Forest Research

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Using an Evapo-Transpiration model to predict the current and future impact of pine wilt disease caused by pine wood nematode, *Bursaphelenchus xylophilus* in Europe

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rephrame

Outline of Presentation

- Development of ETpN (Evapo-Transpiration + Nematode) model – Extension of original ETp (Evapo-Transpiration) model.
- Model Calibration & Validation – Portugal & Japan
- Simulations in Europe
- User-Friendly Sub-model
- Latency Sub-Model
- Future spread of pine wilt disease due to climate change
- Conclusion

Pine Wilt Disease

- Pine Wilt Disease (PWD) is a xylem restricting disease caused by pine wood nematodes (PWD), *Bursaphelenchus xylophilus* that enter the tree and through feeding on cells surrounding the resin ducts, cause cavitations in the tracheids.
- Pine sawyer beetles (*Monochamus* spp.) vector the nematodes. The nematodes are carried from dead trees to living trees when the beetles emerge in spring from dead wood and feed on the young shoots of pine trees.
- The pine wood nematode, native to North America does not kill native American pines. Many Asian and European pines are highly susceptible.
- Pine wilt disease can kill pine trees within a few weeks to a few months from being infested.
- PWN can persist inside living trees without causing PWD if conditions are not right, i.e. climate not hot enough.

Modified Model

Modifications to Original ETP model:

1. Nematode element: calculates number of adult nematodes N_i and juveniles J_i on day i, with a temperature dependent growth rate: r_i

$$N_i = N_{i-1} + r_{i-3} N_{i-4} - r_{i-19} N_{i-20}$$
$$J_i = J_{i-1} + r_i J_{i-14} - r_{i-3} N_{i-4}$$

2. Photosynthesis element: relating nematode number to the severity of cavitations and using logistic curves to restrict photosynthesis.
3. Available energy element: calculates the energy E_i on day i, dependent on photosynthesis Ph_i and nematode number. The amount of energy used in defence is related to number of nematodes

$$E_i = [1 - (1 - \sigma) f_1(N_i)] E_{i-1} + f_2(\lambda, \omega) Ph_i$$

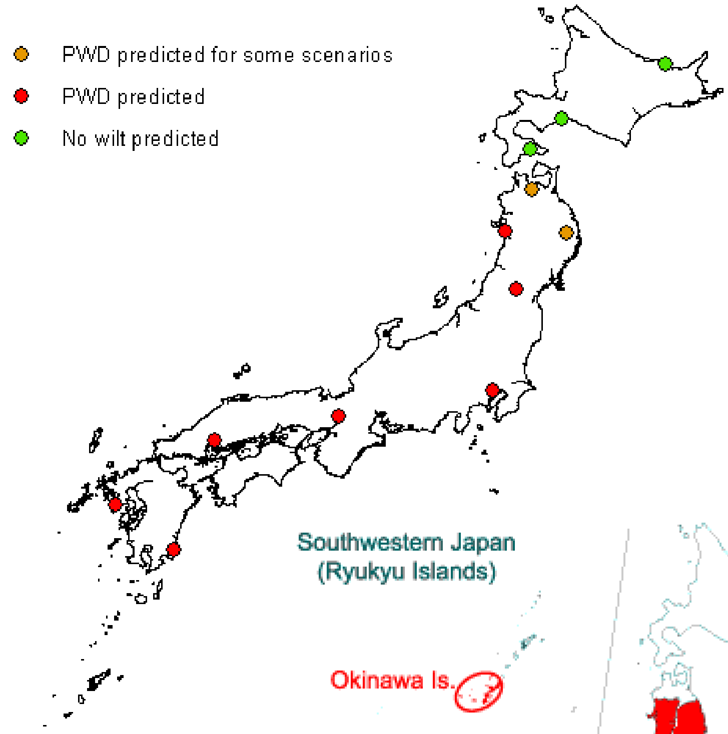
where σ is resistance, λ is day length and ω is leaf area of tree.

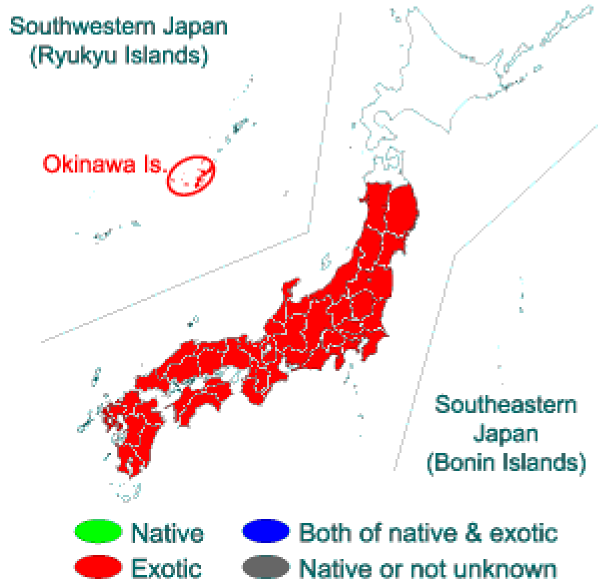
Forest Research — Model Input and Parameters

- The ETpN model requires **daily climate data** or **monthly climate data** plus **standard deviations** as model input.
- The model also requires parameters relating to **soil, tree species, local properties** and in the modified model we require: **initial nematode number, infestation day, tree tolerance and initial storage energy.**
- Sensitivity Analyses show that the key parameters affecting model output are **inoculation day** and **tree tolerance**. The key climatic inputs that drive the model are MST – mean summer temperature, MAT – mean annual temperature and MSP – mean summer precipitation.

