SNS-report within the Selfoss declaration on sustainable forestry

Risk assessment and establishment of a system to address potential pathogens in Nordic and Baltic forestry as a result of climate change

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Cover photographs (clockwise from upper left): Spore trap by Lasse Modin; Boreal forest, Nordic-Baltic forest pathology workshop and Jan Stenlid inspecting infected wood by Johanna Boberg.

Contents

Executive Summary

This report brings together the critical contemporary thinking on invasive forest pathogens in the Nordic and Baltic countries, as assessed by the leading forest pathologists in each country. The threat of invasive forest pathogens to the health of our forests is a very real one and while the region has had few major disease outbreaks thus far, this situation is unlikely to continue indefinitely. This is especially the case, given the current predicted changes in climate and increases in the trade of wood, wood products and live plant material. In order to reduce the future potential impact of forest pathogens in the Nordic and Baltic countries, a region-wide scheme is recommended to help optimise management and reduce pathogen spread. The following recommendations should form the key elements of such a scheme:

Legislation and Management

- Developing a detailed emergency response plan for each country (or regionally) to be invoked in the case of the incursion of a new forest pathogen. Although species-specific plans exist, a more general plan should be developed including the allocation of responsibilities, funding and outlining an emergency response and advisory team.
- Specific legislation for invasive species (including forest pathogens) in each country could improve the facility and speed with which new incursions can be dealt with.
- Improved phytosanitary regulations for imported plants and wood material including more comprehensive phytosanitary certificates, improved vigilance around points of entry of forest pathogens (such inspection and surveillance services) and a focus on high risk import pathways rather than individual pathogens of interest.
- A review of the protocols for importing plant and wood products which considers placing restrictions on the size of imported plants, restricting import of plants in soil, and restricting the import or high risk genera (such as *Rhododendrons*).

Developing a framework for invasive forest pathogens

- A comprehensive framework for the detection and monitoring of new and invasive forest pathogens in the Nordic and Baltic countries is likely to be most reliable if a number of different techniques are used in combination. This report recommends the use of spore trapping and sentinel plantings that target high risk sites (e.g. ports, nurseries, airports, high tourist areas) in combination with widespread forest monitoring, potentially as an addition to existing forest monitoring programmes.
- Expertise in forest pathology and plant inspection and surveillance is sorely lacking in many countries and, in its current form, cannot deal effectively with the sheer quantity of import material or the areas of forest. More resources need to be allocated to training plant health officials and better links should be created between on ground staff and researchers/forest pathology experts.

Developing a framework for forest pathology extension

- Each country needs to develop a comprehensive strategy for forest pathology extension and communication with stakeholder groups such as forest workers, policy makers and the general public. This would greatly improve the capacity to respond to and deal with new incursions of forest pathogens.
- More specifically, there appears to be a potential for forest pathology extension services to be better developed to support the surveillance and detection of invasive forest pathogens. This include allocating resources more effectively to provide appropriate training for forest owners and forest professionals carrying out forest health surveys and involving forest pathology researchers more in education and dissemination of their research.
- An improved forest extension can also provide early warning of changes in the level of pathogens already established. This can speed up responses in forestry and make them more timely and cost efficient.

Future research needs

As outlined in this report, there are still many unanswered questions about invasive forest pathogens. Most particularly, more research needs to be carried out to understand which pathogens are most likely to become a threat to Nordic and Baltic countries in the future and, how this can be prevented or managed successfully. More specifically this report recommends:

- Increased research programmes on anticipating and avoiding introductions of potentially invasive species. This can include research on what makes an organism invasive and how climate change influences the potential for disease outbreaks.
- Long-term, strategic planning and research around potential forest health problems.
- Research on the links between disturbance ecology and the biotic agents of disturbance.
- Research on management practices aimed to handle invasive or emerging forest disease.
- Practical research to understand the most efficient way in which to design surveillance and monitoring programmes such as the number of survey sites required, the optimal distribution of survey sites, the number of sentinel trees at each site and their optimal distribution as well as the quantity and type of spore trap used.
- A closer examination of the social aspects of invasive species such as effective ways to engage the general public, public attitudes to invasive species in the region and improving communication between stakeholder groups and researchers.

1. Introduction

Forest diseases can have a decisive ecological and economic impact on forest ecosystems. The anticipated climate change is expected to lead to an increase in the introduction of forest pathogens in the Nordic and Baltic countries as well as influence disease levels of native pathogens. The increased level of trade in woody plants and plant products throughout the world also contributes significantly to the spread and introduction of new pathogens.

In order to prevent future disease, it is important to improve disease monitoring and to understand the pathways by which pathogens can be introduced and spread. Pathogens arriving in the Nordic and Baltic countries fall in to three main categories: pathogens already known from other parts of the world (long distance dispersal), pathogens known from southern Europe (short distance dispersal and moving with climate change) and pathogens that are harmless in other areas of the world but become pathogenic once they arrive (unknown pathogens). There are two main mechanisms by which pathogens can spread: natural pathways including the movement of fungal spores on air currents or by insect vectors, and human-mediated pathways such as nursery stock or wood products. Any warning system developed to monitor the introduction of forest pathogens needs to examine both sets of pathways and understand the risks posed by each. This report outlines a comprehensive monitoring and warning system for forest pathogens in Nordic and Baltic countries to reduce the impact of forest diseases in the future.

This report stems from a short-term project funded by the Nordic Forest Research Cooperation Committee (SNS) within the Selfoss declaration on sustainable forestry. During the project forest pathologists from all Nordic and Baltic countries met twice to discuss the risks and preventative measures related to invasive forest pathogens in relation to climate change in Northern Europe. The outcome of the two meetings is this report and a presentation at the SNS 40-year anniversary conference in Copenhagen in July 2012. The participants in the project were:

- Jan Stenlid, Rimvydas Vasaitis, Elna Stenström, Johanna Boberg and Anna Hopkins, Swedish University of Agricultural Sciences (SLU), Sweden
- Iben M. Thomsen, Forest & Landscape, University of Copenhagen, Denmark
- Arja Lilja, Jarkko Hantula, Finnish Forest Research Institute (Metla), Finland
- Halvor Solheim, Norwegian Forest and Landscape Institute, Norway
- Halldór Sverrisson, Agricultural University of Iceland and Icelandic Forest Research, Iceland
- Talis Gaitnieks, Latvian State Forest Research Institute (Silava), Latvia

- Rein Drenkhan, Estonian University of Life Sciences, Estonia
- Vaidas Lygis, Institute of Botany of Nature Research Centre, Lithuania

This report provides a summary of the meetings held and, more specifically, aims to*:*

- evaluate existing risk assessments of invasive pathogens to determine the threat to Nordic and Baltic countries
- evaluate the existing biosecurity/ invasive species policies in each country in the region
- review existing mechanisms for warning systems for invasive pathogens worldwide
- outline a framework for the detection and monitoring of invasive pathogens (such as spore traps and sentinel plantings and where to place them, who is responsible for them)
- outline a framework for forest pathology extension on invasive pathogens (such as providing a diagnostics service for forest pathogens, raising awareness among forest owners about pathogen invasions)
- make recommendations for policy on invasive pathogens

In addition, this project will fulfil the following two aims not discussed in this report:

- to formalise the already established network between forest pathology researchers within Nordic and Baltic countries
- to improve the interaction and cooperation between our established network of experts in forest pathogen management and the forest industry and policy makers. This could then be used for future activities and for consultation in the case of incursions.

2. Background: Forest diseases in a changing world

2.1 Economic and ecological impact

The primary economic impact of forest diseases are based on tree mortality, decreased productivity, reduced wood quality and damage to timber value. There are also costs involved in control operations to prevent or reduce disease epidemics and secondary insect attacks, reduction in property value and reduced opportunities for recreation and tourism. The total economic loss associated with certain pathogens is difficult to calculate but some attempts have been made.

Dutch elm disease, which has been detrimental to the population of elm in Sweden, has been estimated to cause an annual cost of between 83 to 2053 million SEK (Gren et al. 2009). These estimates include costs associated with control operations to limit further spread of the disease and lost value as urban trees. The wide range of costs anticipated depends on which aspects to include in the calculations. Another example is an economic assessment of the damage caused by the invasive pathogen *Ceratocystic fagacearum* causing wilt in oaks (*Quercus* spp) in central US (Haight et al. 2011). Using a landscape model to simulate the spread of the disease the authors estimated the total cost involved in removal of diseased trees over a ten year period to USD18-60 million for one single county. Still, the authors state that this prediction is an underestimate because it is only related to the direct cost of tree removal. The cost does not include other losses related to reduced services such as landscape aesthetics and residential property values. The property losses related to tree disease can be substantial as shown by Kovacs et al (2011). These authors estimated the property losses to single family homes in developed land in California communities due to *Phytophthora ramorum* infections on oak trees (*Quercus agrifolia*). The total sum was estimated to be USD135 million over the period 2010-2020, which is significantly more than the cost for removal and replacement of dead oaks (USD7.5 million). A further aspect is the exclusion from export markets due to quarantine regulations at the importing side.

