A Risk Assessment Model on Pine Wood Nematode in the EU

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Abstract

Pine wood nematode, *B. xylophilus* poses a serious threat for the European forest industry. This study applies a quantitative risk assessment to analyze the risk of pine wood nematode in the EU, by estimating the reduction expected within forestry stock available for wood supply and its downstream roundwood market. Spatial analysis is used to join information on climate suitability, host distribution, pest spread and value of assets. Economic impacts are presented spatially on a NUTS-2 scale based on partial budgeting technique and for the EU as a whole based on partial equilibrium modeling. Results highlight the Southern regions of Europe as high risk areas with a total impact on available forestry stock of 19,000 M € after 20 years of an outbreak and no regulatory control measures. Welfare analysis of the roundwood market, inwhich its production represents 2,5% of forestry stock, demonstrates the ability of the producers to pass most of the negative impact to the consumers by charging higher prices. Reduction in social welfare estimated at 2,043 M €, where consumer surplus decreased by 2,622 M € and net producer surplus, affected and non-affected producers, increased by 579 M €.

Keywords: Risk assessment – pine wood nematode – economic analysis - EU

1. Introduction

Since the last century, the increase in international trade of goods and human movements has led to an extension of harmful organisms, exotic pests, beyond their natural range of dispersal. Most introductions of exotic organisms remain unnoticed as the organisms are not able to establish in new geographical areas, but, some have become serious pests of enormous economic impact (*Liebhold et al., 1995).* Successful establishment and spread of an introduced organism into a non-native habitat depends upon a complex interaction of several factors, including climatic suitability, host availability and ability of the organism to increase its population density above the damage thresholds.

According to the International Plant Protection Convention (IPPC) and the World Trade Organisation Agreement on the Application of Sanitary and Phytosanitary Measures (WTO SPS Agreement) (WTO, 2009), any measure against the introduction and spread of new pests must be justified by a science-based pest risk analysis (PRA). As a result, PRAs are an essential component of plant health policy, allowing trade to flow as freely as possible, while minimizing to a reasonable and justifiable extent the risk of introduction of plant pests. Pest risk assessment is considered as the key element in the pest risk analysis as it determines the potential establishment, spread and economic consequences of an exotic pest.

The common practice of pest risk assessments is usually limited to separate spatial modeling of establishment and spread potential and rarely includes an evaluation of the impacts. As a result, modeling and visualizing of the potential economic impacts and their spatial aspects have often been neglected, even though total risk of both invasion and impact clearly varies between geographic domains, especially when the pest risk analysis area is large as the European territory. The objective of this study is to quantify the potential economic impacts of the forestry pest pine wood nematode which threatens to spread to the whole of the EU coniferous tree production and to visualize spatially the resulting economic consequences to enable spatial informed decision making with respect to risk management options.

The pinewood nematode (PWN), *B. xylophilus*), is a major forestry pest that originates from North America, but has spread to Europe [Portugal (Mota et al., 1999)], and East Asia (OEPP/EPPO, 1986). There are about 55 described *Bursaphelenchus* species and of those, *B. xylophilus* is considered the most significant. Most *Bursaphelenchus* spp. are restricted to conifer species, but being a "host" for *B. xylophilus* does not necessarily mean that the nematode is feeding on the tissues of the tree. The nematodes may live on fungi resident within the tree tissues and therefore not all trees "infested" with PWN go on to develop symptoms of pine wilt disease (Sathyapala, 2004).

As the whole of continental Portugal has been considered to be a demarcated area for PWN since May 2008, it is subject to emergency measures set out in Decision 2006/133/EC to prevent the further spread of PWN. These include compulsory heat treatment for all newly produced wood packaging material leaving Portugal. Currently, Portugal has largely insufficient capacity for the required heat treatment of the wood materials that it produces and thus leading to the chance of a spread of the nematode (Anonymous, 2008). Strengthening the control measures may be required to prevent further spread and to eradicate the pest in Portugal. However, these control measures must be cost effective. In order to choose the optimal control method, it is required to know the expected economic consequences on the European scale in forest production and downstream markets that may result from a possible future spread of PWN from Portugal when no control measures are imposed. The described risk assessment will provide this insight together with information on the distribution of the losses among Europe.

