests (Cadahía et al., 1975) and is commonly observed in pine forests; it is also common in the cedar forests of North Africa. Defoliation damage is extremely serious in young reforested areas where it may lead to death of trees, directly or as a consequence of attack by bark beetles or other wood-boring insects. In mature forests trees are rarely killed but significant losses occur in volume growth (EPPO/CABI, 1997).

Calas (1897) estimated a 60% reduction in height growth of *Pinus nigra* trees. In young reforestations of *P. radiata*, Cadahía & Insua (1970), by controlling infestations on young trees, demonstrated losses of wood volume increment between 14 and 33% for light and high infestations, respectively. Bouchon & Toth (1971) showed by dendrochronological techniques that forests of *P. nigra* periodically subject to heavy attacks lost about 45% of their volume in 50 years. Lemoine (1977) found a reduction of 30% in circumference growth after an attack on *P. pinaster* in Les Landes (France). Defoliation of *P. nigra* subsp. *nigricans* on Mont Ventoux by *T. pityocampa* caused a missing growth ring the year after a severe attack, resulting in radial growth reductions of 35% (Laurent-Hervouet, 1986). In Corsica, radial growth losses on *P. nigra* subsp. *laricis* were 20% for the 28 years studied, but the attacks only took place every other year (EPPO/CABI, 1997).

Defoliation damage and the presence of caterpillars are important on amenity trees in recreational and residential areas, where defoliation may also cause severe deterioration and greater maintenance costs. In addition, the caterpillars have urticating hairs from the 3rd instar onwards (Demolin, 1963), which may cause allergies resulting in conjunctivitis, respiratory congestions and asthma (Ziprkowski & Roland, 1966). These effects occur not only when the caterpillars are present, but also during the following summer because of the persistence of allergenic hairs in the remains of winter nests. This problem not only affects recreational and residential areas but also hinders silvicultural operations and grazing in forests (Marti Morera & Barri Baya, 1959).

Control measures

Chemical and biological control treatments are mainly applied by ULV aerial spraying with rotary atomizers at 5 litres/ha, with petroleum oil or vegetable oils as solvents. Dosages of the active ingredients are as follows (Robredo, 1980; Robredo & Obama, 1987): 45-56 g/ha of the insect growth regulator (IGR) diflubenzuron; 1.7-2.6 g/ha of the pyrethroid cypermethrin; 0.65-1.00 g/ha of the pyrethroid deltamethrin; and different formulations of *Bacillus thuringiensis* at the rate recommended by each manufacturer. All larval instars are susceptible to these treatments, but the 4th and 5th instars need the highest dosages. At this stage of development, during the winter months, the impact of pyrethroids on the beneficial insect fauna is minimized (Robredo & Obama, 1991).

In small areas or at low population density, mechanical control is also recommended, by cutting and burning of winter nests. Sex pheromone traps may be used, both for monitoring and for mass trapping (Cadahía et al., 1975; Montoya, 1984; 1988).

The major parasitoids and predators of *T. pityocampa* are as follows (Biliotti, 1958; Biliotti et al., 1965; Cadahía et al., 1967; Demolin & Delmas, 1967; Demolin, 1969c; Du Merle, 1969).

On eggs: The parasitoids *Tetrastichus servadei* (Hymenoptera: Eulophidae), *Oencyrtus pityocampae* (Hymenoptera: Encyrtidae), *Trichogramma* sp. (Hymenoptera: Trichogrammatidae), *Anastatus bifasciatus* (Hymenoptera: Eupelmidae), and the predators *Ephippiger ephippiger* (Orthoptera: Tettigoniidae), *Barbitiste fischeri* (Orthoptera: Tettigoniidae) (EPPO/CABI, 1997).

On larvae: The parasitoids *Phryxe caudata* (Diptera: Larvaevoridae), *Compsilura concinnata* (Diptera: Tachinidae), *Ctenophora pavida* (Diptera: Tachinidae), *Erigorgus femorator* (Hymenoptera: Ichneumonidae), *Meteorus versicolor* (Hymenoptera:

Braconidae) and the predator *Xantandrus comtus* (Diptera: Syrphidae) (EPPO/CABI, 1997).

On pupae: The parasitoids *Villa brunnea* (Diptera: Bombyliidae), *V. quinquefasciata* (Diptera: Bombyliidae), *Coelichneumon rudis* (Hymenoptera: Ichneumonidae) (EPPO/CABI, 1997).

The most important diseases (Vago, 1958; Atger, 1964) are caused by the viruses *Borrelina* sp. and *Smithiavirus pityocampae*, the bacteria *Bacillus thuringiensis* and *Clostridium* sp., and the fungi (mainly on pupae) *Aspergillus flavus*, *Beauveria bassiana*, *Cordyceps* sp., *Metarhizium anisopliae, Paecilomyces farinosus, P. fumoso-roseus* and *Scopulariopsis sp.*

Plants for planting of the genera *Pinus* and *Cedrus* should be inspected for the presence of egg masses and caterpillar colonies of *T. pityocampa*. Likewise, nursery plants with attached growing medium should be inspected for the presence of pupae. Ideally, consignments of plants for planting, in particular those with attached growing medium, should come from an area found free, together with its immediate vicinity, from *T. pityocampa* (EPPO/CABI, 1997).

Distribution and years of first finding disease or pest in individual countries

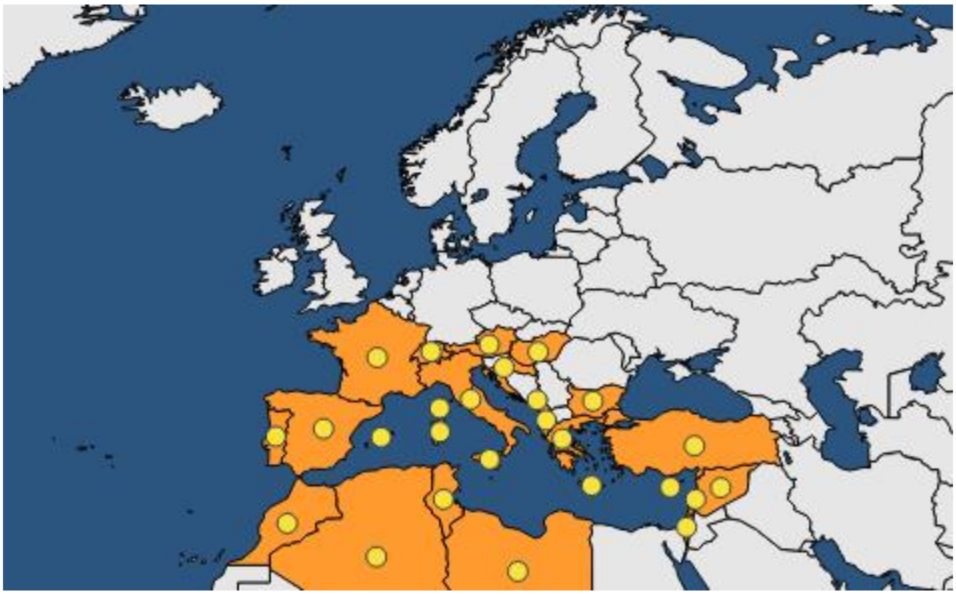

Fig. 16 Distribution of *Thaumetopoea pityocampa* in Europe (EPPO, 2016)