Forest diseases can also cause damage which is extremely difficult to assess in terms of monetary value. These include effects on heritage trees and other trees of significant cultural value, detrimental effects on ecosystem functioning, such as nutrient cycling (Holzmueller et al. 2010), as well as effects on biodiversity by attacking fundamental tree species important in their ecosystems. Both ash (*Fraxinus excelsior*) and elm (all three species; *Ulmus glabra*, *U. minor* and *U. laevis*), for example, have decreased drastically in numbers in Sweden and Denmark due to fungal diseases and as a result were listed as 'vulnerable' on the Swedish red list in 2010 (Pihlgren et al. 2010). Furthermore, this threatens all organisms associated with ash and elm, such as different lichens, fungi, insects and plants (Thor et al. 2010). The greatest economic losses associated with invasive species in forests are actually suggested to be related to these losses of non-market values (Holmes et al. 2009). The high cost associated with the introduction of invasive non-native species warrants an increased focus on prevention measures, based on early warning of their arrival. Costs associated with prevention measures should be compared with the cost for controlling an already established pathogens (Leung et al. 2002).

2.2 Climate projections for northern Europe

The Intergovernmental Panel on Climate Change (IPCC) presents several scenarios of greenhouse gas emissions used to project future global climate trends until year 2100. These scenarios assume differences in future demographic, economic and technological developments and are considered equally likely to occur. The most commonly used scenarios for climate modelling are A2 (high emissions), B2 (low emissions) and A1B (intermediate level of emission) (IPCC 2000).

Globally, the average global temperature is projected to increase by 1-6°C. The increase will not be evenly distributed but will instead differ depending on season and geographical location. On average, the temperature is projected to increase more during winter than summer and more in higher latitudes than in lower latitudes. The average global annual precipitation will also increase so that wet areas today are likely to be even wetter and dry areas even dryer. In addition, the frequency of extreme events such as extreme heat and heavy precipitation is likely to increase.

Specific changes projected for the Nordic and Baltic area to the year 2100 include:

- An average winter temperature increase by 1-7°C with a higher increase in northern parts
- An average summer temperature increase by 1-5°C with a higher increase in southern parts
- An average winter precipitation change ranging from a decrease of 10% to an increase of about 70%. The variation between different climate scenarios and climate models used is very high, especially for the Norwegian west coast and Iceland. In the other countries the average winter precipitation is projected to increase from 10% to 60%.
- An average summer precipitation decrease by up to 30% in the southern parts while precipitation will increase in the northern parts of Norway, Sweden and Finland, typically by up to 20% (but Norwegian west coast up to 80%). Iceland is projected to receive up to 20% more or less precipitation depending on climate model used.

These climate data scenarios are provided by the Swedish Meteorological and Hydrological Institute (SMHI) using the Rossby Centre Regional Climate Model (RCA3) (Kjellström et al. 2005) and based on either the German Max-Planck-Institute climate model (ECHAM)

(Jungclaus et al. 2006; Roeckner et al. 2006) or the British global climate model HadAM3H from the Hadley Centre. The simulations are based on the IPCC scenarios A2 and B2 and climatic data from the period 1961-1990 is used as reference. The large variation in the projected climate scenarios arise partly from the different emission scenarios used and partly because the two global climate models used project different patterns in the major wind directions (west or east dominating wind directions). The latter will especially affect the precipitation patterns.

2.3 Climate change effects on tree pathogens

Disease is the result of an interaction between a susceptible host and virulent pathogen and conducive environmental conditions. Both the host susceptibility and the virulence of the pathogen are affected by climatic factors such as temperature and precipitation patterns as well as extreme climatic events (Garrett et al. 2006). Thus, the predicted alterations to weather patterns brought about by climate change have the potential to have a profound effect on disease patterns in the Nordic and Baltic regions.

Climatic factors will affect the survival, reproduction, spread and infection of pathogens and may thereby alter stages and rates of development of the pathogen ie. affect the virulence. The climate will also affect the host and may induce stress and modify resistance. In addition, vectors and alternate hosts may be affected. Taken together this may lead to changes in the pathogen-host interaction and cause a shift in the current balance between the host tree and the pathogen leading to increased or decreased damage. The direction and magnitude of responses will differ depending on the pathogen-host complex in question. As a consequence, the relative importance of the type of diseases present, the specific pathogens and the number of important pathogens may change.

Many pathogens in northern Europe are currently limited by the low winter temperatures. The increased average temperature projected for the future may enable pathogens to overcome environmental thresholds that earlier limited their geographical range. This may lead to a shift in distribution within the Nordic and Baltic countries and pathogens earlier observed in the southern parts of Europe may be able to establish in the northern parts. The improved environmental suitability may also allow or promote establishment of new pathogens from other parts of the world introduced via anthropogenic activities, e.g. trade (see section 2.4). Climate change may also increase introductions of exotic tree species as means to adapt forestry to future climate. New potential hosts may lead to new host-pathogen complexes being formed.

Taken together climate change may:

- Influence both pathogen and host thereby changing the resulting disease of already established pathogens in the Nordic and Baltic countries
- Lead to a shift in distribution of pathogens within Europe when pathogens ‘move together’ with the changing climate. This will lead to establishment of for us new pathogens
- Enable new arrivals of distant invasive species, both known and unknown species

2.4 Trade and invasive species

New introductions of invasive pathogens have increased drastically during the last century. In Europe the highest rates of introductions of invasive species has occurred during the last decade (Hulme 2009). Since 1800 the introduction of alien fungi to Europe has increased exponentially (Desprez-Loustau 2009). Of all recorded alien fungi, 77% where plant pathogens. This increase in the number of introductions has been related to globalisation, international travel and, most specifically, to trade of plant and wood products (Brasier 2008; Hulme 2009; Liebhold et al. 2012). This long distance transport has circumvented natural barriers such as mountains and oceans earlier hindering a global distribution of many pathogens.

There are a number of examples of invasive forest pathogens that have caused catastrophes to forest trees worldwide. The best known case is Dutch Elm Disease which has threatened the elm populations both in Europe and North America since the 1930s. This disease is caused by pathogens in the genus *Ophiostoma* that are easily transported in wood. Another example is Chestnut blight (caused by *Cryphonectria parasitica*) which was introduced to North America in the early 1900s and had a disastrous effect on the American chestnut tree population (Hepting 1974). The fungus *C. parasitica* was then introduced to Europe via Italy in around 1938 and spread throughout southern Europe in the population of European chestnut (*Castanea sativa*) (e.g. Milgroom et al. 1996). More recently, in the beginning of 1990s, an undescribed disease on tanoak (*Lithocarpus densiflorus*) and different oak species (*Quercus* spp) was observed in California, US. More than a million trees have been killed in coastal forests in Western US since then (Meentemeyer et al. 2011). The high mortality in infected trees prompted the name ‘Sudden oak death’ and the causal agent was identified 10 years later as *Phytophthora ramorum* (Rizzo et al. 2002). The European version of this pathogen was described in 1993 and until 2009, was mainly a problem in rhododendron in nurseries and in park trees surrounded by infected rhododendrons. However, in 2009 *P. ramorum* began causing extensive mortality of Japanese larch in the UK (Brasier & Webber 2010).

In common for these pathogens is that they were all introduced via trade with plants or plant products. The causal pathogen of Dutch elm disease is thought to have been spread globally through the international trade of timber and untreated logs (Brasier & Buck 2001). Chestnut blight, caused by a pathogen native to East Asia, is thought to have been introduced into North America on nursery stock (Kliejunas 2010) and the introduction of *P. ramorum* into both North America and Europe is related to nurseries and the trade of ornamental plants, especially *Rhododendron* spp. (Pautasso et al. 2008).

International trade encompasses several important pathways for the dispersal of forest pathogens such as wood and wood packaging material, vegetative imports e.g. seeds and live plants via for example nurseries. In Europe the fungal dispersal associated with horticulture and ornamental activities were found to be responsible for most introductions (DAISIE; Brasier 2008; Santini et al 2012 unpublished).