2. Materials and methods

The scope of the assessment is to estimate the economic impact resulting from PWN affected trees measured in lost wood volumes in all conifer tree species present in the EU and the subsequent impact on the round wood market resulting from the wood loss.

The key processes within the performed assessment focus on the quantification of the economic impact in relation to the establishment and spread potential of PWN. To link these processes spatial information analysis was combined with economic modeling.

- GIS software is used to spatially integrate data on PWN establishment (determined by climate suitability and host distribution), spread and value of assets (wood production) to identify the areas that are expected to be infested and the value of assets in these areas.
- The economic analysis consisted of two techniques to determine the direct (host related) impact as well as the indirect (non-host related) impact. .
    1. The partial budgeting technique to estimate the direct impact and to obtain insight in the distribution of losses within EU and
    2. Partial equilibrium modeling to estimate the change in social welfare, resulted from direct and indirect impact, on EU level by considering the mitigation and adaption efforts done by the producers.

2.1. Data sources

An extensive dataset of the Alterra[1]/European forest institute (EFI) is used as data source for the assessment (Nabuurs et al., 2007). This set contains climatic data obtained from the public database WORLD CLIM on 1 km^2 resolution level, tree distribution data (conifer or broad leaved) on 1 km^2 resolution level, information on the distribution of trees species and their age on NUTS-2 resolution level, and economic data such as wood production volume and value on the NUTS-2 resolution level. Pest spread data (i.e. expansion range in space and time of the nematode within Europe) is from unpublished work based on Robinet et al. (2009) at a resolution level of 51 km^2(5.5 km x 9.3 Km).

In order to combine the different resolution levels of the datasets, spatial up-scaling techniques are applied (Fig. 1). The resolution of the model results is provided at the NUTS-2 level. In the process of up-scaling, the 1 km^2 resolution climatic data (i.e. temperature and precipitation) are up-scaled by summing to the NUTS-2 level, then spread (8 km^2) is overlaid on the polygon production dataset (NUTS-2 level) using spatial join technique in GIS, and up-scaled to the NUTS-2 level by getting the proportion of the grid-cells that are infested in each polygon (i.e. counting the infested vs. the non-infested grid-cells in each polygon). Finally, the impact is calculated by multiplying the expected area of infestation in the NUTS-2 with corresponding production volumes (see paragraph on impacts).

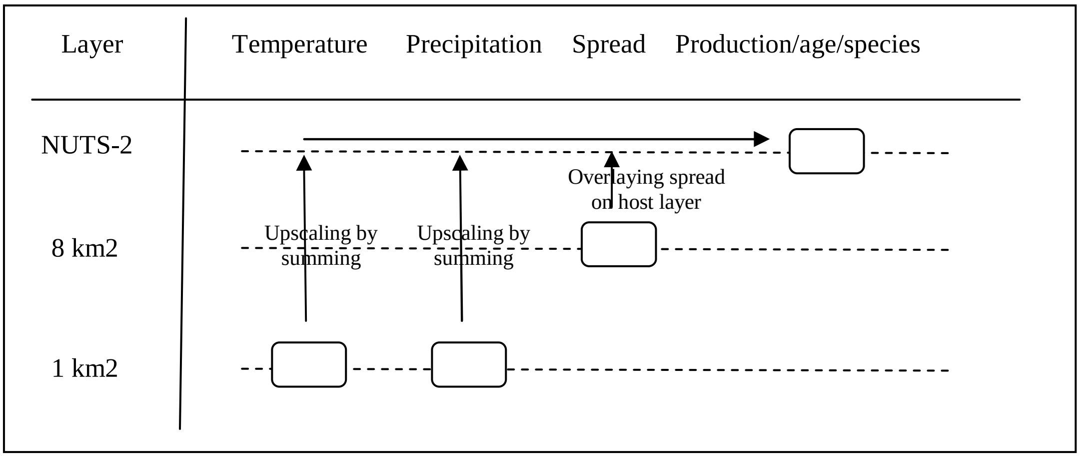

Figure 1 Aggregation of various data resolution levels by up-scaling.

