RAPID COMMUNICATION

The influence of the North Atlantic Oscillation on the potential distribution areas of *Bursaphelencus xylophilus* in Europe based on climatological reanalysis data

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Abstract

Pine wood nematode (*Bursaphelenchus xylophilus*) (Aphelenchida: Parasitaphelencidae) is one of the most harmful agents in coniferous forests. The most important vectors of pine wood nematode are considered to be some *Monochamus* species (Col.: Cerambycidae), which had been forest insects with secondary importance before the appearance of *B. xylophilus*. However, the continuous spreading of the nematode has changed this status and necessitated detailed biological and climatological investigation of the main European vector, *Monochamus galloprovincialis*. The potential distribution area of *M. galloprovincialis* involves those areas where the risk of the appearance of pine wood nematode *B. xylophilus* is significant. The main objective of our analysis was to obtain information about the influencing effects of North Atlantic Oscillation (NAO) on the potential European range of *B. xylophilus* and its vector species *M. galloprovincialis* based on the connection between the mean temperature of July in Europe, the distribution of day-degrees of the vector and the NAO index. Our assessment was based on fundamental biological constants of the nematode and the cerambycid pest as well as the ECMWF ERA5 Global Atmospheric Reanalysis dataset. Our hypothesis was built on the fact that the monthly mean temperature had to exceed 20°C in the interest of an efficient expansion of the nematode. In addition, the threshold temperature of the vector involved in the calculations was 12.17°C, while the accumulated day-degree (DD) had to exceed the annual and biennial 370.57°DD for univoltine and semivoltine development, respectively. Our finding that a connection could be found between a mean temperature in July above 20°C and NAO as well as between the accumulated day-degrees and NAO can be the basis for further investigations for a reliable method to forecast the expansion of pine wood nematode and its vector species in a given year.

Keywords: *Bursaphelencus xylophilus*, distribution, ECMWF ERA5 reanalysis dataset, NAO, pine wood nematode, temperature

The pine wood nematode, *Bursaphelencus xylophilus* (Steiner and Buhrer, 1934) Nickle, 1970 (Aphelenchida: Parasitaphelencidae) is one of the most devastating pests of some species of pine and less frequently of other coniferous genera, such as *Abies*, *Larix*, and *Picea* (Evans *et al.* 1996). The first obvious external symptom is the yellowing and wilting of the needles, leading to eventual death of the tree (Mamiya 1983). The pest is native to North America, but it has already spread all over the world since the beginning of the twentieth century. In Europe, the species is already established in Portugal and in some localities of Spain (references starting from 1999), but it has also been occasionally detected in imported timber and wood package material from Finland, Norway, Sweden, France and other countries (EPPO 2019). If global warming trends continue, the pine wood nematode (*B. xylophilus*) could become a particularly important forestry pest in the near future owing to its appearance and potential spread in these northern European regions (in the first instance: Scandinavian countries) (Kempeneers *et al.* 2011). Some *Monochamus* species (Coleoptera: Cerambycidae) play a role in its spread as vectors, therefore it could easily invade and destroy pine forests (Giblin-Davis *et al.* 2003). With regard to these facts, the pine wood nematode and its vectors are regulated by the European Union (EU 2000) and by other EPPO countries, on the basis of a detailed Pest Risk Analysis (Evans *et al.* 1996).

Obviously, both the local and the global expansion of this nematode pest is connected to several specific eco-climatological features which can influence the potential distribution of this species. Among others (Gruffudd *et al.* 2019) a mean temperature in July above 20°C is a potential factor, which is widely considered to be the main source of disease outbreak (Rutherford *et al.* 1990; Gruffudd *et al.* 2016). In order to try to predict the mean temperature of July, a large-scale process was needed which can be a reliable predictor of this parameter. The North Atlantic Oscillation (NAO) is one of the most relevant atmospheric phenomena which highly influences short-, medium- and long-term weather patterns from the USA to Russia (Li *et al.* 2013). The NAO is an interannual fluctuation of sea level pressure (SLP) between the Icelandic low and the Azores high pressure systems (Glowienka-Hense 1990). If the meridional SLP gradient is enhanced, the NAO is in its positive phase with strong westerly winds and significant advection of mild moist air masses toward northern Europe. An anticyclone with no precipitation and greater daily temperature range govern the weather in central Europe and on the Iberian Peninsula especially in winter (Trigo *et al.* 2002). The negative phase of NAO spells weak meridional gradient in SLP owing to cold and dry air in northern Europe, and to milder and wetter air streams over the Mediterranean (López-Moreno and Vicente-Serrano 2008).