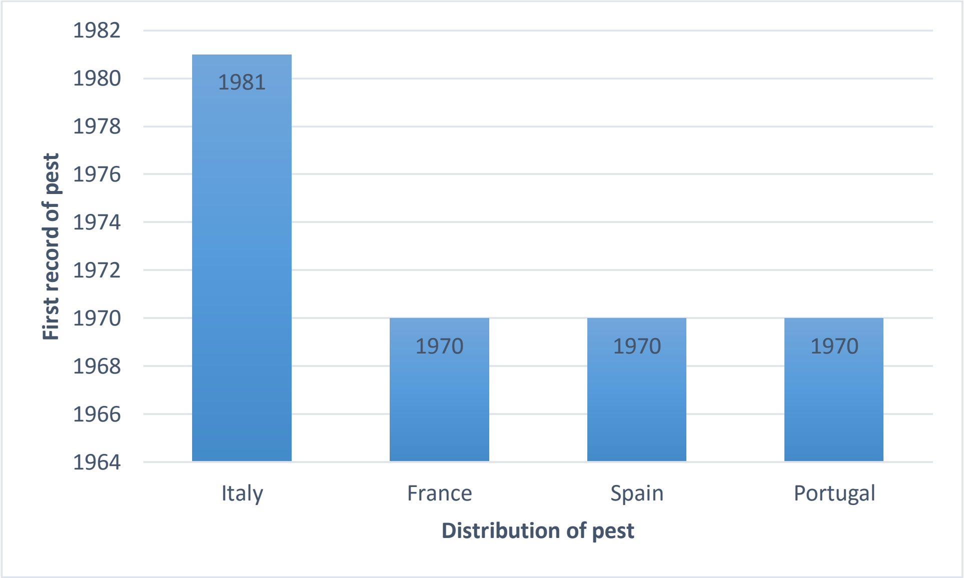

Fig. 17 Years (EPPO, 2002) of first record of disease or pest in individual countries

5.6. *Sphaeropsis sapinea* (Fr.) Dyko & B. Sutton

Synonyms: *Botryodiplodia pinea* (Desm.) Petr. 1922, *Diplodia conigena* Desm. 1846, *Diplodia pinastri* Grove 1916, *Diplodia pinea* (Desm.) J. Kickx F. 1867, *Granulodiplodia sapinea* (Fr.) M. Morelet & Lanier 1973, *Macrophoma pinea* (Desm.) Petr. & Syd. 1926, *Macrophoma sapinea* (Fr.) Petr. 1962, *Phoma pinastri* Lév., *Sphaeria pinea* Desm. 1842, *Sphaeropsis ellisii* Sacc. 1884, *Sphaeropsis pinastri* (Lév.) Sacc. 1884

Order and Family: *Lecanorales: Acarosporaceae*

Common names: Sphaeropsis blight, dieback of pine, Diplodia blight, Diplodia canker

Continent of origin

The origin of *S. sapinea* is unknown (CABI, 2014).

Identification

Features of *S. sapinea* have been described by Waterston (1970) and Sutton (1980). Pycnidial conidiomata are dark, solitary or aggregated, immersed to erumpent, ovoid (up to approximately 250 µm diam.), and ostiolate. When produced on autoclaved needles placed on culture media, conidiomata may be superficial. Necks of conidiomata may be elongated when produced on such needles or produced on or in media. Conidiogenous cells are 15-20 µm long. Conidia are ovoid to obovoid, rounded at the apex and may be blunt or truncate at the base, initially hyaline to yellowish becoming dark brown, usually 0-1 (but may be 3 or more) septate, thick-walled and approximately 30-45 x 10-16 µm. Conidia may be smooth or exhibit pits in conidial walls, a character that is highly variable (Swart et al., 1993). Microconidia that are hyaline, cylindrical with rounded ends, aseptate, 2.5-6 x 1-2 µm may also be produced (Wingfield and Knox-Davies, 1980).

Hosts

The main host species include all pine species (occurring in more than 35 species of genus *Pinus*), most of which on the *Pinus nigra, P. sylvestris, P. mugo. P. resinosa* and *P.*

ponderosa. But the occurrence was observed also in other conifers - *Abies* spp., *Larix* spp., *Picea* spp., *Pseudotsuga* spp., *Chamaecyparis lawsoniana, Cupressus* spp., *Cedrus deodoro, Araucaria cunninghamii* and *Thuja orientalis* (CABI, 2014).

Biology

The fungus overwinters in infected needles, cones, and woody tissue both on and beneath the tree. During wet weather from March through September, the fruiting bodies mature and release brown, oval spores. The spores are distributed by wind, water, animals, and people to the new growth, where they germinate on the needles. The fungus enters needles through the stomata or may enter branches through wounds caused by hail, insects, or pruning. The infection reaches the base of the needle in a matter of hours, leaving a small, brown lesion with a resin drop at the point of entry (CABI, 2014).

The fungus continues to grow into the twig and results in browning of the attached needles and subsequent cankers on the twig. Needle elongation is diminished after infection and dying shoots turn yellow-green before becoming straw colored. A girdling canker is produced when the disease reaches twigs, branches, and the main trunk. This canker may also exhibit resin flow. Tissue above the canker dies and major portions of the tree may be killed as a result (CABI, 2014).

In the second year, cones can become infected. While this does not harm the tree in any way, infected cones serve as a large reservoir of spores and contribute to the spread of the disease. This disease is present year-round. Douglas-fir and spruces have occasionally been observed with Diplodia tip blight. In most cases, this has been a result of unusual circumstances that have high disease pressure due to adjacent infected pines in windrows or nursery blocks (CABI, 2014).

Symptoms and damage

A few brown needles at the tip of the current season's growth are the first evidence of tip blight. These blighted needles are usually located on the lower branches of the tree. Needles that are in the early stages of development stop growing after infection and therefore appear stunted when compared to healthy needles. The number of blighted needles increases until the new growth for that year has been killed. This stunted and dead new growth on lower branches draws attention to the disease (CABI, 2014).

With a hand lens you may see minute black fruiting bodies (pycnidia) at the base of diseased needles, especially under the papery leaf sheath. These are sure signs of this disease (CABI, 2014).