2.2 Establishment

Establishment of *B. xylophilus* and its vector *Monochamus* spp. is dependent on climate, and more specifically on temperature and precipitation in the target area. Usually, development and reproduction of *B. xylophilus* occurs between 15-30ºC. However, development of nematodes has been reported between 35-40ºC in piles of wood chips (Dwinell 1986). It is important to distinguish between climatic thresholds required for survival of the nematode and the thresholds required for symptom expression of wilt disease in the trees that leads to tree mortality as described in the praragraph on “direct impacts”.

In the EU, except for high altitude areas and some northern regions, all areas have average daily summer temperatures between 15-30ºC, and are therefore suitable for

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[1] http://www.alterra.wur.nl/uk/

the establishment of *B. xylophilus* provided that host trees are present (Evans et al.,1996).

- Availability of suitable hosts

Conifer trees are the main host for PWN. *Pinus* spp. is considered the most susceptible species, but the nematode host list also includes species of *Abies, Chamaecyparis, Cedrus, Larix, Picea* and *Pseudotsuga* as well (Evans et al., 1996).

From the Alterra dataset the following host related information is obtained;
(1) fine resolution data for tree area per forestry type (i.e. either conifer or broad leaved) on 1 km2 (fig.2) and (2) coarse resolution data (NUTS-1 or NUTS-2 level) for age class distribution, area (ha) and growing stock available for wood supply (m^3) for 26 countries of the EU. Data representing the situation in Hungary were lacking, therefore Hungary is s not considered in the calculation.

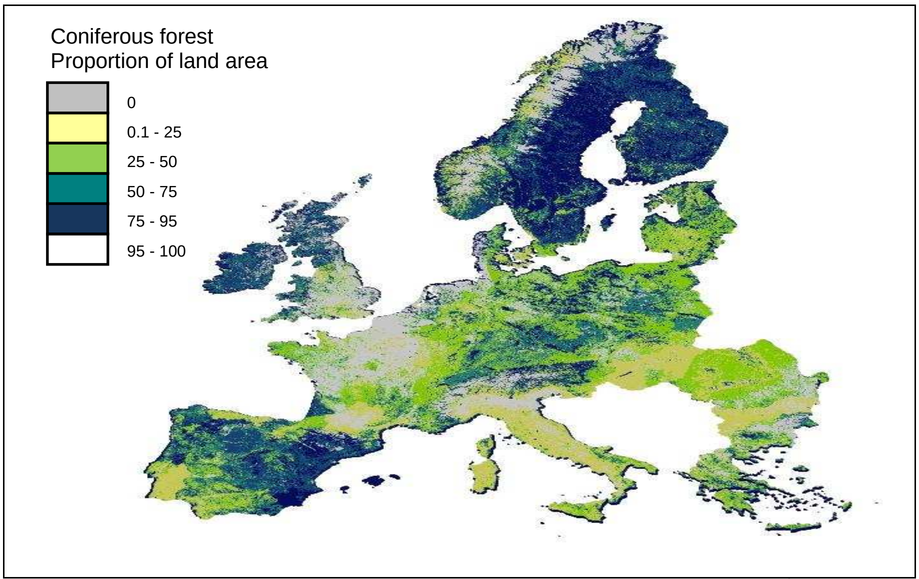

Figure 2 Coniferous forest as a proportion of land area (1 km^2 resolution)

- Suitability of environment

Climatic data is obtained from “World Clim” database. World Clim is a set of global climate layers (climate grids) with a spatial resolution of 1 square kilometer. The data layers are generated through interpolation of average monthly climate data from weather stations on a 30 arc-second resolution grid (often referred to as "1 km^2" resolution). Variables included are monthly total precipitation, and monthly mean, minimum and maximum temperature, and 19 derived bioclimatic variables (Hijmans et al., 2005). In our analysis we differentiated between climatic requirements (in terms of temperature and precipitation) for establishment and for damage expression (fig.3). Damage expression, i.e. wilt disease, is illustrated below in the impacts section. Wilt disease expresses when the nematode is present under warm and draught conditions.