3. Future potential threats to Nordic and Baltic forestry

The future damage by forest pathogens in Nordic and Baltic forestry due to climatic changes will depend on several interacting factors. Overall, an altered climate will affect plant diseases by:

- directly affecting the fungal pathogens already present (due to changes in temperature, humidity etc) and subsequently increasing or decreasing the future disease frequency
- increasing stress in the host trees and making them more susceptible to disease
- affecting the vector or alternating host of some fungal pathogens and thereby affecting the disease incidence
- affecting the competing microflora
- altering the climate in such a way that it becomes suitable for new fungal pathogens.

The following tables provide a list of the most important current and predicted future forest pathogens in the Nordic and Baltic countries (Tables 1 and 2).

Table 1: Forest pathogens already well established in most Nordic and Baltic countries, whose distribution is predicted to change under future conditions

Pathogen	Disease	Forestry Hosts	Comments
Heterobasidion annosum	Heterobasidion root rot	*Pinus* spp., *Picea* spp.	
Heterobasidion parviporum	Heterobasidion root rot	*Picea* spp.	
Armillaria spp.	Armillaria root rot	Many hosts	
Lophodermium seditiosum	Lophodermium needle cast	*Pinus* spp.	Not in Iceland
Gremmeniella abietinum	Scleroderris canker	*Pinus* spp.	Large tree type only
Cronartium flaccidum	Scots pine blister rust	*Pinus* spp.	
Chrysomyxa abietis	Spruce needle rust	*Picea* spp.	
Thekopsora areolata	Cherry spruce rust	*Picea* spp.	
Melampsora pinitorqua	Pine twisting rust	*Pinus sylvestris*	

Table 2: Forest pathogens not yet present, not widespread in most Nordic and Baltic countries but whose distribution or disease severity may increase in the region under future conditions. Fungi that are newly emerging as pathogens are also included even if they are known to have been present in the region previously

Pathogen	Disease	Hosts	Comments
Heterobasidion abietinum	Heterobasidion root rot	*Abies* spp.	Not yet present
Diplodia pinea	Diplodia shoot blight, Diplodia whorl canker	*Pinus* spp.	
Endocronartium harknessii	Western gall rust	*Pinus* spp.	Not yet present
Phytophthora ramorum	Ramorum blight	Multiple hosts	
Phytophthora plurivora	-	Multiple hosts, *Picea* spp.	
Phytophthora kernoviae	-	Multiple hosts	
Phytophthora alni	Root and collar rot	*Alnus* spp.	
Phytophthora lateralis	Cedar die back	*Thuja sp.*	Introduced 2012 to Sweden
Neonectria sp.	-	*Abies* spp.	New species
Neonectria fuckeliana	-	*Picea* spp.	
Hymenoscyphus pseudoalbidus	Ash dieback	*Fraxinus* spp.	
Mycosphaerella pini	Dothistroma needle blight, Red band needle blight	*Pinus* spp.	
Dothistroma pini	Dothistroma needle blight, Red band needle blight	*Pinus* spp.	Not yet present
Mycosphaerella dearnessii	Brown band needle blight	*Pinus* spp.	
Gibberella circinata	Pine pitch canker	*Pinus* spp.	Not yet present
Cyclaneusma minus	Cyclaneusma needle blight	*Pinus* spp.	
Ophiostoma novo-ulmi	Dutch elm disease	*Ulmus* spp.	Not yet present in Finland

Outlined below is a brief description of some of the most important pathogens and how they are expected to be affected by a changing climate.

3.1 Effects on fungal pathogens already present, leading to a change of disease frequency

Climatic factors such as temperature and humidity influence the pathogen by controlling reproduction, spore release, dispersal and infection. Thus, a changing climate will affect disease development and how these changes can affect forest pathogens already established in the region are illustrated by the root rot fungus *Heterobasidion annosum* s.l. and the needle cast fungus *Lophodermium seditiosum*.

***Heterobasidion* spp.**

The root rot fungus *Heterobasidion annosum* s.l. is native to and the most destructive pathogen in boreal and temperate conifer forests. The fungus has been estimated to cause losses to the European forestry sector of 580 million euros annually (Woodward et al. 1998). The species complex actually consists of two species with differential host preferences; *H. parviporum* that mainly infects Norway spruce (*Picea abies*) and *H. annosum* s.s. that prefers Scots pine (*Pinus sylvestris*) but also infects Norway spruce and several other tree species. The fungus infects new sites through freshly cut stumps and subsequently spreads to adjacent trees via root grafts. Prevention measures by applying the biocontrol agent Rotstop® on the stump surface at harvest are available. Rotstop® is mainly used in areas where the problem is widespread, i.e in southern Sweden and Finland. *H. parviporum* is established in the whole area, while the distribution of *H. annosum* s.s. in northern Fennoscandia (above 61°N) is limited (Korhonen et al. 1998). The reason for the limited distribution in the northern parts is not known, but climatic factors could partly be responsible (Michael Müller, pers comm.). An increased distribution of *H. annosum* s.s. in the north would lead to increased damage especially since the use of preventive stump treatment is limited in this area.

The longer vegetation periods predicted for the future would also mean a longer period when the fungus is able to infect new stands. The basidiospores of *Heterobasidion* spp. are mainly released during the summer (Redfern & Stenlid 1998) and the fungus establishes less frequently when the temperature drops below 5°C.

There is also an additional risk that another species, *H. abietum*, could be introduced. This species is mainly found in southern Europe where the main host, different *Abies* species, has their main distribution (Korhonen et al. 1998). If introduced into the Nordic and Baltic countries this species would threaten planted *Abies*.

None of the *Heterobasidion* species are established in Iceland.

Lophodermium seditiosum

Lophodermium seditiosum causes needle cast of pine. It is especially common on seedlings in nurseries and new plantations can be severely infected with reduced growth and increased mortality. It mainly causes problems in southern Fennoscandia and the Baltic countries. Severe outbreaks are related to wet conditions during the previous summer in May, June, July and August (Hanso & Drenkhan 2012). The pathogen is not found on Iceland and in Denmark the problems with *L. seditiosum* are only found in nurseries.

This species could spread northwards as a result of a changing climate with warmer and wetter conditions predicted for the northern parts of Fennoscandia. Dryer conditions during summer in the southern parts could possibly decrease problems with this pathogen in this area.

3.2 Climate related stress of host trees and increased susceptibility to infection

Climate related stress of the host trees can lead to increased susceptibility to infection by pathogens. The damage caused by some of the most common and important pathogens in the Nordic and Baltic area, *Armillaria* spp. and *Gremmeniella abietina* have a clear relationship with weather induced stress.

***Armillaria* spp.**

There are several different species of *Armillaria* in the Nordic and Baltic countries and some of these are very difficult to separate based on morphological characters. The ability to infect living hosts and cause rot damage differ between the species but common is that damage is mainly observed when the trees are stressed. Stress is often induced by abiotic factors such as drought (Desprez-Loustau et al. 2006). Increased frequency of extreme events, such as drought, in the future would then increase the damage caused by *Armillaria* spp. This would also increase the risk associated with species otherwise regarded as saprotrophic. Stress can also be induced by biotic factors such as defoliation by insects or infection by other pathogens. This has been observed in Denmark where ash infected by *Hymenoscyphus pseudoalbidus* (causing ash dieback) is often killed by secondary infection by *A. gallica* (Skovsgaard et al. 2010).

The different *Armillaria* spp. also have different geographical distributions and differ in their northern limit. *Armillaria borealis* appears to be the most common in the region and has been observed as far north as 69°N (Keča & Solheim 2011). *Armillaria cepistipes* is also common but mainly distributed in southern and central part of Fennoscandia. *A. gallica* and *A. ostoye* have an even more southern distribution. In a survey made in Norway, only one record of *A. ostoye* and *A. gallica* was found at 59°N (Keča & Solheim 2011). *Armillaria mellea* s.s. is only found in Denmark. A warmer future climate could lead to a more northern distribution amplifying the potential future risk posed by these species.

Gremmeniella abietina

Gremmeniella abietina is one of the most serious pathogens in the Northern Hemisphere (Nevalainen 2007) attacking all three major conifer tree species Norway spruce (*Picea abies*), Lodgepole pine (*Pinus contorta*) and Scots pine (*Pinus sylvestris*). *G. abietina* causes dieback of shoots and buds and forms cankers on stems and branches. Defoliation in older trees leads to reduced growth, decreased vitality, and increased sensitivity to secondary parasites, e.g. pine shoot beetle (*Tomicus piniperda,* (Sikström et al. 2005) and the disease causes mortality in young trees. Over the recent decades *G. abietina*-induced damage of Scots pine has increased.