The main objective of our analysis was to obtain information about the influencing effects of NAO on such parameters like the mean temperature of July above 20°C in Europe, and the distribution of day-degrees of *Monochamus galloprovincialis.*

In order to establish a putative connection between NAO and the spreading of *B. xylophilus* and its vectors in Europe, the monthly mean temperature in July was calculated between 2003 and 2018. The gridded temperature data were retrieved from the www.ecmwf.int website, ERA5 Global Atmospheric Reanalysis dataset (Copernicus Climate Change Service (C3S) 2017). Daily, four temperature data were applied (0, 6, 12, 18 UTC) to calculate the monthly mean temperature on 2,437 grid points with 55.8 km × 55.8 km (0.75° × 0.75°) resolution. The northwestern corner of the domain was N60°W11.25°, the southeastern corner was N39°E51°. The monthly NAO indices were retrieved from the dataset of NOAA Climate Prediction Centre (www.cpc.ncep.noaa.gov). In order to calculate the monthly mean standardized 500 mb height anomalies in the region of 20°N and 90°N, and so the NAO index, the Rotated Principal Component Analysis (RPCA) (Barnston and Livezey 1987) was used with data standardized between 1950 and 2000 (NOAA Climate Prediction Center 2008). One-way ANOVA was employed to identify the connection between the mean temperature above 20°C in July and the NAO index. As a second step, the relationship between the accumulated day-degrees of the vector species, the NAO index was studied between 2003 and 2018. The accumulated day-degrees of *M. galloprovincialis* was calculated in the growing season between 15th April and 30th November on each grid point. To map the voltinism of *M. galloprovincialis* in Europe, the cumulated temperature amount (T) in the growing season was calculated as:

$$T = \Sigma_n \times (t_{AVG} - t_0),$$

where: Σ_n = number of days in the growing season, t_{AVG} = daily average temperature, t_0 = biological threshold 12.17°C.

The annual and biennial accumulated day-degrees had to exceed 370.57°DD for univoltine (one generation per year) and semivoltine (one generation develops during several years) development, respectively. To reveal the connection between day-degrees and NAO, one-way ANOVA and multiple linear regression (*MLR*) were used on each grid point. The calculations and visualization were performed by R language and statistical computing (R Development Core Team 2008).

According to the study of Rutherford *et al.* (1990), a significant factor in disease expression is the mean temperature of July that optimally exceeds 20°C. While NAO is a large-scale atmospheric phenomenon, and it has higher variability in winter (Hurrell and Deser 2009), it presumably has a great influence on the temperature in July in Europe. Figure 1A shows the NAO indices and the number of grid points with monthly temperatures above 20°C in July between 2003 and 2018. To confirm the statistical connection, one-way ANOVA was used (Table 1). It was assumed that the data had normal distribution $N(m, \sigma^2)$ with m expected value and σ^2 variance. Null hypothesis (H_0) declares that there is no significant difference between the area (number of grid points) above 20°C in July and the NAO indices. A Fischer's F-test was performed. The calculated F-value is 533.4453, while the critical F-value with n-2 freedom of degree (df = 31) and on 0.05 significance level is 4.17087. The calculated value exceeds the critical value. Besides, the p-value is 1.16×10^{-20}. Based on these results it can be stated that H_0 can be rejected, because there is significant