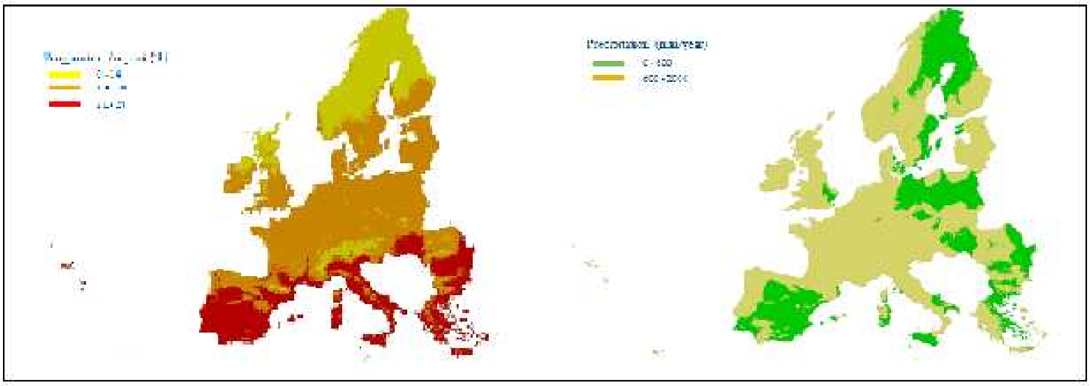

Figure 3 Mean August isotherms (left) and annual precipitation (right) in Europe

2.3 Spread

Pine wood nematode potential spread in the EU till year 2030 is predicted by the spread model (unpublished work based on Robinet et al., 2009). The spread model considers short distance spread of the nematode mediated by long-horned beetles modelled by a diffusion model and long distance spread mediated by potential anthropogenic pathways and the human population density modelled by stochastic, individual based model. The output of the model is presented as a probability of presence of PWN and of pine wilt disease in each grid-cell at EU level. The size of the grid-cell is around 0.08×0.08^{o} (≈ 51 km^2). The model study included 200 replicate simulations to determine the spread till year 2030. The mean resulting probability of presence in each grid-cell was subsequently used to determine the aggregated infestation level in 2030 in each NUTS-2 polygon and at EU scale (Fig 4). The infestation level is defined by the proportion of the grid-cells that is predicted by the model to be infested by the nematode/wilt disease in the EU.

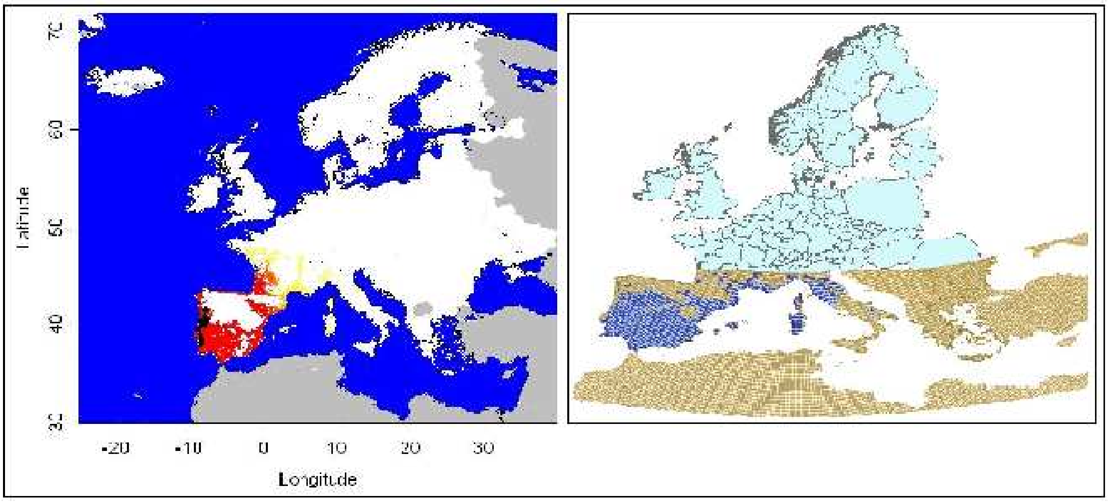

Figure 4 Spread of pine wood nematode (left) and pine wilt disease (right) estimated for 2030 *(unpublished work based on Robinet et al.,2009)*