G. abietina can cause large scale epidemics, the last one occurred in 2001 and damage was reported from a large part of Fennoscandia. In Sweden, the epidemic covered more than 450 000 ha (Wulff et al. 2006) and the monetary loss was estimated to reach up to 250 million USD (excluding additional losses due to reduced growth of survived trees) (Hansson et al. 2004).

Gremmeniella abietina is commonly found in asymptomatic host tissue and it appears that the fungus can sustain as an endophyte and that disease is caused when the environmental conditions are conducive. Outbreaks of *G. abietina* have been linked to several different weather variables. High precipitation rates in combination with low mean temperature in May and August/September was found to correlate to disease outbreaks in Denmark and Holland (Thomsen 2009). Frost events in late spring and early summer has been suggested to stimulate disease development in Finland (Sairanen 1990), and relatively mild winter temperatures has also been related to disease development (Marosy et al. 1989).

Increased temperatures in future climate scenarios would point towards decreased problems with this pathogen in the future while the anticipated mild winters could possibly have the opposite effect. The complexity is also increased due to the different races of *G. abietina* (small tree type and large tree type), which are reproductively isolated from each other (Uotila et al. 2000). The large tree type has been responsible for most serious epidemics thus far due to its capability to attack higher branches of large trees whereas the small tree type depends on snow cover and therefore only causes damage on seedlings, on the lowest branches or on stem base (Karlman et al. 1994). Finally, the evaluation of climatic change effect on *G. abietina* is complicated even more by the recent observations of the large tree type in Spain (Botella et al. 2010), where climatic conditions are considerably milder and dryer than to those in Nordic and Baltic countries.

The tree provenance and age distribution has also been related to large scale outbreaks of *G. abietina* (Hansson 1998; Thomsen 2009). Northern provenances of pine are generally more resistant against *G. abietina* than more southern varieties. In many of the countries forest owners are recommended to plant southern provenances to adapt to a changing climate, but this could possibly increase the risk of future problems with *G. abietina*.

The opportunistic nature of *G. abietina* is comparable to that of *Diplodia pinea,* although the latter is connected to warmer climate condition (see section 3.4).

3.3 Climate effects on vectors and alternating hosts

The effect of a changing climate on the pathogens that are dependent on a vector to spread to new hosts or on the availability of alternate hosts to fulfill their life cycle are very difficult to predict. There are several examples and below some are outlined.

Ophiostoma novo-ulmi

Ophistoma novo-ulmi, the causal agent of Dutch elm disease, leads to wilting and mortality of all Elm species in the region. The disease is vectored by elm bark beetles (*Scolytus* spp). There appear to be a northern climate related limit for the vector, which then also limits the distribution of the disease. For example, the disease is found in all countries except Finland and Iceland where the beetles are absent. In Norway, Dutch elm disease is now a slow progressing disease in the Oslofiord area where trees are killed each year, but regeneration of new trees is not restricted so the volume of elm is not decreasing (Solheim et al. 2011). This is a good example on how the climatic effects on the vectoring insect will affect the distribution of the disease. Higher temperatures could, potentially increase the survival and rate of development of insect vectors and thereby increase disease severity. A warmer and drier growing season could also increase the rate of disease progress, ie wilting.

Rust fungi

Most rust fungi are dependent on the alternate host to fulfill their life cycle. The most damaging rust fungus in the Nordic and Baltic countries is Scots pine blister rust (or cronartium rust or resin-top) which is caused by two morphologically similar species *Cronartium flaccidum* and *Peridermium pini*. These rusts may cause considerable growth losses (Martinsson & Nilsson 1987). *Cronartium flaccidum* completes its life cycle by alternating between pine and various kinds of seed plants (eg species belonging to the genera *Paeonia, Vincetoxicum, Pedicularis* and *Melampyrum sylvaticum*). *Peridermium pini* on the other hand spreads directly from pine to pine. Thus, for *C. flaccidum* the effect on changing environmental conditions will depend heavily on the effect on the viability and distribution of the alternate hosts. Other examples of rust fungi important in the Nordic and Baltic region and there alternate hosts are listed in Table 3.

Table 3: Important rust fungi in the Nordic and Baltic region their main host and alternate hosts

Species	Common name	Main Host	Main alternate host
Thekopsora areolata	Cherry spruce rust	*Picea* spp	*Prunus padus* and other *Prunus* spp.
Chrysomyxa abietis	Spruce needle rust	*Picea* spp	None
Chrysomyxa ledi	Spruce needle rust	*Picea* spp	*Rhododendron* spp. or *Ledum palustre*
Melampsora pinitorqua	Pine twisting rust	*Pinus sylvestris*	*Populus tremula*
Melampsoridium betulinum	Birch rust	*Betula* spp.	*Larix* spp.
Melampsoridium hiratsukanum	Alder rust	*Alnus* spp.	*Larix* spp.

3.4 Potential Pathogens

The anticipated change in climate can make the Nordic and Baltic countries suitable for establishment of new pathogens. There are several species of pathogens that have been recently observed in some or in all of the countries and others that have not yet arrived. Some examples are outlined below.

Mycosphaerella pini

Dothistroma needle blight or red band needle blight is caused by two morphologically similar species, *Mycosphaerella pini* (anamorph *Dothistroma septosporum*) and *Dothistroma pini*.

Only the former species is found in the Nordic and Baltic countries. The fungus infects the needles and causes premature needle drop. It is one of the most damaging diseases on pine in the world (Barnes et al. 2004) and has earlier caused widespread damage in the southern hemisphere, especially in plantations of *Pinus radiata*. But, since the 1990s it has spread considerably in the northern hemisphere. In the late 1990s, an epidemic affected more than 37 000 ha of *Pinus contorta* in British Columbia, Canada (Woods et al. 2005). The heavy defoliation caused considerable tree mortality also of mature trees. Similarly, the pathogen has increased tremendously in the UK since the mid-1990s and is currently found in many forests of *P. nigra*, *P. contorta* and more recently also on *P. sylvestris*. Significant mortality is reported from *P. contorta* stands, especially in eastern and northern Scotland (www.forestry.gov.uk).

The fungus was first observed in Lithuania on *Pinus mugo* in 2002 (Jovaišiené & Pavilionis 2005) and in Estonia from samples of diseased *Pinus nigra* needles in 2006 (Hanso & Drenkhan 2008) and has since been found in all the Baltic and Nordic countries (Müller et al. 2009; Solheim & Vuorinen 2011) except Iceland.

The disease appears to be favored by prolonged humidity in combination with high temperature (Woods et al. 2005), which points towards potential increase in disease severity in the future. Improved climatic suitability for the pathogens in the area has also been shown using CLIMEX, a climatic envelope model, to study potential distribution in a future climate (Watt et al. 2011). Future disease frequency will ultimately depend on the susceptibility of the different pine species to infection. The susceptibility of the most commonly found species, *P. sylvestris,* is not fully known.

***Phytophthora* spp.**

The genus *Phytophthora* include many plant pathogens with high impact. During the last century epidemics of *Phytophthora* species has devastated forest ecosystems worldwide causing both enormous economic losses as well as significant ecological damage (Kovacs et al. 2011). *Phytophthora* species appear to be especially unpredictable as plant pathogens because of an intrinsic capacity to rapidly adapt and change behaviour. Host jumps are observed frequently and there is a high risk of hybridization between closely related species (Érsek & Nagy 2008). High risk activities are trade of live plants and in close proximity of potential hosts in nurseries (see section 2.4).

Phytophthora ramorum, for example, is the causal agent of 'Sudden oak death' in California, and has since the beginning of 1990s killed more than a million trees (Meentemeyer et al. 2011). *Phytophthora ramorum* is an especially serious pathogen because of its broad host range and capable of infecting more than 100 different host species (Kliejunas 2010). In 2009, the pathogen was found to cause extensive mortality of Japanese larch in the UK (Brasier & Webber 2010). The pathogen has also been found to infect blueberries (*Vaccinium myrtillus*) in Norway (Herrero et al. 2010), which is of special concern for Scandinavian forest ecosystem. *Phytophthora ramorum* is a quarantine species in EU and all countries are therefore monitoring potential incursions closely.