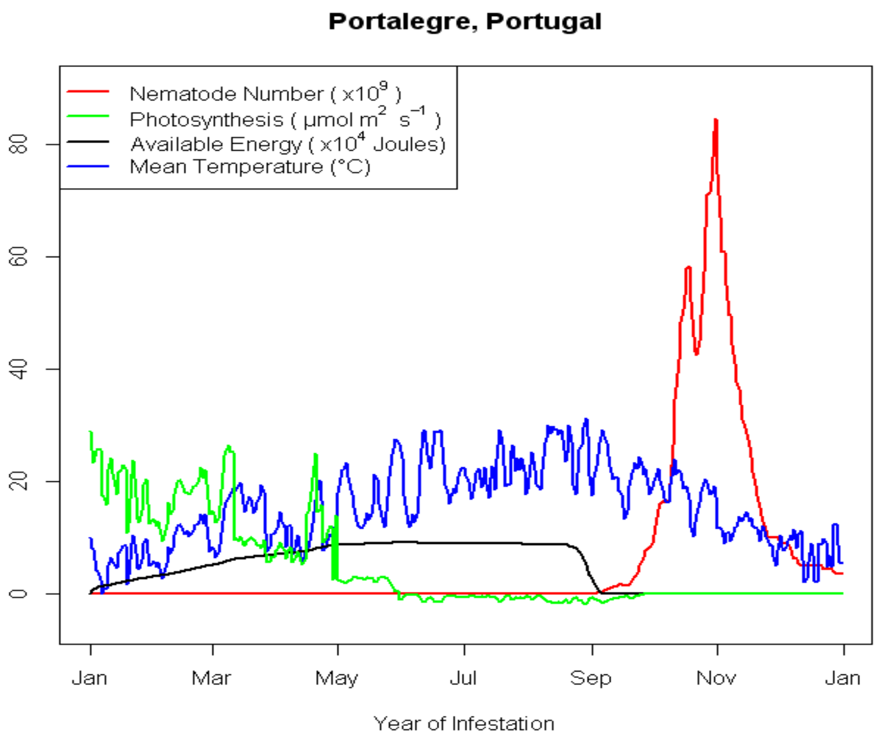
Model Validation - Japan

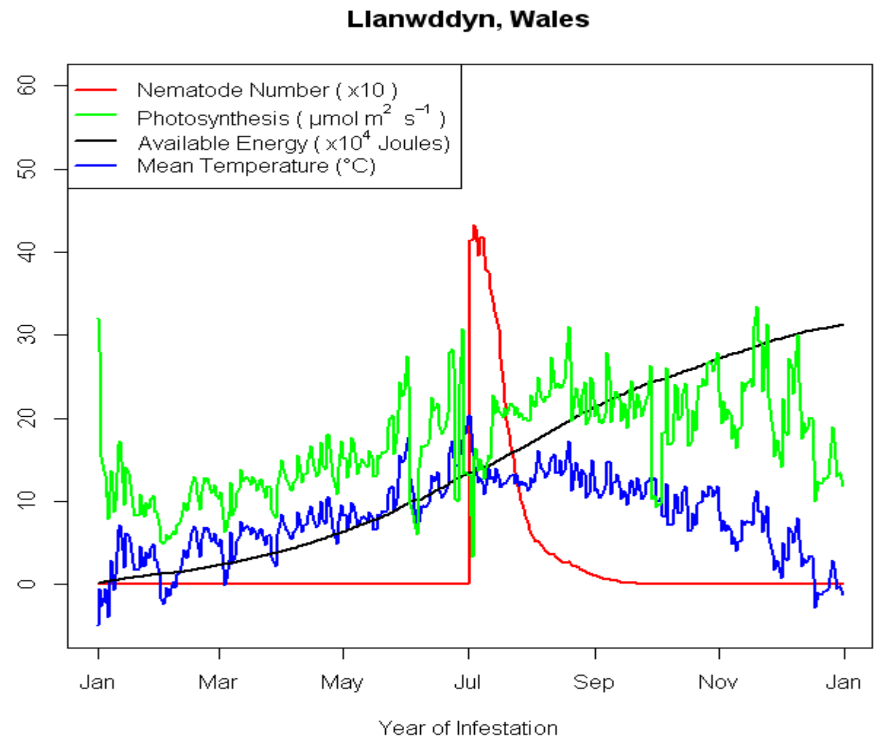
- We use data from Portugal and Spain and results from the literature to calibrate the model. Levels of tolerance in the interval:$0.1 <= \sigma <= 0.3$ give accurate output in the ETpN model.
- The ETpN model is run for 12 locations in Japan.
- The bottom right map (National Institute for Environmental Studies - Invasive species of Japan) shows the extent of PWD in Japan.
- The ETpN model predictions for Japan are in agreement with what has been observed in Japan.