Symptoms of tip blight are not restricted to the needles. Future tree growth is often reduced by damage to or death of terminal buds during infection. Twigs may be infected and become stunted or deformed. Stunted twigs may exude resin which traps blighted needles before they fall to the ground. Close examination of these twigs reveals cankers at the first branch whorl and often near the leaf scars of blighted needles. Enlargement of these cankers results in the girdling of the twig and rapid death of the branch tip. In most cases, these symptoms are not observed beyond the current season's growth (CABI, 2014).

Fig. 18 Diplodia blight *Sphaeropsis sapinea* symptoms (Forestryimages, 2016)

Dispersal and introduction pathways

Conidia of *S. sapinea* are released under moist conditions and disseminated by rain splash or wind-driven rain. Thick-walled conidia are very durable and could remain not germinated but viable for long periods on seed, debris, other plants, wood products, etc. Feci et al. (2002) demonstrated that conidia are carried by the cone bug *Gastrodes grossipes*, which is associated with cones of *Pinus nigra* in Italy.

In trade, the pathogen could be moved on or in cones, seed, any above- or below-ground organ of colonized seedlings or larger trees or their parts, logs, green lumber, and chips, bark or mulch. The ability of *S. sapinea* to persist asymptomatically on or in trees and tree parts provides additional potential for movement (CABI, 2014).

Economic impact

Whether or not losses have been expressed in economic terms, significant damage has been caused by *S. sapinea* in a variety of situations. Palmer and Nicholls (1985) reported loss of 35% of 1-year-old red pine seedlings in a Wisconsin nursery (loss of more than 1 million seedlings). In the same state, mortality of newly planted or established red pine saplings during a drought year was as great as 95% in some plantations. Lower stems and root collars frequently yielded *S. sapinea*, which proliferates to rapidly girdle and kill many trees under these conditions (Stanosz and Cummings Carlson, 1996; Stanosz et al., 2001). Nicholls and Ostry (1990) reported tree mortality in *Pinus banksiana and P. resinosa* plantations ranging from 2 to 51% in Minnesota and Wisconsin, and indicated that *S. sapinea* was consistently associated with dead trees. Trees in windbreaks also have been severely damaged in central USA (Peterson and Wysong, 1968).

Losses in the production of *Pinus radiata* in the southern hemisphere have been reported in more detail. Zwolinski et al. (1990a) quantified the losses resulting from a post-hail outbreak of dieback induced by *S. sapinea* affecting approximately 2000 ha of mostly *P. radiata* in the Cape Province of South Africa. The timber loss in compartments prematurely harvested was about 28% of the volume and 55% of the value of potential production. The percentage volume loss increased with plantation age, with the greatest losses recorded on good quality sites. Great losses were also documented for a *P. radiata* stand affected by *S. sapinea* in New Zealand (Currie and Toes, 1978). There was a close association between the severity of dieback, tree malformation, and loss in merchantable tree volume. A reduction of 63% in merchantable tree volume was estimated. In contrast, despite a high incidence of top death in some (usually younger) stands of *P. radiata* in north-eastern Victoria, Australia, the overall effect on tree growth and on volume and value of merchantable wood was small (Wright and Marks, 1970). The volume of degraded wood in this study ranged from 0.5 to 5.5% of the possible volume (CABI, 2014).

Control measures

The damage caused by this disease is most severe on old or weakened trees. Old trees or trees exposed to unsuitable growing conditions, mechanical injury, or damage by insects may eventually be killed. Thorough weekly watering during extended dry periods of the growing season and spring broadcast fertilization will result in a tree that is more vigorous and more resistant to tip blight (CABI, 2014).

When only a few branches of a tree show symptoms of tip blight, a program of pruning and sanitation should help minimize disease. Prune off blighted twigs and destroy or discard them. Since fungal spores can be transported to healthy twigs during the pruning operation, prune when the tree is dry. Disinfect pruning tools before each cut by swabbing the cutting blades with a solution of 70% rubbing alcohol between each cut. Rake up all blighted needles, twigs, and especially cones which harbor the fungus and destroy or discard them (CABI, 2014).

Fungicide applications have reduced the incidence of shoot blight and may be appropriate for nurseries, Christmas tree plantations, ornamental plantings and windbreaks (CABI, 2014).

Distribution and years of first finding disease or pest in individual countries

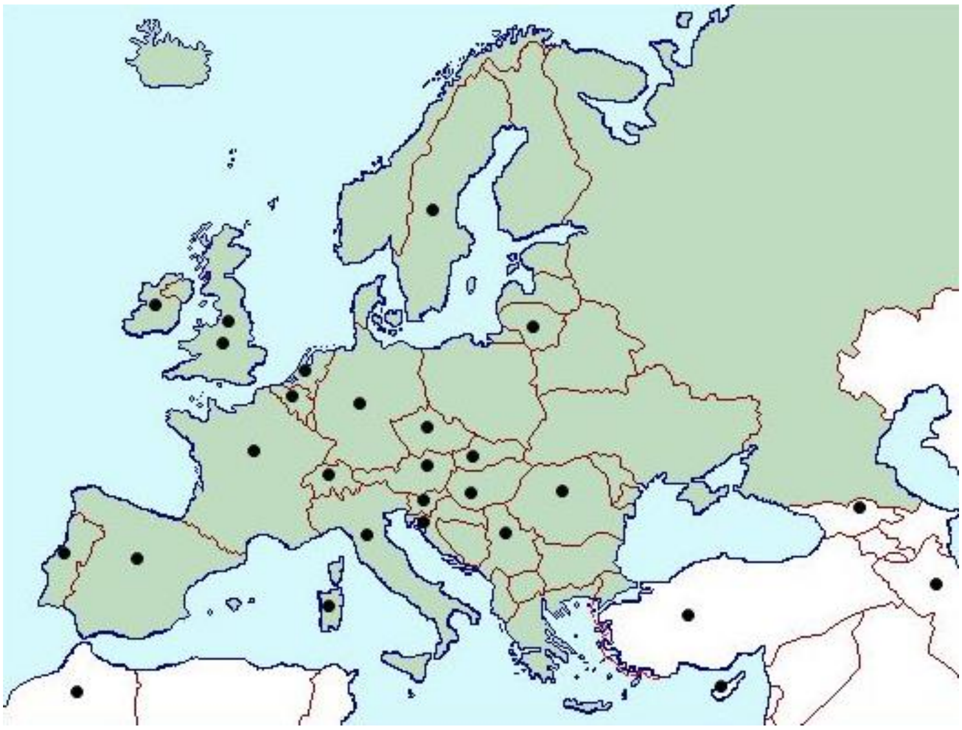

Fig. 19 Distribution of *Sphaeropsis sapine* in Europe (CABI, 2014)