2.4 Economic impacts

2.4.1 Direct Impacts

The direct impact is calculated by Partial budgeting (PB). PB is a method that addresses the additional costs and lost revenues that are incurred at the producer level when a pest invades (Soliman et al., 2010). The severity of wilt disease as measured in lost wood volume depends on the tree mortality rate. Mortality rate in turn depends on climate suitability, tree species and tree age.

- Climate suitability

Two factors, moisture deficit and high temperatures, have been consistently associated with the expression of pine wilt disease in Japan and in parts of the USA (Rutherford & Webster, 1987). Manifestation of PWD from a PWN infestation is strongly reliant on average daily summer temperature (>20ºC) and annual precipitation (<600 mm) levels in the target area (Sathyapala, 2004). The probability of PWD expression in northern Europe is considered to be low (De Guiran & Boulbria 1986; Evans *et al*. 1996; Braasch and Enzian 2004), while pine forests situated in areas in central and southern Europe with a current average summer temperature above 20°C are more likely to fall victim to the disease (Rutherford and Webster 1987). Areas which meet the conditions for wilt disease expression corresponded with the areas demarcated in the establishment assessment.

- Tree species

The susceptibility or tolerance/resistance of tree species to PWN varies (Evans, 1996) Figure 5 demonstrates the distribution of trees among the EU by their susceptibility.

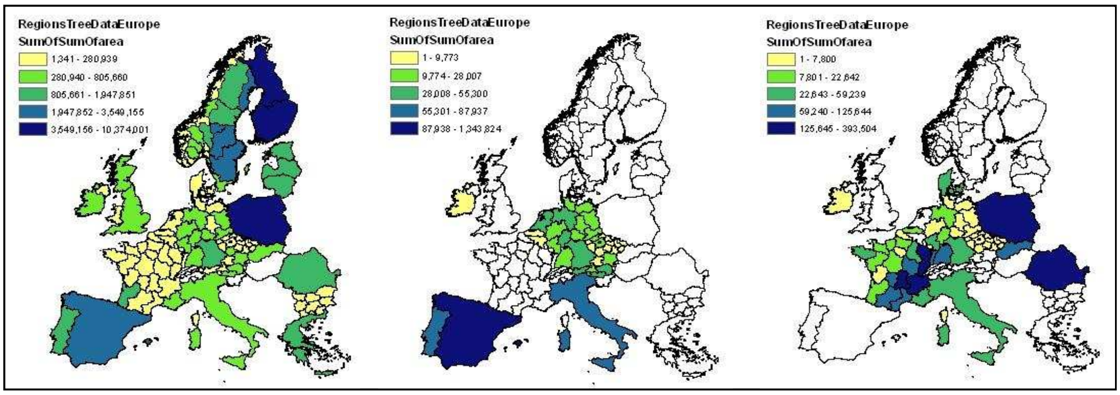

Figure 5 Host area distribution by species vulnerability, categorized by susceptible (left), intermediate (middle) and resistant (right).

- Tree age

In some cases susceptibility seems to depend on the age of the inoculated trees (Bain & Hosking, 1988). Wingfield *et al* (1984) demonstrated that seedling plants of *Pinus* species were highly susceptible to *B. xylophilus*. Inoculation studies conducted on mature *Pinus banksiana*, *P. resinosa* and *P. nigra* in a forest situation failed to kill the trees or produce any detectable damage. However all seedlings of the same pine species inoculated with *B. xylophilus*, under greenhouse conditions, were killed (Wingfield *et al* (1984)).
In the risk assessment model we accounted for the distribution of trees by age and assumed a threshold of 20 years to apply different mortality rates.