New *Phytophthora* species are discovered frequently. Since the 1990s the number of species known to science has doubled and many of these were associated with forests and natural ecosystems (Brasier 2009). In the UK the forest commission has also observed damage caused by another relative, *P. kernoviae* which was observed for the first time in Cornwall, UK in 2003. Recently, in Finnish nurseries four non-native species of *Phytophthora* was discovered (Lilja et al. 2011). Two of them, *P. plurivora* and *P. pini*, were found to be highly pathogenic to Norway spruce (*Picea abies*) in pathogenicity trials (Rytkönen et al. 2012). In Norway it has been evident that *P. plurivora* has escaped from nurseries to nature (Talgø et al. 2009). In May 2012, *P. lateralis* was reported reported on *Thuja sp.* in Sweden (Kristianstadsposten 11/6 2012)

Phytophthora alni is also a new species found to infect alder (Brasier et al. 2004). The zoospores are easily spread along the river and the pathogens thereby threaten riparian ecosystems. *Phytophthora alni* has been observed in the rivers on the west coast of Sweden and Lithuania but is not found in Finland, Denmark, Norway or Estonia. *Phytophthora alni* is thought to be a hybrid of two closely related species (Ioos et al. 2006).

Sphaeropsis sapinea

*Sphaeropsis sapinea (*anamorph *Diplodia pinea*) is an important pathogen on conifers throughout the world. The pathogen causes shoot blight and several other symptoms such as bark necrosis, cankers, blue stain and often infects the cones of many species of *Abies*, *Cedrus, Juniperus, Picea, Pseudotsuga* and of over 30 species of *Pinus* (Sutton 1980; Stanosz et al. 1999). The fungus may live in seedlings, trees, cones and seeds as an endophyte for long periods of time (Smith et al. 1996; Stanosz et al. 2005). These latent infections have been involved in the movement of the pathogen around the world (Burgess et al. 2004). This disease has until recently mainly caused problems in the southern hemisphere. It has been established in southern Europe for a long time but has since the 1990s been reported to cause more damage (Fabre et al. 2011).

In southern Europe, the occurrence of *S. sapinea* in healthy *Pinus nigra* was positively correlated with a high insolation index (Maresi et al. 2007). The incidences of epidemics increased after serious drought in 2003 in central Europe (Jankovský & Palovčíková 2003; Blaschke & Cech 2007). Droughts in Estonia in 2002 and 2006 supported the establishment of *S. sapinea* after incidental introduction, probably by pine seeds or planting material through a forest nursery (Hanso & Drenkhan 2009). In September 2007, this fungus was observed for the first time on scales of fallen cones under a middle-aged *P. nigra* tree in Southern Estonia (Hanso & Drenkhan 2009). It is unknown how fast the fungus can shift from one host tissue to another in Estonia and spread from cone scales (and shoots) to needles, buds, roots and stem, thereby causing considerable losses (Drenkhan & Hanso 2009).

Rust fungi

Endocronartium harknessii, the causal agent of Western gall rust or pine-pine gall rust originate from North America and is currently not found in Europe (EPPO 2012). Main host are two- and three-needled *Pinus* spp. including jack pine (*P. banksiana*), lodgepole pine (*P. contorta*), Scots pine (*P. sylvestris*), Aleppo pine (*P. halepensis*), mountain pine (*P. mugo*) and Austrian pine (*P. nigra*). *Endocronartium harknessii* is an autoecious rust, able to complete its lifecycle on a single species of host (Hiratsuka 1969). *Endocronartium harknessii* causes gall formation on branches and stems sometimes accompanied by a small witches' broom and thereby have a negative effect on form, lumber content and growth rates of the trees. Individual trees may be killed but the fungus is not known to wipe out entire stands. If, introduced into the Nordic and Baltic countries this pathogen could have a devastating impact.

3.5 Emerging threats and unknowns

It is not possible to predict all of the potential pathogens which may become problematic in the region in the future. Several pathogens and potential pathogens have recently been discovered in the region and the degree to which these may cause damage in the future is unclear.

Increased observations of *Cyclaneusma minus* have been reported from Estonia but the actual damage caused is not fully understood. The disease has not been reported from Norway, Sweden or Denmark, but was recently observed in Finland (Michael Müller, personal communication). *Cyclaneusma minus* was found on *P. sylvestris* the first time in Estonia in Tartu forest nursery in 1999 (Hanso & Hanso 2003). Subsequently, the fungus was found every year in a single pine seed bed of that nursery, but not elsewhere in Estonia. Since 2007, however, several findings of *C. minus* were registered, first in south Estonia and since 2008 the fungus has been found throughout Estonia. The fungus was found in northern Latvia in 2009 (Drenkhan & Hanso 2009; Drenkhan 2011). Incidences of the fungus are increasing, but *C. minus* has not hitherto caused any significant damage in Estonia (Drenkhan 2011).

A new *Neonectria* species has recently been observed causing cankers and resin flow in firs (*Abies* spp.) in Norway and Denmark (Talgø et al. 2012a; Talgø et al. 2012b) and has also been observed in Sweden. The distribution in other parts of Europe is as yet unknown.

4. Legislation

The development of legislation and its implementation is a critical component of the armoury available to deal with invasive pathogens. Current legislation for invasive species is primarily produced at the EU level, except in Norway and Iceland who are not members of the EU. The implementation of this legislation, however, is generally the responsibility of individual member states, and consequently the degree of implementation varies greatly. In addition, individual countries have extra legislation, often predating the EU which contributes towards their management of invasive pathogens. Overall however, there is a perception that for most countries, both the legislation itself, and its management could be improved to provide Nordic and Baltic states with better protection against the threat of invasive species. The following provides a brief overview of the different legislation present in each of the Nordic and Baltic countries as it relates to forest health and to invasive pathogens and their management. The information was derived from a survey of the participating researchers (see Appendix 1).

Overall, all Nordic and Baltic countries have a legislation that applies to invasive pathogens. In some cases, it is derived directly from the EU legislation while in other countries additional legislation is also available. Norway, while not a member of the EU, has very similar legislation to that suggested by the EU, while Iceland (also not a member of the EU) has quite different legislation, probably related at least in part to its isolation. Of all the countries examined, Lithuania appears to have the most comprehensive and detailed legislation relating to forest health issues. Despite this, few countries in the Nordic and Baltic region appear to have specific legislation relating to invasive species, outside of those regulations imposed by the EU. In addition, where legislation does exist, it is primarily designed for application to other invasive species ('macro' invasive species like weedy plants and invasive animals) and so is a nature conservation issue rather than a forestry or agriculture one.

Legislation relating to invasive pathogens, and its implementation, can be broadly divided into three categories: prevention and interception, early detection and surveillance, and reporting. The first, 'prevention and interception' primarily involves the control of the movement of pathogens entering each country (before or at the border). The second, early detection and surveillance covers the search for and discovery of the presence of new invasive pathogens after arrival. The final topic, reporting and dealing with invasions, addresses what actions are undertaken after the discovery of a new invasive organism within each country.

4.1 Implementation of legislation

Most countries in the Nordic and Baltic region have several government departments that deal with various aspects of invasive species legislation. In many cases the responsibility lies with the Agriculture, Food Safety or Environment Agencies. In Denmark, for example, the

Danish Nature Agency is responsible for managing state forests, but it is the Danish AgriFish Agency that deals with invasive species and quarantine restrictions. Only if the invasive organism is not listed for quarantine and is a non-agricultural pest or disease or invasive plant is the Nature Agency involved. In Latvia and Lithuania however, the State Forest Agency appears to be more involved and the State Plant Protection Agency deals with quarantine issues. **Clearly this diversification of responsibilities could be problematic when making rapid management decisions about invasive forest pathogens.**

4.2 Emergency Response to Incursions

Emergency response mechanisms following the detection of invasive forest pathogens of concern differ between different countries in the region. In Finland, Sweden, Denmark, Norway and Iceland the EU regulations are used for response to specific known invasive species such as the Pine Wood Nematode or *Phytophthora ramorum.* In the case of other unknown or unexpected pathogen invasions, the appropriate response mechanisms are unknown for all the above countries except Norway, where there are also comprehensive guidelines in the case of less specific pathogen incursions. In the Baltic states, the EU regulations are also followed but there are much more comprehensive guidelines than in the Nordic countries for how an incursion can be dealt with.

4.3 Existing monitoring programmes

Monitoring programmes primarily focus on post-border mechanisms for discovering incursions of pathogens. In a general sense it includes both monitoring programmes close to potential points of entry (ports, airports etc) as well as forest health surveillance in forests and urban areas. Early detection is critical to the success of eradication programmes; the more contained the incursion is, the lower the likely cost of eradication. There is, however, a trade-off between the high cost of regular surveillance for early detection and the cost of eradication (see Fig 1).