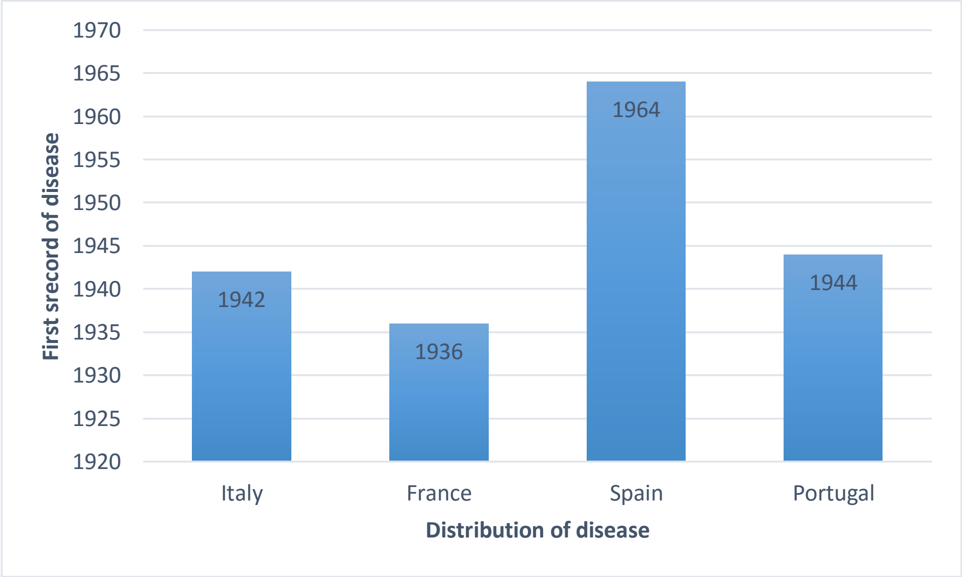

Fig. 20 Years (EPPO, 2002) of first record of disease or pest in individual countries

5.7. *Gremmeniella abietina* (Lagerberg) Morelet

Synonyms: *Ascocalyx abietina* (Lagerberg) Schalpfer
Crumenula abietina Lagerberg
Lagerbergia abietina (Lagerberg) J. Reid
Scleroderris abietina (Lagerberg) Gremmen
Scleroderris lagerbergii Gremmen
Anamorph: *Brunchorstia pinea* (P. Karsten) Höhnel
Synonyms: *Brunchorstia destruens* Eriksson
Brunchorstia pini Allescher
Excipulina pinea P. Karsten
Septoria ponea P. Karsten

Taxonomic position: *Fungi: Ascomycetes: Helotiales*

Common names: Brunchorstia disease (in Europe), scleroderris canker (in USA)

Continent of origin

G. abietina is indigenous to Europe (EPPO/CABI, 1997).

Identification

Pycnidia occur on stems and needles, are gregarious or solitary, dark-brown to black, stromatic, multilocular, without ostioles, up to 1 mm wide; the wall is several cells thick, composed of outer sclerotized and heavily pigmented cells and inner wall pseudoparenchyma. Conidiophores completely line the inside of the pycnidial cavity, are hyaline, cylindrical. Conidia (blastospores) hyaline, cylindrical, somewhat curved, tapering towards the apices, mostly three-septate, not constricted at the septum, 25-40 x 3-3.5 μm (EPPO/CABI, 1997).

Apothecia appear on stems and axes of the needles, gregarious, erumpent, superficial, about 1 mm diameter, with short stipes. Hymenium cream-coloured, receptacle dark-brown to black, margin opaque. Excipulum composed of several layers of polygonal cells heavily pigmented and sclerotized towards the margin and provided with irregular cell protuberances on the outside. Asci subclavate, short-stipitate, inoperculate, eight-spored, 100-120 x 8-10 µm; ascus wall bitunicate. Ascospores biseriate, hyaline, ellipsoidal, sometimes slightly curved, ends rounded, mature spores three-septate not constricted at the septum, 15-22 x 3-5 µm. Paraphyses hyaline, filiform, septate (Punithalingam & Gibson, 1973).

Hosts

The host range of *G. abietina* is mostly confined to species of *Abies, Picea* and *Pinus,* which occur widely in the EPPO region. Main hosts are *Picea abies, P. contorta* and *Pinus sylvestris*. The following hosts have been recorded: *Abies sachalinensis, Larix leptolepis, Picea glauca, P. mariana, P. rubens, Pinus banksiana, P. cembra, P. densiflora, P. flexilis, P. griffithii, P. monticola, P. mugo, P. nigra var. austriaca, P. nigra var. corsicana, P. nigra var. maritima, P. pinaster, P. pinea, P. ponderosa, P. radiata, P. resinosa, P. rigida, P. sabiniana, P. strobus, P. thunbergii, P. wallichiana, Pseudotsuga menziensii*. The five needled pines seem to be more resistant than the two- and three-needled group (Skilling & O'Brien, 1979).

Biology

The fungus enters the apical buds and developing shoots by germinating conidia or ascospores, especially during cool, wet springs. Wounded needles, buds and shoots are particularly susceptible to infection. In Central Europe, conidia and ascospores are released from November to July (Gremmen, 1968). After entrance, the fungus kills the bud and proceeds downwards into the stem and needle fascicles. Shoots start dying in the following spring from the tips. Needle bases turn orange to brown while the tip may be still green and finally fall off. Small, black pycnidia appear at the base of dead needles or on dead shoot tips throughout the year but more commonly in spring and early autumn. Apothecia occur in the same place as pycnidia but 1 year after the shoots die. The entire crown may be infected, which causes significant loss of foliage, further weakening of the trees due to secondary attack by other fungi and insects, and finally death (EPPO/CABI, 1997).

The fungus overwinters as mycelium in the conifer host or as immature fruiting bodies. *G. abietina* is seasonal in its development in the host plant. It is capable of infecting the host while it is actively growing, but rapid development of disease symptoms can take place while the host plant is dormant. Mortality incurred during the development of an epidemic depends on the size of the host plant at the time of infection. Very small trees, such as nursery seedlings, are susceptible and die soon after infection, usually in the first year. Larger trees take several years to succumb, usually dying one branch at a time (EPPO/CABI, 1997).