Mortality is commonly expressed in terms of loss of volume or basal area per year. Mortality is usually analyzed at the stand level (e.g., average annual mortality per acre per year); or at the population level (e.g., total annual mortality per year for a given region) (FIA, 2003). A resistant species, Masson pine, *Pinus massoniana*, an indigenous species found in 19 southern provinces of China, has suffered from 40%–50% of the tree mortality in southern China (Chai & Jiang, 2003; AAAFD, 1980). Sutherland *et al.* (1991) demonstrated that with susceptible species, such as *Larix laricina* and *L. occidentalis,* suffered 90% mortality when infected at high temperatures. Furuno *et al* (1993) reported approximately 80% mortality of *P. radiata* (intermediate species) to wilt disease in Japan in an experiment conducted from 1960 to 1990. Other experiments conducted in Japan on mature *P. radiata* trees, where a different insect vector (*M. alternatus*) of PWN occurs, recorded tree mortality rates as high as 60% (Sathyapala, 2004). Sathyapala (2004) conclude that in new Zealand (where average daily summer temperature between 18-20), a 60% mortality rate is expected. Simulation presented in the final report of the EU PHRAME project (Anonymous, 2007) suggests that up to 90% of susceptible pine trees (*maritime Pinus,* susceptible species) could die in the Setubal region of Portugal. Mamiya (1983) showed that 90% of the diseased trees (i.e. red and black Japanese pine, which are considered as susceptible species in our model) in Kyushu, Japan has died. Within the performed risk assessment model, mortality rates varied by tree age and vulnerability category (Table 1).

Table 1 Tree Mortality rate due to Pine wilt disease

Age	**Vulnerability**		
	Susceptible	**Intermediate**	**Resistant**
0-20	100% [a]	100% [a]	40 – 50% [e]
20-160	90% [b]	60-90% [c,d]	

[a] Bain & Hosking, 1988

[b] Mamiya, 1983

[c] Sathyapala, 2004; Sutherland et al., 1991

[d] Anonymous , 2007

[e] Chai & Jiang, 2003

2.4.2 Indirect impact

The partial equilibrium (PE) modeling is used to account for the indirect impact of PWN. PE accounts for mitigation (e.g. producers set higher prices to pass part of the negative impact to the consumers) and adaptation (e.g. adjust the production practices to reduce the negative impact of the pest) effects taken by the producers. Therefore, the partial equilibrium modeling extends the impact analysis to the consumers, thereby determining total welfare effects on EU level.

Pine wood is of main importance with regard to the wood supply chain. Due to the complexity of the supply chain of the forestry industry, focus of the indirect impact assessment is on roundwood. The setup of the partial equilibrium model for roundwood is as follows: two markets are distinguished, a domestic market (EU) and a foreign market (rest of the World). Supply and demand are presented in the domestic market, where demand depends on domestic price and consumer behavior. The domestic supply is divided between affected producer and non-affected producers, where supply of affected producer depends on domestic price, producer behavior and the proportion of farmers that is not affected by the pest, while affected producers depend on the previous parameters of non-affected producers in addition to the proportional yield loss, caused by the disease, and by the reduced net price for the product that affected farmers experience as a result of increased costs of production. Furthermore, price in the domestic and world market are linearly related. Trade balance between domestic and foreign markets is expressed by the excess supply (demand) resulted from the difference between domestic supply and demand, which should be equal to excess demand (supply) in the foreign market. The excess demand (supply) of foreign market in return will depend on world price and foreign consumer (producer) behavior.