In most countries, forestry monitoring and surveillance programmes are carried out for a list of specific species of quarantine concern. This list is generally the one determined by the central EU authorities, with the occasional national additional species (such as the Asian longhorned beetle *Anoplophora glabripennis* and Plum pox virus in Denmark). For organisms with no official quarantine status, there is no general monitoring in Finland, Norway or Sweden e.g. general surveys for new or unexpected species. Some smaller research projects may contribute to forest monitoring for new species but these are usually part of small individual studies at universities or research institutes and are not considered for long-term monitoring. In Iceland, the Icelandic Forest Research Institute does some monitoring and in Estonia there are some shorter research projects run through the universities to look for invasive species. In Lithuania and Latvia however, there is continuous monitoring of forest health which implicitly includes monitoring for new species.

Clearly a comprehensive early detection and surveillance system would significantly improve the capacity of Nordic and Baltic countries to respond quickly to incursions of invasive pathogens. However, it would likely require extensive resourcing and enforcement from authorities. Other, less formal tools have been suggested to supplement reporting through the current plant health system. Adding to the current forest survey system that takes place in many of the countries may be possible.

4.4 Gaps in the current legislation

As outlined above, the primary method of entry into and spread between Nordic and Baltic countries is through the trade in plants and wood products and the movement of people. All Nordic and Baltic countries appear to have similar restrictions on importing plant material. In addition, there are frequently more specific regulations relating to material from known high risk areas or containing known threatening organisms. Overall however, there is a perceived need for improved legislation in all countries to deal with the increasing threat posed by invasive pathogens arriving in plant and wood products.

Plants imported into EU member states as well as Norway and Iceland are required to have a phytosanitary certificate authorized/approved by the exporter which states that the plant is free from known pests and pathogens. This certification system is based primarily on a visual inspection of the plants, both at point of origin and upon arrival into the EU. Inspection focuses on a list of known symptoms; the potential cryptic nature of many pests and pathogens are not taken into account. For example, *Fusarium circinatum*, the causal agent of pine pitch canker, can be present in asymptomatic seedlings for prolonged periods before causing disease symptoms (Storer et al. 1998). Other organisms such as *Phytophthora* species, bacteria and viruses may also not be found using visual screening due to the microscopic nature of their propagules. Given this, visual inspections are unlikely to be a single reliable method for finding even regulated organisms. In addition, the implementation or management of the current legislation is insufficient as it depends on the enforcement of inspection protocols in both the exporting and importing countries, meaning the legislation is only as strong as the weakest link, or least enthusiastic inspector.

There are several more minor changes that could easily be made to legislation which may help to prevent the introduction of new pathogens. Current phytosanitary certificates do not always show the original country of origin of the plants. For example, a seedling grown in say, Mexico, could be shipped and held in the USA for a prolonged period before export, in which case the phytosanitary certificate could only state the USA as the origin. Including the transport pathway from the country of origin to final destination in the certificate would greatly decrease the risk associated with importing plants. Furthermore, placing some restrictions on commercial imports such as introducing a maximum plant size that can be imported, not importing plants in soil and excluding some high risk genera may help to reduce import risks (Brasier 2005; Evans 2010).

Another key criticism of the current legislation is that it only acts against the introduction of known invasive pathogens. As not all invasive species are known to cause problems before they arrive in the new country, it is impossible to create a list which includes every possible threat. One way to avoid this problem could be to shift the focus of legislation from a list of individual pest and pathogen species of concern, to consider high risk pathways such as plants for planting and wood products (Richardson & Hood 2010; Webber 2010). Alternatively, the system used in countries with strong biosecurity policies, like Australia, could be followed, where imported products have to be on a safe list of host species.

Overall there is a perception that the implementation of the legislation could be improved. One of the key problems with dealing with species incursions is that the systems in place are often slow and this makes it difficult to respond in an appropriately timely manner. A well designed strategy for responding to new threats and funding rapid interventions is warranted in all countries examined. This could be based on the successful systems in place in New Zealand and Australia and could also be implemented for all invasive species, not just those affecting forests. Other criticisms of the current implementation include an overall lack of expertise in forest health issues in the authorities that deal with invasive species, and a lack of funding for monitoring and forest health support services. Together these issues mean that there are too few people working in plant inspection and monitoring and there is a lack of continuity in any existing monitoring programmes.

5. Early warning systems for invasive forest pathogens

A comprehensive early warning system is fundamental to early eradication or other action to control invasive forest pathogens. There are several mechanisms or techniques which are available to detect new forest pathogens including regular forest surveys, monitoring of high risk sites, planting sentinel trees and spore trapping. Of these, the reliability of the first three is dependent on the quality of surveillance used. Incursions of new forest pathogens are quite frequently found through passive surveillance i.e. accidental discoveries; however this type of surveillance is not likely to be especially reliable or timely. In contrast, active surveillance, involving regular surveys in specific areas of interest, is much more likely to lead to early detection (Brockerhoff et al. 2010). For example, six of 10 recently established forest pests and diseases in New Zealand were detected through standard active surveillance programmes (Myers & Hosking 2002). One of the primary difficulties with early detection systems is that during the early stages of an incursion, invasive species are generally rare, making detection more difficult. This is especially the case with pathogens since they are frequently cryptic prior to causing damage and can become quite widespread before any disease or damage is observed. For this reason, surveys targeting possible points of entry (e.g. ports, airports, timber mills, nurseries) or host species are often used (high risk site surveys). However this requires some knowledge of what the potential pathogens may be or how they will arrive (Hulme 2006).

In addition to surveys of existing trees near high risk sites of interest, specific sentinel plantings can also be used. This involves planting host trees of interest in the vicinity of high risk sites such as ports, airports, tourist destinations and taking prevailing wind currents into account. The trees planted could include important forestry species or trees with a high amenity value. These trees are then monitored regularly for the appearance of new disease symptoms. With the agreement of other partners, sentinel trees can also be planted and monitored outside the country of interest, for example along the border with neighbouring countries or even in other countries who regularly trade with the original country. Botanic gardens, arboreta and other experimental plantings can also be used as part of a network of sentinel trees (Britton et al. 2010).

Spore trapping is a completely different type of early warning system. While the three surveillance methods above rely on detecting disease symptoms or signs of pathogens on trees, spore trapping can directly detect the presence of spores of new pathogens which are often present long before disease symptoms start to appear. For this reason spore trapping could be considered to be a very early warning system. Historically, spore trapping methods relied upon morphological identification of spores to determine the species present. Recent advances in molecular biology however mean that spore traps are now used to detect and monitor a whole variety of fungal pathogens including examining annual spore deposition of the forest pathogens *Fusarium circinatum* (Garbelotto et al. 2008) and *Neonectria fuckeliana* (Crane et al. 2009). The efficacy of spore trapping efforts depends on a variety of factors including the type of spore traps used, the location of traps, the monitoring period and of course, the molecular techniques used to detect the spores. While spore traps have been commonly used to detect specific pathogens of interest (using species specific PCR techniques or morphology), efficient screening of spore trap samples for unknown or unexpected pathogens is now also possible using high throughput sequencing techniques such as 454 pyrosequencing (Hopkins and Stenlid., unpublished data). One of the drawbacks of the spore trapping method is that even if spores of a particular pathogen are detected, further research will need to be undertaken to determine whether they will cause disease and become problematic under the given climatic conditions unless the pathogen is already well studied.

Each of the surveillance strategies outline above can be used to detect specific species of interest or to act as a broader screening for unknown, new or expected pathogens. In the case of the first three surveillance techniques, disease symptoms caused by specific pathogens can be surveyed or broader screening can be carried out to look for sick or unhealthy trees. For spore trapping, as outlined above, molecular techniques now also allow us to target specific species or to do a general screen of the species caught by the spore trap.

5.1 A framework for the detection and monitoring of invasive pathogens

A comprehensive framework for the detection and monitoring of new and invasive forest pathogens in the Nordic and Baltic countries is likely to be most reliable if it draws on a number of the different techniques described above. For this reason, a three-way approach is suggested that uses both sentinel plantings and forest health monitoring to look for new disease symptoms and spore trapping as an early warning for new incursions. In addition, the system can be made even more efficient by targeting both the sentinel plantings and the spore trapping towards high risk sites.