Symptoms and damage

Initial infection by *G. abietina* occurs in developing shoots in the spring (Gremmen, 1968). However, the first symptoms may not appear until the following winter when resin exudation can be observed on the buds. Brown necrotic areas develop at the base of the buds and in the cortex of the current year's shoot. In the spring, many infected buds fail to flush and the 1-year-old needles turn orange to brown, beginning at the base and gradually extending to the tip, followed by needle-cast as the result of dieback of these shoots. A characteristic yellow coloration of the xylem tissues can also be seen (Read, 1967). When buds are only partially infected, poor, distorted shoots may be produced. Infected shoots may also survive, in which case areas of depressed necrotic tissue may be found. At this stage affected trees have many dead shoots in the crown and, if the attack is severe, some trees will die. One year later bunches of light-green needles may develop from adventitious buds, present at the base of the dead shoots and sometimes giving the appearance of small witches' brooms. However, trees often survive and adventitious buds develop below the point of dieback to provide new growth (Gremmen, 1972).

Pine seedlings in the nursery should be inspected for orange to brown discoloration at the base of needles in early May. By July, needles and branch tips become brown. Needles fall from branch tips when the slightest pressure is applied. In young pine trees, green discoloration appears beneath the bark of dead branches. Stem cankers are rare but small branch cankers are commonly found. Throughout the year, but mostly in spring and early autumn, black pycnidia or light-brown apothecia should be visible at the base of dead needles or on dead branch tips (EPPO/CABI, 1997).

Fig. 21 Scleroderris canker of pine and spruce *Gremmeniella abietina* symptoms (Forestryimages, 2016)

Dispersal and introduction pathways

Conidia liberated from infected tissues are dispersed under wet conditions by a water splash mechanism (Votila, 1985). Long-distance dispersal of the fungus is thought to occur largely through wind-borne ascospores. Absence of ascospores in the European strain clearly has implications for disease spread. Transport of infected nursery stock or movement of infected Christmas trees of *P. sylvestris* may provide alternative means of long-distance dispersal. Magasi & Manley (1974) showed that *G. abietina* can survive for a period of 10 days in branches of 9-year-old *P. sylvestris* trees cut for the Christmas tree trade, regardless of whether they are left outdoors or brought indoors and subjected to dry, warm conditions.

Economic impact

Brunchorstia dieback was reported to have devastated *Pinus nigra* var. *maritima* in Scandinavia in about 1880 and to have severely attacked *P. cembra* in Sweden in recent years. In the UK, it occurs mainly on *P. nigra* var. *maritima* and only occasionally on *P. sylvestris*. It has also caused loss to *Picea abies* in continental Europe over the last century (EPPO/CABI, 1997).

G. abietina was first identified in North America in 1962 and since then has been an increasing threat to *Picea*, *Pinus resinosa* and *P. sylvestris* forests.

The disease is typified by death of the growing point and the apical needles of the lower branches of pine and spruce. Under severe conditions all the foliage of the host may be affected and die. It is most damaging to species that are grown towards the limit of their range and attacks are favoured by shaded conditions, by dense, badly aerated plantations in which humidity is high, and by weather damage, such as temperature oscillations during shoot elongation. The disease may kill young trees as well as reducing growth and causing distortion of older trees. It can also cause serious nursery loss (EPPO/CABI, 1997).

Control measures

The disease may be controlled in the nursery using the fungicide chlorothalonil applied about seven times from May to mid-August (Skilling & Waddell, 1970; 1974). On the forest scale, however, once *G. abietina* is established in a plantation it is almost impossible to control. The use of chemicals is not practicable in plantation crops where careful selection of disease-free planting material, as well as selection of planting sites at some distance from affected plantations, are important considerations (EPPO/CABI, 1997).

Planting material of tree species included in the host range of *G. abietina* should be chemically treated with the fungicide chlorothalonil prior to movement. Before export to countries free from the disease, Christmas trees should be inspected for canker during the summer before trading. Immersion of diseased seedlings in warm water (55°C) and immersion or spraying with dilute sodium hypochlorite eradicated the pathogen with no apparent loss in needle colour or retention (Hudler & Neal, 1990). Regulatory action by the USA and Canada now prohibits the movement of Christmas trees and nursery stock from areas where the European strain is present (EPPO/CABI, 1997).

In affected plantations, the optimum time to carry out sanitation fellings is the first winter after symptoms of the disease have appeared (EPPO/CABI, 1997).

Distribution and years of first finding disease or pest in individual countries

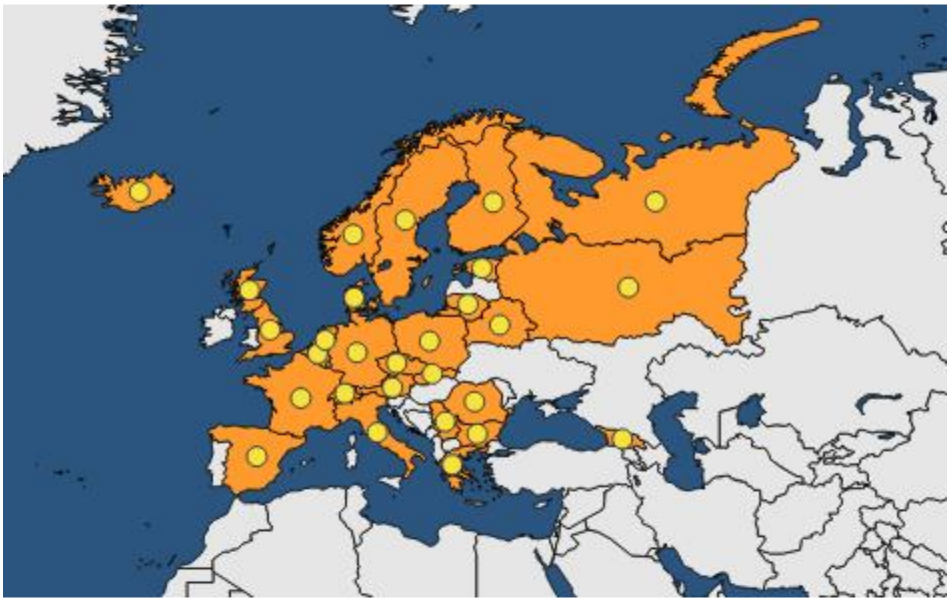

Fig. 22 Distributon of *Gremeniella abietina* in Europe (EPPO, 2016)