Moreover, we assume that (1) crop products in the EU and in ROW are perfect substitutes and their respective prices differ only by the transportation costs and tariffs, (2) the domestic market for the potentially affected commodity is perfectly competitive, implying product homogeneity and, (3) the contribution of domestic producers of theaffected commodity to the total world supply is insufficient to exert influence on the world price, the exchange rate and domestic markets for other commodities. The demand and supply in the EU are given by equations 1a-1g (based on Surkov et al., 2009).

$$D_i = \chi_i P_i^{-\eta_i} \tag{1a}$$

$$SA_i = (1-h_i)\beta_i (v_i P_i)^{\theta_i} z_i \tag{1b}$$

$$SN_i = \beta_i P_i^{\theta_i} (1-z_i) \tag{1c}$$

$$S_i = SA_i + SN_i \tag{1d}$$

$$P_i = WP_i + \mu_i \tag{1e}$$

$$X_i = S_i - D_i \tag{1f}$$

$$X_i = \upsilon_i \alpha_i (WP_i)^{\omega_i} \tag{1g}$$

where D_i and S_i are, respectively, demand and total supply of the ith crop in the EU, SA_i and SN_i are the supply of the ith crop by the affected and not affected producers, P_i is the price of ith crop in the EU, η_i and θ_i are the elasticities of demand and supply of the ith crop in the EU, WP_i is the world market price of the ith crop, μ_i is the wedge between the price in the EU and on the world market, and χ_i, and β_i, are parameters. X_i is the excess supply (demand) of ith crop in the EU and ROW, respectively, ω_i is the elasticity of excess demand (negative) or supply (positive) of the ith crop in ROW and υ_i is a parameter and α_i is the proportion of the banned export The impact of pest introduction on supply by the affected growers (equation (1b)) is represented by three parameters: h_i - a horizontal percentage shift in the supply curve due to yield reduction, v_i - a simultaneous vertical percentage shift in the supply curve because of the increased crop protection costs, and z_i - the size of an outbreak, i.e. the percentage of growers of the ith crop affected by pest outbreaks. Input used within the partial equilibrium analysis are presented in table 2.

Table 2 Parameters used in the partial equilibrium model

Parameter	**Round wood**	**Parameter**	**Round wood**
Production (1000 m^3) [a]	295,705	Consumption (1000 m^3) [a]	309,499
Imports (1000 m^3) [a]	37,475	Exports (1000 m^3) [a]	23,681
Total supply	**333,180**	**Total Demand**	**333,180**
Supply elasticity [C]	0.8	Demand elasticity [b]	-0.11
Producer price (€/m^3) [a]	46.6	World price (€/m^3) [a]	48.13
Excess Foreign supply in ROW	5.7		

[a] UNECE/FAO Forest Products Statistics, 2004-2008

[b] Kangas & Baudin (2003).

[C] *Zhu et al., 1998*

3. Results

3.1 Direct impact by timber loss

Table 3 and figure 6 show the direct impact expressed in timber loss measured in m^3 and in Euros. The direct impact is presented on country level for Portugal, Spain and Italy, and on NUTS-2 level for France.

Table 3 Direct damage of PWN in Europe

Country	Provence	Proportion of infested area (%)	Impact 1000 (m^3)	Impact 1000 (€)
France	Aquitaine	17	13	641
France	Corse	55	9	445
France	Languedoc-Roussillon	51	17	815
France	Limousin	2	11	545
France	Midi-Pyrenees	23	17	829
France	Provence-Alps Cote d'Azur	39	12	591
France	Rhone-Alps	10	19	930
Italy	Italy	29	8	409
Portugal	Portugal	81	94,466	4,402,127
Spain	Spain	68	318,637	14,848,510
Total	**EU**	**26%**	**413,215**	**19,255,846**

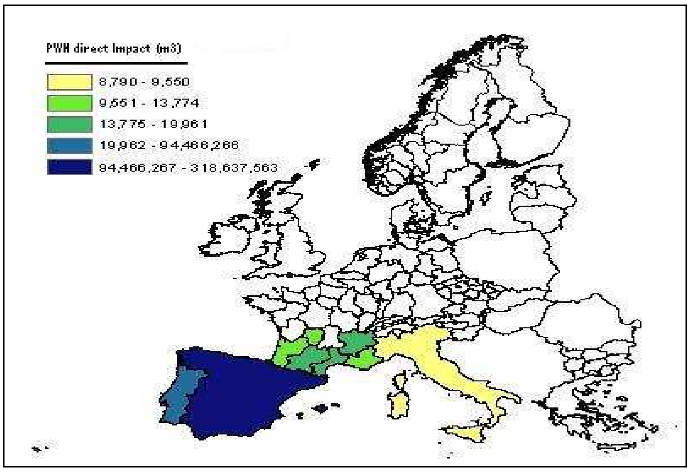

Figure 6 Distribution of PWN direct impact among Europe (m^3)