1. A widespread network of spore traps, covering the Nordic and Baltic countries, would be the ideal system for the early detection of forest pathogens. As previously discussed, a network of spore traps that targets high risk sites, is likely to be a more efficient use of resources. Similar types of high risk sites could be used with a particular focus on sites located in long-distance air currents bringing spores from other regions. Spore traps could also be located alongside existing networks of traps present in some countries to detect pollen levels in major cities and towns. This would make maintenance of the traps more feasible. The processing of spore traps, using molecular methods, could be carried out by government or research labs in each country, or could be centralised in labs in few countries where high-throughput sequencing is already established such as SLU in Sweden. This outsourcing of trap processing could even be aligned with the current forest diagnostic services provided in each country. In addition, the data collected could easily be stored for future use

and would provide an important foundation for research, particularly relating to the epidemiology of important forest pathogens.

2. Regular forest monitoring is already carried out in most Nordic and Baltic countries to some degree. Here we propose that, where appropriate, existing monitoring schemes are supplemented to include more general forest health surveillance for new disease symptoms. Surveys of amenity trees in towns and cities are also recommended here. Initially, this would mean training for forest surveyors, however with the appropriate support material and support services (such as competent diagnostics services) current routine survey work could become even more informative. Clearly surveys carried out several times a year would be optimal, however even annual surveys would significantly increase the chance of detecting new diseases. Reporting systems such as phone applications connecting straight to internet-based databases could make this an efficient and effective system of maintaining records.
3. Sentinel plantings could be set up in high risk areas such as near ports with high traffic levels, near international transit and cargo airport terminals, near nurseries with high levels of imported stock and even along country borders. The tree species used in such plantings could include both the dominant forest crop species of the country in question plus any other important amenity trees (such as elm, ash, horse chestnut etc). While planting of some new sentinel trees would likely be required, existing plantings such as arboreta, botanic gardens and other experimental plantings could also be harnessed. Surveys of all such sites would have to be carried out at least annually and this could either be included as part of existing national forest inventory schemes or outsourced to other appropriately skilled organisations.

Clearly, with each method outlined above there are significant questions which remain unanswered about their implementation. The number of survey sites required, the distribution of survey sites, the number of sentinel trees at each site and the distribution, quantity and type of spore trap used are all issues for which further research must be carried out to give optimal results. Although the use of any one of these detection and monitoring systems would greatly increase the possibility of finding new invasive forest pathogens, the use of all three systems together would greatly increase the chances of finding new diseases and being able to respond to them in a timely manner.

5.2 Early warning systems and pathogen control

A comprehensive monitoring and early warning system could play a critical role in developing and using silvicultural actions to control forest pathogens. Predicting imminent disease outbreaks could lead to early control measures and greatly reduce the effect of forest diseases. Possible immediate silvicultural actions include:

- Stump treatment
- Thinning
- Salvation harvesting
- Seed collection

For example, should *H. annosum* be detected spreading further north in Fennoscandia appropriate preventative measures could be instigated such as stump treatment. Currently, stump treatment is not subsidised in northern Finland and is therefore not widely used. Thus, information obtained from the monitoring system could feed back to changes in policy and prevent unnecessary production losses. Similarly, if increased levels of shoot dieback or pine needle pathogens, such as *G. abietina* and *M. pini*, were detected during monitoring preventative measures such as stand thinning could greatly reduce the spread of the pathogen and thus reduce the impact of the diseases. Early detection and warning system could also allow time to plan and carry out salvation logging in cases where diseases are predicted to be severe.

Regular monitoring and surveillance could also feed into more long term control measures such as:

- Provenance selection
- Breeding programmes
- Biological control development

Damage cause by *Armillaria* spp is significantly correlated with drought stressed trees. If monitoring detected an increase in *Armillaria* in a particular region selecting more drought resilient provenances or tree species could prevent excessive damage. Early detection programmes could also be used to predict what diseases may be prevalent in the future (eg by early spore detection) and this may help to guide breeding and biological control programmes. Breeding is currently thought to be the best solution to build a resistance within the Ash population against present outbreaks of Ash dieback and should be a useful approach against other diseases in the future.

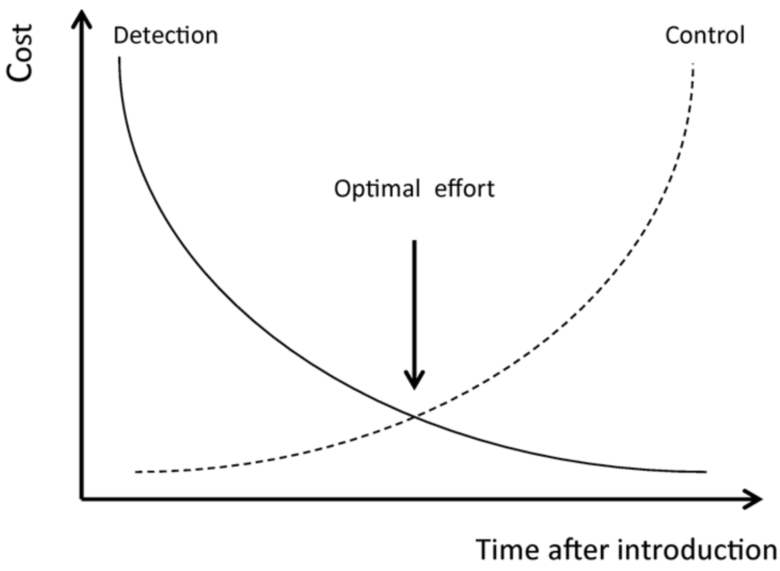

Fig 1. A conceptual model showing the cost for detection and monitoring of forest pathogens versus that for control and management by the pathogen in relation to time after introduction.

The development of an efficient detection and monitoring system should also be compared to the management and control operations of an already established pathogen in economic terms. This can be illustrated in a conceptual model (Fig 1). The cost for detecting a pathogen in very small amounts, ie in the beginning of an epidemic, is associated with a very high cost. As time progresses the levels of the pathogen will increase and thus the cost for detection will decrease. Conversely, the cost for controlling and manage a disease will grow with time as the levels of the pathogen increase. Optimizing economic efforts will be lowest at the balance between detection and control. Currently, the cost for detection and monitoring is very small compared to the costs associated with management and losses due to forest pathogens. In Sweden, about 10 million SEK is spent on monitoring for both insect pests and fungal pathogens in forests (C. Fries, Swedish Forest Agency, pers. comm.). This can be compared to the roughly 6 million spent on controlling Dutch elm disease on Gotland, Sweden, in 2011, (Karin Wågström, Swedish Forest Agency Gotland, pers. comm.), which is one disease in one county. The cost associated with the damage caused by pathogens is even higher. *Heterobasidion* root rot, for example, cost 2 million SEK every day for Swedish forest owners (see also section 2.1 and *G. abietina* in section 3.2). Thus, including damage instead of control in the conceptual model would warrant an even higher economic input into detection and monitoring.

One complicating factor is that the cost associated with the different activities, ie detection and monitoring, control and productivity losses are carried by different parties in society.

6. Forest Pathology Extension

6.1 Forest professionals and policy makers

Forest pathology extension should be considered as a critical part of the strategy to deal with invasive forest pathogens. Extension service can be considered to target three main groups: forest professionals, policy makers and the general public. Currently most countries in the Nordic and Baltic regions provide advisory services for forest pathology. These are run either by university departments or research institutes and are often funded in part by the central government and occasionally supported by contributions from the end users. 'Videntjenesten' (www.videntjenesten.dk) an information service at Forest and Landscape, University of Copenhagen, is one example. The level of engagement of these advisory services differs between countries but their general tasks include diagnosing forest health problems, running seminars and field trips and preparing information such as leaflets. In almost all countries, the onus is on the forest owners or the general public to contact the advisory service to seek information. The exception to this is in Lithuania, where forest owners are required to do their own forest health surveys and so need to be better trained and informed.

In all countries examined, there appeared to be a potential for forest pathology extension services to be better developed to support the surveillance and detection of invasive forest pathogens. This included allocating resources more effectively to provide appropriate training for forest owners and forest professionals carrying out forest health surveys and involving forest pathology researchers more in education and dissemination of their research.

6.2 Engaging the public about invasive forest pathogens

Public engagement around invasive forest pathogens is an area which has received sparse attention until quite recently. There are numerous advantages to arousing public interest in invasive forest pathogens including the potential for public involvement as passive surveyors and the power of public pressure to influence decision makers. This power is especially evident when you consider the strength of public involvement in organic and locally sourced foods, genetically modified organisms and climate change. When considering invasive species in general, public opinion seem to miss the urgent threat to biological conservation (Lambertini et al. 2011) and in this context, the effects of invasive pathogens are even less well understood by the public. This may be due to problems in communicating some of the complex biological concepts relating to pathogens and a lack of understanding of the role of humans in the spread of diseases (Stenlid et al. 2011).