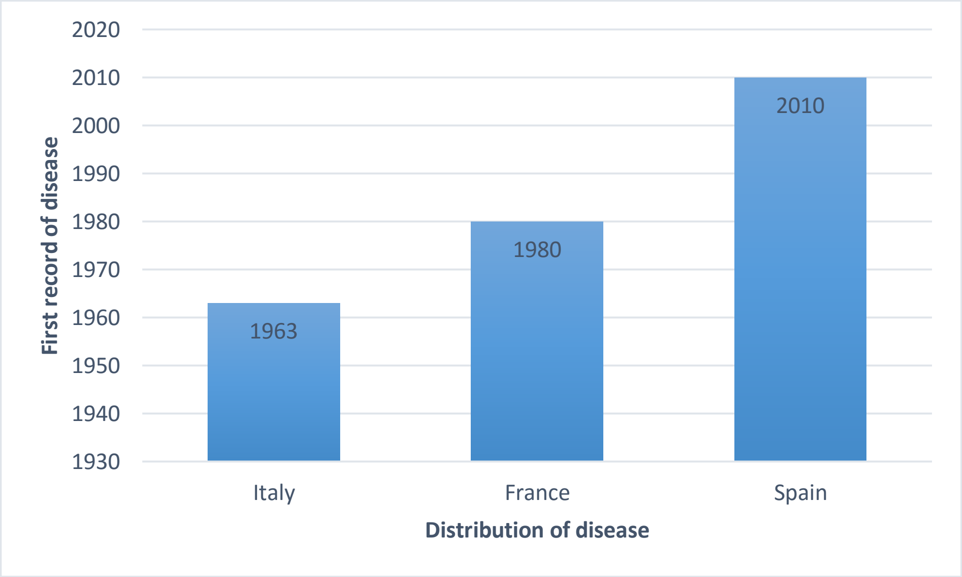

Fig. 23 Years (EPPO, 2002) of first record of disease or pest in individual countries

5.8. *Heterobasidion irregulare* Otrosina and Garbelotto (2010)

Synonym: The names "North American *H. annosum* P ISG"; *Fomes annosus, Fomitopsis annosa, Polyporus annosus* are also mentioned in the literature.

Taxonomic position: *Fungi; Basidiomycota; Russulales; Bondarzewiaceae*

Phytosanitary categorization: EPPO A2 list

Common names: Annosus root and butt rot

Continent of origin

H. irregulare originates from North America, where it is commonly found in the Eastern and Western parts, and less commonly found in the central part (EPPO/CABI, 1997).

Identification

Heterobasidion annosum sensu lato, associated with root and butt rots, was long regarded as a single species until mating experiments, phylogenetic studies, and the existence of different host preferences led to the description of separate fungal species. Among these, *Heterobasidion irregulare* has recently been described as a new species belonging to the *H. annosum* complex and originating from North America. However, *H. irregulare* was introduced into Lazio region in Italy, most probably during World War II by US troops via infected wood material. Research studies have demonstrated that *H. irregulare* has spread from its initial introduction site (Castelporziano) and is currently causing extensive mortality in several *Pinus pinea* stands. Dr Gonthier (University of Torino) and Dr Garbelotto (University of California, Berkeley) who have studied *H. irregulare* extensively during the last decade, recently contacted the EPPO Secretariat and suggested that this pathogen should be added to the EPPO Alert List because of the risk it may present to pine trees in the EPPO region and it happened in 2015 (EPPO/CABI, 1997).

Hosts

H. irregulare mainly attacks *Pinus* spp. In its native range, it has been found in several *Pinus* species (e.g. *P. elliottii, P. jeffreyi, P. palustris, P. ponderosa, P. radiata, P. resinosa, P. taeda*), as well as on *Calocedrus decurrens* and *Juniperus virginiana*. In its invaded range, *H. irregulare* has mostly been found on *P. pinea*, and occasionally on *P. halepensis*. Inoculation experiments have confirmed that *H. irregulare* is pathogenic on both *P. pinea* and *P. halepensis*, and have showed that *P. sylvestris*, which is the most widely distributed pine species in Europe, is also susceptible. Since *H. irregulare* commonly attacks *Juniperus virginiana* in the USA, attention should be paid to the possible susceptibility of *Juniperus* species present in the EPPO region. Finally, during spore trapping studies, the presence of *H. irregulare* was observed in Italian oak woodlands, probably living as a saprophyte without causing any disease, but this suggest that oak stands can be a habitat for *H. irregular* (EPPO/CABI, 1997).

Biology

The disease cycle of *Heterobasidion irregulare* begins with natural wounds on trees or cut stumps. Basidiospores are wind-blown and land on tree wounds. The spores then germinate and the mycelia, or vegetative structure of the fungus, grows into the wood. The mycelia colonizes the wood by decomposing the lignin and cellulose, producing a stringy white rot. It spreads from tree to tree by root grafts, killing trees in an ever widening circle. The sexual reproductive structures of the fungus, annual or perennial basidiocarps, appear on decomposing stumps and at the base of dead trees and release spores in summer and fall to mid-winter. The highest sporulation occurs from late summer to when the conks freeze. When the conk temperatures are above freezing the spores of the fungus are released and carried by wind currents to land in open wounds or stumps of cut trees. The fungus can survive freezing temperatures both as mycelia and as basidiocarps, and overwinters in the roots and stem tissue of trees. The mycelia produce infectious conidia, but it is unknown how these fit into the disease cycle. When the fungus has obtained enough nutrients it grows a basidiocarp on the outside of a trunk or stump of a tree in the eastern US or inside a hollow stump in the western US (EPPO/CABI, 1997).

Symptoms and damage

H. irregulare causes root and butt rots on its host plants. In both its native and invaded range, tree mortality is observed. *H. irregulare* colonizes the cambial layer and sapwood of its hosts, both in the root system and at or just above the root collar. The mycelium colonizes the wood, resulting in the early stages of infection in a darker, almost purple stain in the wood, and later producing a stringy white rot. The sexual reproductive structures of the fungus (basidiocarps) appear on decomposing stumps and at the base of dead trees. Disease incidence is reported to increase with stand age at rates that depend on host species and silvicultural management techniques. The disease affects species composition, stand density and structure of forests. When tree mortality occurs, gaps develop in the forest canopy, resulting in changes of light, moisture and temperature of the forest. In Italy, extensive tree mortality occurs in the dry costal *P. pinea* stands around Rome. In the most affected sites, mortality centres including dozens of trees and with diameters larger than 50 m have been observed (EPPO/CABI, 1997).

Fig. 24 Symptoms of *Heterobasidion irregulare* (EPPO, 2013)

Dispersal and introduction pathways

H. irregulare spreads from tree to tree by root contact or grafts, spreading outward in concentric rings emanating from the stump or tree that represented the original infection site. Primary infection is effected by airborne propagules (mainly basidiospores) on freshly exposed wood surfaces (e.g. in particular stump tops, or stem and root wounds). Once established through primary infections, the fungus may spread and infect uninjured trees by vegetative growth of the mycelium through root contacts or grafts (secondary infections). Although the fungus produces both sexual spores and conidia, only sexual spores seem to cause infections in nature. Colonization proceeds downward to the root system at a rate of up to 20 cm per month, depending on climate and host species. *H. irregulare*, as is the case for other species in the *H. annosum* s.l. complex, is not able to freely grow in the soil but may remain active in dead stumps and in the root system for decades. Although spores of *H. annosum* s.l. have been reported to travel hundreds of kilometres, there is an increasing body of evidence pointing to a geographically limited range of effective spore dispersal that results in fungal establishment. A model has proposed that only 0.1% spores travel 100 m. Other studies indicated that effective spore dispersal was between 98 and 1255 m. In Italy, the rate of spread of *H. irregulare* has been estimated at 1.3 km per year, but considering that available habitats are very fragmented in the outbreak area, a much faster rate of colonization may be expected in other parts of the EPPO region. Over long distances, the introduction into Italy clearly shows that wood packaging material and other wood products can be a pathway. The possible role of non-host plants carrying saprophytic populations of the fungus remains to be clarified (EPPO/CABI, 2013).