3.2. Indirect impact

The results of the partial equilibrium analysis show that domestic supply of round wood (affected and non-affected producers) will decrease by 26.9 M m^3 (9%), which will increase the domestic market price from 47 to 56 €/m^3 (18%), and this domestic price increase will drive the domestic demand to decrease. The shortage in domestic supply (gap between supply and demand) will be covered by an increase in the imports which account for 21.2 M m^3 (57%). At the same time, the increase in domestic price will trigger an increase in the world price. The increase in prices will trigger again the supply to increase leading to an equilibrium in the market. The majority of the negative impact will be absorbed by the consumers. The net social impact (impact on producers and consumers) is estimated at 2,043 M €, where the negative impact on consumers is 2,622 M € and a positive impact on producers of 579 M €.

4. Conclusions and recommendations

The above analysis demonstrates that pine wood nematode will lead to enormous negative economic consequences on the conifer forests and forestry industry in Europe. The economic impacts considered were timber loss, changes in domestic supply and demand, changes in trade balance, effects on domestic and world prices and changes in social welfare that are determined by producer and consumer surpluses. A high timber loss is estimated in southern Europe, namely in Portugal, Spain, Italy and France. An average mortality rate in the risk area is estimated at 80%. Loss in standing volumes available for wood supply for Portugal and Spain are the highest and are estimated at 61% and 54%, respectively. This high loss is due to wide spread of PWN in these countries, which are important suppliers of wood in the EU and conifer tree species available in both countries are ranging from susceptible to intermediate species. In Italy, conifer host trees are available in low densities which will reduce the impact. Concerning France, only southern parts could be affected by the nematode. The analysis shows that the round-wood producers will be able to pass most of the negative impact to the consumers by charging higher prices. The small slope (less elastic) of demand/supply leads to an equilibrium (market clearing) through prices instead of quantity adjustment in response to the PWN invasion. Due to the fact that demand elasticity is much smaller (0.11) than supply elasticity (0.8), consumers will bear a greater proportion of the PWN invasion burden than producers. Elasticity used in the model is point of estimation elasticities, which may require a sensitivity analysis for caution.

In this study, PB has a wider scope in assessing the impact than PE, despite the fact that PE covers beside direct impacts also the indirect impacts. PB covers the loss in stock available for wood supply and as the stock is used by current and future generations, PB considers the temporal dimension of the impact, which is not taken into account in the PE. Within the PE focus is on consequences of the annual production of round-wood which is equivalent to 2.5% of the forestry stock. Modeling only the round-wood market in PE and ignoring the impact on other downstream markets such as other woodworking industries, pulp and paper industries and the printing industries could lead to underestimating the impact, while ignoring the substitutes markets in the analysis could lead to overestimating the impact.

Assessing the economic impact using partial equilibrium technique rather than partial budgeting prevent overestimating the impact on producers by taking into consideration mitigation and adaptation possibilities. This means that to determine the overall risk of a pest within a permanent host like forestry, partial budgeting is enough, however partial equilibrium is needed if we desire to know the details of the distribution of the risk between producers and consumers, the size of indirect costs (e.g. reduction in exports without an export ban), and the effectiveness of mitigation and adaptation strategies of producers to transfer the negative impact to the consumers.

In this study the potential economic consequences are presented at the NUTS-2 regions. This risk assessment depends on inputs for the area that is climatically suitable for establishment, the rate of spread and mortality rates. Since the NUTS-2 regions cover quite wide areas, some of these inputs represent a broad approximation. However, for a PRA analyst this spatial output representation should be sufficient for policy analysis as it is able to provide insight in the total economic impact distributed over the endangered area and the relative damage compared to the attainable yield.

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