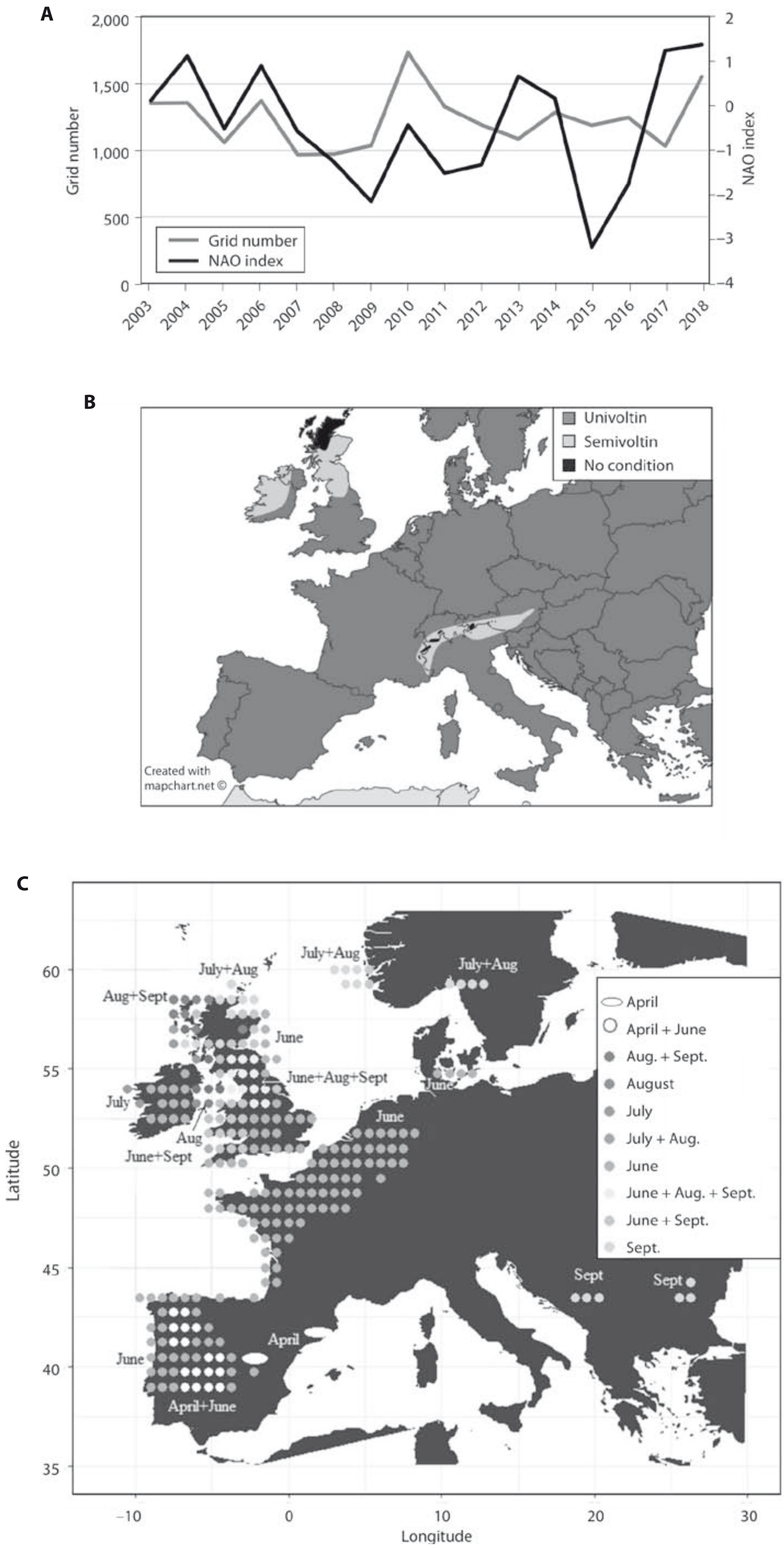

Fig. 1. (A) The expansion area (grid number) of the monthly mean temperature above 20°C in July in Europe and the North Atlantic Oscillation (NAO) indices between 2003 and 2018. (B) Voltinism of *Monochamus galloprovincialis* in Europe based on threshold temperature 12.17°C and accumulated day-degrees 370.57 °DD. (C) Significant months of NAO indices which have a major role in accumulation of day-degrees (°DD)

Table 1. Results of one-way ANOVA calculated between the grid number of the mean temperature in July above 20°C and the North Atlantic Oscillation (NAO) index in July in the corresponding year

ANOVA	*SS*	*df*	*MS*	*F*	*p*-value	*F* crit.
Between	12,237,714.86	1	12,237,715	533.4453	1.16×10^{-20}	4.170877
Inside	688,227.0052	30	22,940.9			
Sum	12,925,941.86	31				

SS – sum of squares; *df* – degrees of freedom; *MS* – mean squares

correlation between the two studied variables. Since the prediction of atmospheric pressure is more reliable than 2-meter temperature, NAO can be a proper predictor in forecasting the expansion of the area above 20°C in July.

Another critical factor to the spreading of the pine wood nematode is the habitat of its vector, the *M. galloprovincialis*. Figure 1B shows the voltinism of *M. galloprovincialis* in Europe calculated between 2003 and 2018. Most of Europe, including the British Isles up to the southern border of Scotland and the eastern coastal region of Ireland, cover the univoltine development areas. The semivoltine development area can be found in Scotland up to the Ivnerness-Glasgow line and in the Alps. There are no suitable conditions for development in northern Scotland and on the higher peaks of the Alps. In order to evince the connection between monthly NAO index and the accumulation of day-degrees, multiple linear regression was used on each grid point. The independent variables were the monthly NAO indices (April–November) over 15 years, and the dependent variables were the values of day-degrees on 2,437 grid points. Figure 1C shows the months when the NAO had significant influence on the accumulation of day-degrees. In western and southwestern parts of Europe including a part of Benelux, France, Portugal, Spain, as well as the southeast part of England the NAO had a significant influence on the accumulated day-degrees in June. On the Iberian Peninsula in April and June, in northern Scotland and in the southern part of the Scandinavian Peninsula in July and August NAO had a major role on the day-degrees. The most complex effect of NAO can be observed on the British Isles and in Ireland. The farthest part of Europe which links to NAO are the south-eastern parts of Europe, where there is a significant influence of NAO on day--degrees in September.

Climate has long been considered to be an important factor, often impacting the periodicity of forest pest mass reproduction and the severity of the problem that it causes (Hepting 1963). Accordingly, during the last decades, the effects of climate change on forestry ecosystems have received increasing attention. Abiotic changes as a whole have gradually altered ecological processes, as well as flight phenological features and distribution patterns of both native and adventive pests in forests all over Europe and North America, presenting new challenges for forest managers (Pureswaran *et al.* 2015). The North Atlantic Oscillation is a new approach to predicting the interannual variability of those major parameters like the temperature of July above 20°C, or the day-degrees of the vector species, which can influence the spreading of the nematode in a given year. Furthermore, the regions in Europe and the growing season months were specified as to where and when the NAO can be applied as a predictor.

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