Pathway – plants for planting, wood and wood products (including wood packaging material) of *Pinus* spp and other host species (EPPO/CABI, 1997).

Economic impact

Pinus spp. trees are widely planted across the EPPO region for forestry and amenity purposes. In both its native and invaded range, *H. irregulare* causes extensive tree mortality. The most affected pine species in Italy, *P. pinea*, has been used and cultivated for its edible pine nuts since prehistoric times around the Mediterranean Basin, and is a valuable tree in the Mediterranean landscape. The fact that *P. sylvestris*, *P. halepensis* and *Juniperus* spp. might also be susceptible to *H. irregulare* adds to the risk (EPPO/CABI, 1997).

In the invaded area in Italy, studies have shown that both the exotic *H. irregulare* and the native *H. annosum* sensu stricto were occurring. Although *H. annosum* s.s. was relatively rare and causing very limited mortality, the native species is being gradually replaced by the exotic one. In some conditions, *H. irregulare* has been shown to be a faster colonizer than the native species *H. annosum* s.s. In addition, studies have demonstrated that *H. irregulare* and *H. annosum* s.s. could hybridize which could potentially accelerate the evolution of both pathogenic species and facilitate the adaptation of the invasive species to new environments. Considering the invasive behaviour of *H. irregulare* in Italy, its interaction with native fungal populations, and the currently observed mortality on *P. pinea*, it is desirable to prevent any further spread of this pathogen in the EPPO region (EPPO/CABI, 1997).

Control measures

In North America, control measures against *Heterobasidion* spp. are mainly preventive, and generally aim for containment rather than eradication. These control measures can include: careful stump and root removal combined with digging of trenches (150 cm deep) around infected sites, conducting thinning and logging operations during periods when spore release is absent or low, immediate treatment of stump surfaces with chemicals or a biocontrol agent (e.g. *Phlebiopsis gigantea*) (EPPO/CABI, 1997).

Distribution and years of first finding disease or pest in individual countries

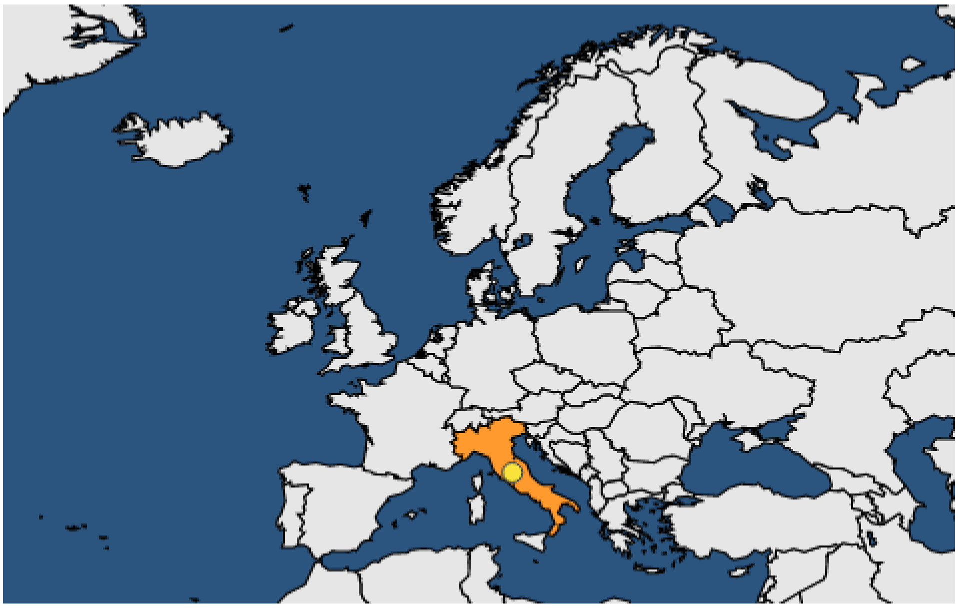

Fig. 25 Distribution of *Heterobasidion irregulare* in Europe (EPPO, 2016)

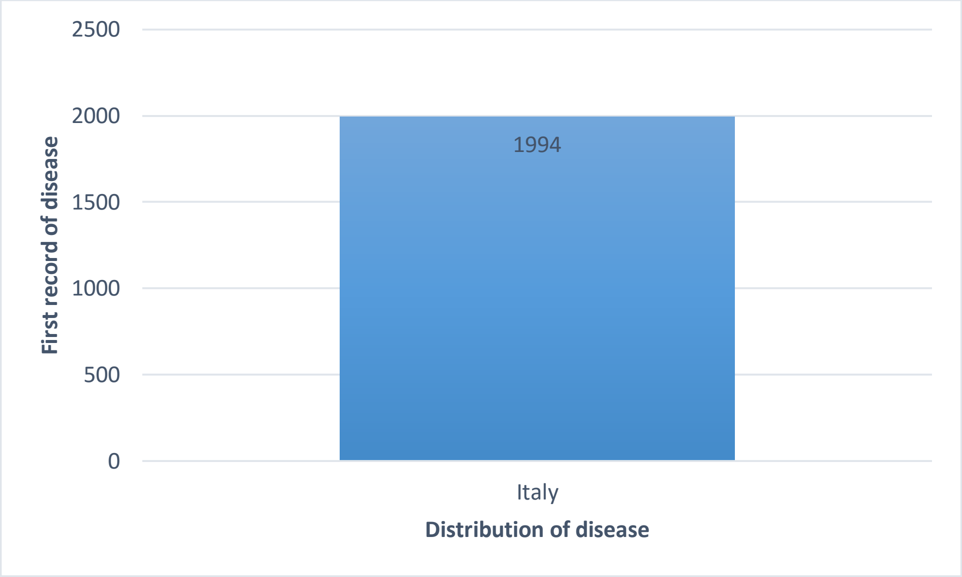

Fig. 26 Years (EPPO, 2016) of first record of disease or pest in individual countries

5.9. Invasive disease and pests of Pines in the South Europe as a threats for other EU regions

According to distribution maps of each invasive disease and pest we can say that the biggest threats to other EU regions are these 4:

- *Bursaphelenchus xylophilus*
- *Gibberella circinata*
- *Thaumetopoea pityocampa*
- *Heterobasidion irregulare*

These species are occurring on pines so far only in the states of South Europe but due to climatic conditions, international trade and other pathways, diseases may soon occur in other areas of whole Europe.