Within the Nordic and Baltic countries there appears to be a wide range in the perceived public awareness of the threat of invasive pathogens for forestry and indeed for general plant health. In Norway and Denmark public awareness was considered to be high due to high profile diseases such as Dutch elm disease and ash decline and other invasive organisms such as giant hogweed and insects such as the horse-chestnut leaf miner. In Latvia and Estonia public awareness was also thought to be high while in Lithuania it was considered to be high for macro invasives (plants, animals) but lower for pathogens and other micro invasive species. In Finland and Sweden the overall perception was that public awareness of invasive forest pathogens was low.

No country in the Nordic and Baltic region appears to have a specific and organised strategy to improve public awareness about invasive forest pathogens or indeed invasive species in general. Some ways to improve public awareness include more publications of research and information in public newspapers and journals, more courses and information about invasive species in study programmes, an email list or newsletter to disseminate research findings to forestry professionals and policy makers, training days for forestry professionals, information posters in public locations such as airports and recreation areas. In some cases, macro invasive species are better known or understood by the public and this could be harnessed to increase awareness about micro invasive such as pests and pathogens.

6.3 A framework for forest pathology extension on invasive pathogens

Any strategy for forest pathology extension work on invasive pathogens (such as providing a diagnostics service for forest pathogens, raising awareness of invasives) needs to incorporate communication with three main groups: forest owners and the forest industry, policy makers and government officials and the general public. It is, however, often difficult to make the link between research carried out at institutes and universities and their impact on the broader community. For this reason, many of the countries in the Baltic and Nordic countries provide some level of forest pathology extension in an attempt to bridge the gap with the community. While the level of forest pathology extension differs between countries, a wider strategy for forest pathology extension is rarely in place.

1. Forest owners and the forest industry (including port and nursery workers): One of the key components in developing a comprehensive monitoring system for invasive forest pathogens is to harness the involvement of forest owners and workers who can act as extra eyes for new diseases. The production and dissemination of information about invasive pathogens (articles in industry magazines, pamphlets, industry field days and workshops) are all effective ways to raise the profile of invasive species within the industry, as is the provision of forest pathology diagnostic services. In many countries in the region these programmes are already being carried out to some extent, however in most cases they would be strengthened by improving the links between forest pathology extension providers and the forest industry. Annual meetings between researchers and industry members that highlight new research may be one such way to do this, with the responsibility on the research and

extension providers to provide new and interesting applications of their work. In addition, regular information provided about research and research applications (in the form of a newsletter or small magazine) could also help to bridge this gap.

2. Policy and decision makers: Forest pathology extension services rarely appear to target policy and decision makers in most of the countries examined. Despite this, support from policy makers could make a significant difference to the national view of and support for invasive species management. Policy makers from key departments could be included in industry-based meetings such as those suggested above and could also be included in the distribution of a newsletter about research applications.
3. The general public: The role that the general public can play both in detecting new invasive forest pathogens and in supporting their detection and management should not be underestimated. In general, public awareness of the importance and impact of invasive forest pathogens could be improved through better communication in the public media and by highlighting news or problems that the public have already heard of e.g. Dutch elm disease in Denmark. Better access to web-based information for interested members of the public would also help, for example the Skogskada website (currently being updated) provides information on forest pests and diseases in Sweden (www-skogsskada.slu.se). Reporting systems such as phone applications connecting straight to internet-based databases could make this an efficient and effective system of maintaining records that is accessible to a wide range of users.

There are many ways in which forest pathology extension work could be improved to raise the profile of invasive forest pathogens in the Nordic and Baltic countries. In addition to the individual suggestions made above, the development and implementation of a comprehensive extension strategy could contribute to significantly reducing the impact of invasive forest pathogens in the future.

7. Summary and Recommendations

This report has brought together the critical contemporary thinking on invasive forest pathogens in the Nordic and Baltic countries, as assessed by the leading forest pathologists in each country. The threat of invasive forest pathogens to the health of our forests is a very real one and while the region has had few major disease outbreaks, this situation is unlikely to continue indefinitely. This is especially the case, given the current predicted changes in climate and increases in the trade of wood, wood products and live plant material.
In order to reduce the future potential impact of forest pathogens in the Nordic and Baltic countries, a region-wide scheme is recommended to help reduce pathogen spread and optimise management. The following recommendations should form the key elements of such a scheme:

Legislation and Management

- Developing a detailed emergency response plan for each country (or regionally) to be invoked in the case of the incursion of a new forest pathogen. Although species-specific plans exist, a more general plan should be developed including the allocation of responsibilities, funding and outlining an emergency response and advisory team.
- Specific legislation for invasive species (including forest pathogens) in each country could improve the facility and speed with which new incursions can be dealt with.
- Improved phytosanitary regulations for imported plants and wood material including more comprehensive phytosanitary certificates, improved vigilance around points of entry of forest pathogens (such inspection and surveillance services) and a focus on high risk import pathways rather than individual pathogens of interest.
- A review of the protocols for importing plant and wood products which considers placing restrictions on the size of imported plants, restricting import of plants in soil, and restricting the import or high risk genera (such as *Rhododendrons*).

Developing a framework for invasive forest pathogens

- A comprehensive framework for the detection and monitoring of new and invasive forest pathogens in the Nordic and Baltic countries is likely to be most reliable if a number of different techniques are used in combination. This report recommends the use of spore trapping and sentinel plantings that target high risk sites (e.g. ports, nurseries, airports, high tourist areas) in combination with widespread forest monitoring potentially as an addition to existing forest monitoring programmes.
- Expertise in forest pathology and plant inspection and surveillance is sorely lacking in many countries and, in its current form, cannot deal effectively with the sheer quantity of import material or the areas of forest. More resources need to be allocated to training plant health officials and better links should be created between on ground staff and researchers/forest pathology experts.

Developing a framework for forest pathology extension

- Each country needs to develop a comprehensive strategy for forest pathology extension and communication with stakeholder groups such as forest workers, policy makers and the general public. This would greatly improve the capacity to respond to and deal with new incursions of forest pathogens.
- More specifically, there appears to be a potential for forest pathology extension services to be better developed to support the surveillance and detection of invasive forest pathogens. This include allocating resources more effectively to provide appropriate training for forest owners and forest professionals carrying out forest health surveys and involving forest pathology researchers more in education and dissemination of their research.
- An improved forest extension can also provide early warning of changes in the level of pathogens already established. This can speed up responses in forestry and make them more timely and cost efficient.

8. Future research needs

As outlined in this report, there are still many unanswered questions about invasive forest pathogens. More specifically this report recommends:

- Increased research programmes on anticipating and avoiding introductions of potentially invasive species. This can include research on what makes an organism invasive and how climate change influences the potential for disease outbreaks.
- Long-term, strategic planning and research around potential forest health problems.
- Research on the links between disturbance ecology and the biotic agents of disturbance.
- Research on management practices aimed to handle invasive or emerging forest disease.
- Practical research to understand the most efficient way in which to design surveillance and monitoring programmes such as the number of survey sites required, the optimal distribution of survey sites, the number of sentinel trees at each site and their optimal distribution as well as the quantity and type of spore trap used.
- A closer examination of the social aspects of invasive species such as effective ways to engage the general public, public attitudes to invasive species in the region and improving communication between stakeholder groups and researchers.

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Appendix 1: Questionnaire for all participants

For each Scandinavian and Baltic country we need to have a brief summary of the existing biosecurity/ invasive species policies (both formal and informal). Please answer the following questions to the best of your knowledge and return to Anna Hopkins by January 27th 2012.

What is the current legislation situation (in addition to the EU legislation)?

- What legislation is there that relates diseases in forests or forest health?
- What legislation is there that relates to the arrival of new species/introduced species?
- What legislation is there that relates to international and domestic trade of wood, plants and plant material?
- Is there any other legislation in your country which may be relevant?

How is the legislation implemented?

- Who is responsible for the legislation and implementation? At what scale and under what circumstances?
- Is there an emergency response strategy in place in case of incursions?
- Are there any existing monitoring programmes in place? Who is responsible for them?

Is the legislation effective?

- Do you see any glaring gaps in the legislation as it is today?
- Are you aware of any problems or difficulties with the way in which the legislation is structured or administered at present?

What opportunities exist for forest pathology extension (e.g. diagnostic services, interaction with forest owners, and the public)?

- What extension services are provided in your country for forest pathology?
- Can you see the potential for forest pathology extension services to be developed further? How?
- What level of public awareness is there about the impact of invasive species?
- Are there any strategies for raising public/forest owner awareness about invasive pathogens?