6. DISCUSSION

Based on the results it was shown that: the largest and most widespread invasive disease and pests in South Europe (Spain, Portugal, France, and Italy) are these following 8:

- *Mycosphaerella pini*
- *Bursaphelenchus xylophilus*
- *Gibberella circinata*
- *Mycosphaerella dearnessii*
- *Thaumetopoea pityocampa*
- *Sphaeropsis sapinea*
- *Gremmeniella abietina*
- *Heterobasidion irregulare*

Three of these eight invasive pests and diseases are listed as quarantine by EPPO (*Gibberella circinata, Mycosphaerella dearnessii* and *Heterobasidion irregulare).*

The most common country of origin of invasive pests and diseases is north and Central America, the origin of *Sphaeropsis sapinea* is unknown, *Gremmeniella abietina* and *Thaumetopoea pityocampa* are probably native to Europe.

Most frequent symptoms of the presence of the invasive disease and pests on *Pinus* spp. are: brown-red spots on needles, wilt and dieback of branches followed by whole tree mortality. Presence of *Thaumetopoea pityocampa* is detected by the cylindrical egg masses laid on the low branches of trees and caterpillars and presence of *H. irregular* is detected by the fungal fruiting bodies present at the base of the stumps and at the base of dead or dying trees.

The main pathways of introduction of invasive pests and diseases to the countries of South Europe include: international transport of infected wood e. g. sawn wood, round wood, wood chips, green lumber and bark or mulch, trade movement of any above- or below-ground organ of infected seedlings or larger trees or their parts e. g. pupae of *T. pityocampa* is transported with plants in attached growing medium which may be infested by buried insect pupae.

Economic impacts caused by invasive species are follows: loss to timber production, losses in volume growth, loss of seed and seedlings, restrictions on international trade which is resulting into enormous financial losses. In Europe, total annual costs of invasive species have been roughly estimated at nearly €10 000 million.

The most common measures against invasive pests and diseases include chemical and biological methods. Application of fungicides, pesticides, insecticide, heat treatment of wood material, fumigation. Most common are also pruning, thinning, felling, cutting, burning of infected trees, branches etc.

Each invasive disease or pest is represented in at least two above-mentioned countries in South Europe. Except of disease *Heterobasidion irregulare*. It has so far found only in Italy. The graphs show that the invasive diseases and pests began to spread around the world in the average since 1977. From invasive disease and pests occurring in South Europe are the biggest threats to other EU regions: *Bursaphelenchus xylophilus, Gibberella circinata, Thaumetopoea pityocampa* and *Heterobasidion irregulare.*

7. SUMMARY

The aim of this diploma thesis was to provide a general overview of invasive disease and pests invading *Pinus* spp. and occurring in states of South Europe (Spain, Portugal, France, and Italy).

Theoretical part is mainly focused on the distribution of invasive disease and pests in Europe, temporal pattern of invasion, evaluating spectrum of main alien and invasive species in Europe, processing list of threats (potentially invasive species) for European pines, occurring on pines outside Europe. Theoretical part also includes chapter about Mediterranen Pines.

Based on the internet databases and scientific articles it was shown that invasive disease and pests on pine trees which are the most widespread in countries of South Europe are: *Mycosphaerella pini, Bursaphelenchus xylophilus, Gibberella circinata, Mycosphaerella dearnessii, Thaumetopoea pityocampa, Sphaeropsis sapinea, Gremmeniella abietina* and *Heterobasidion irregulare.*

Results are focused on processing information about the most important invasive diseases and pests occurring in countries of South Europe which were described according to: other scientific names, common names, taxonomic classification, continent of origin, identification, hosts, biology, symptoms and damage, dispersal and introduction pathways, economic impact and control measures. Results also include measures which are applied against the quarantine disease and pests in EU.

For better orientation and visibility were created graphs with years of the first record of the disease or pests in individual country of South Europe and maps of distribution obtained from internet databases and also were added photos of symptoms and damage.

In my opinion, invasive species represent a serious threat to natural sites around the world. Along with the increased use of natural resources, international trade, environmental pollution and climate change are considered among the main negative factors affecting the existing biodiversity of native ecosystems. I'm afraid that in the future we will face a much greater number of invasive species and thus the worse economic impact.

8. ZÁVĚR

Cílem této diplomové práce bylo poskytnout obecný přehled o invazivních chorobách a škůdcích, kteří napadají rod *Pinus* spp. a vyskytují se ve státech jižní Evropy (Španělsko, Portugalsko, Francie a Itálie).

Teoretická část je zaměřena především na distribuci invazivních chorob a škůdců v Evropě, časový průběh invaze, vyhodnocování spektra hlavních invazivních druhů v Evropě, seznam hrozeb (potenciálně invazivních druhů) pro evropské borovice vyskytujících se na borovicích mimo Evropu. Teoretická část zahrnuje také kapitolu o borovicích, vyskytujících se v mediteránní oblasti.

Z internetových databází a vědeckých článků je patrné, že nejrozšířenější invazivní choroby a škůdci borovic vykytujících se v zemích jižní Evropy jsou: *Mycosphaerella pini, Bursaphelenchus xylophilus, Gibberella circinata, Mycosphaerella dearnessii, Thaumetopoea pityocampa, Sphaeropsis sapinea, Gremmeniella abietina* a *Heterobasidion irregulare.*

Výsledky jsou zaměřeny na zpracování informací, které se týkají nejdůležitějších invazivních chorob a škůdců vyskytujících se v zemích jižní Evropy. Tyto choroby a škůdci byly popsány dle osnovy, která obsahuje: všechna vědecká jména, název choroby nebo škůdce, taxonomické zařazení, zem původu, identifikaci, hostitele, biologii, symptomy a poškození, šíření a způsob zavlečení, ekonomický dopad a kontrolní opatření. Výsledky rovněž zahrnují opatření, jež jsou používána proti karanténním invazivním chorobám a škůdcům v EU.

Dle mého názoru invazní druhy představují vážnou hrozbu pro přírodní lokality po celém světě. Společně se vzrůstajícím využíváním přírodních zdrojů, mezinárodního obchodu, znečišťováním životního prostředí a změnou klimatu jsou řazeny k hlavním negativním faktorům ohrožujících stávající biodiverzitu původních ekosystémů. Obávám se, že v budoucnu budeme čelit mnohem většímu počtu invazivních druhů a tím pádem i horšímu ekonomickému dopadu.

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