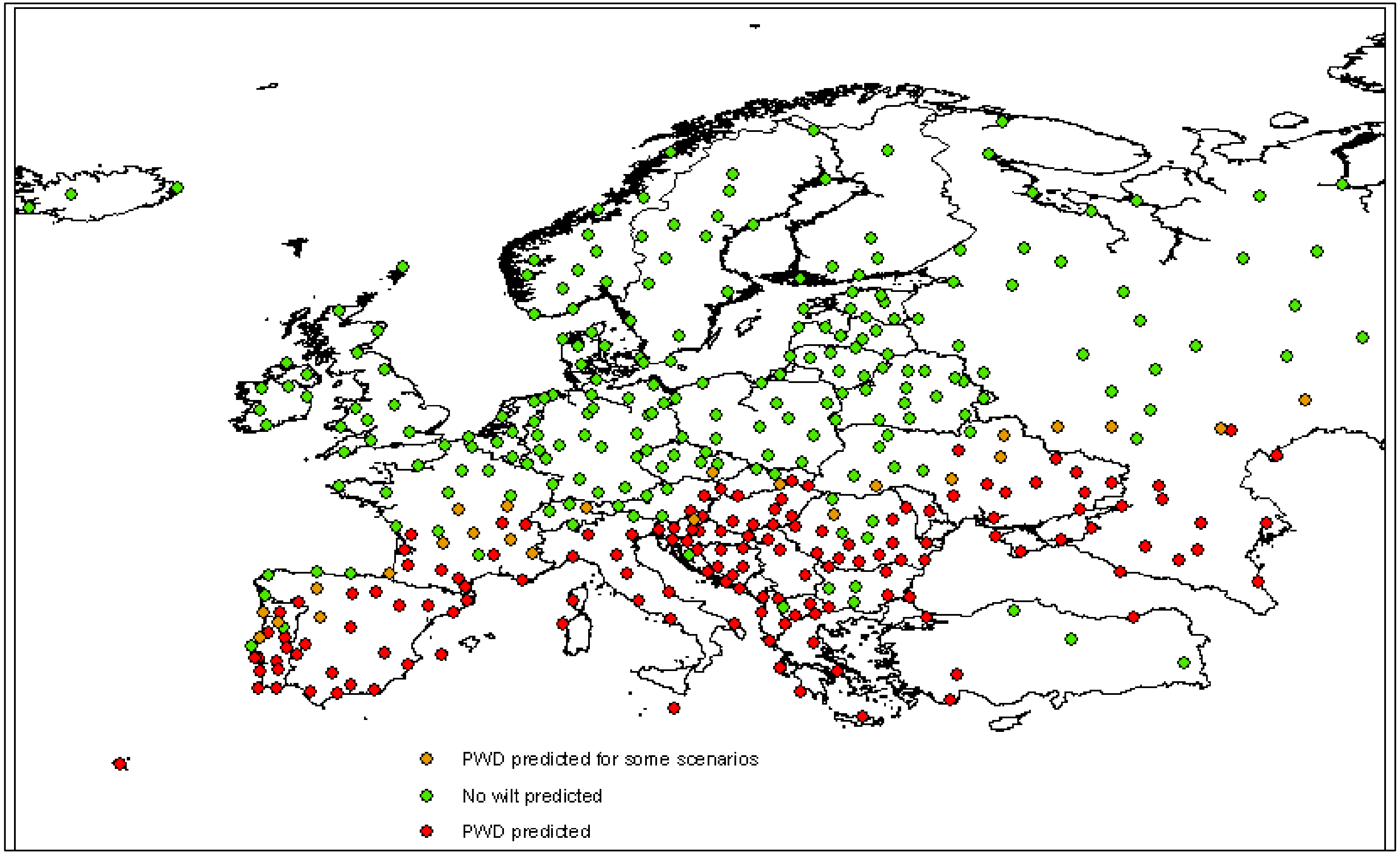
Model Output – Portugal and Wales





- We inoculate 500 nematodes on 1st July. Tolerance is set at 0.17.
- **Llanwddyn:** nematode numbers reduce almost as soon as they enter the tree and by mid Sept have become zero. Mean summer temperature (MST) gets above >20°C for only two days of the year.
- **Portalegre:** MST >20°C for 75% of the days between infestation and death. Tree dies around 10 weeks after infestation.

Predicted Wilt Expression 2009



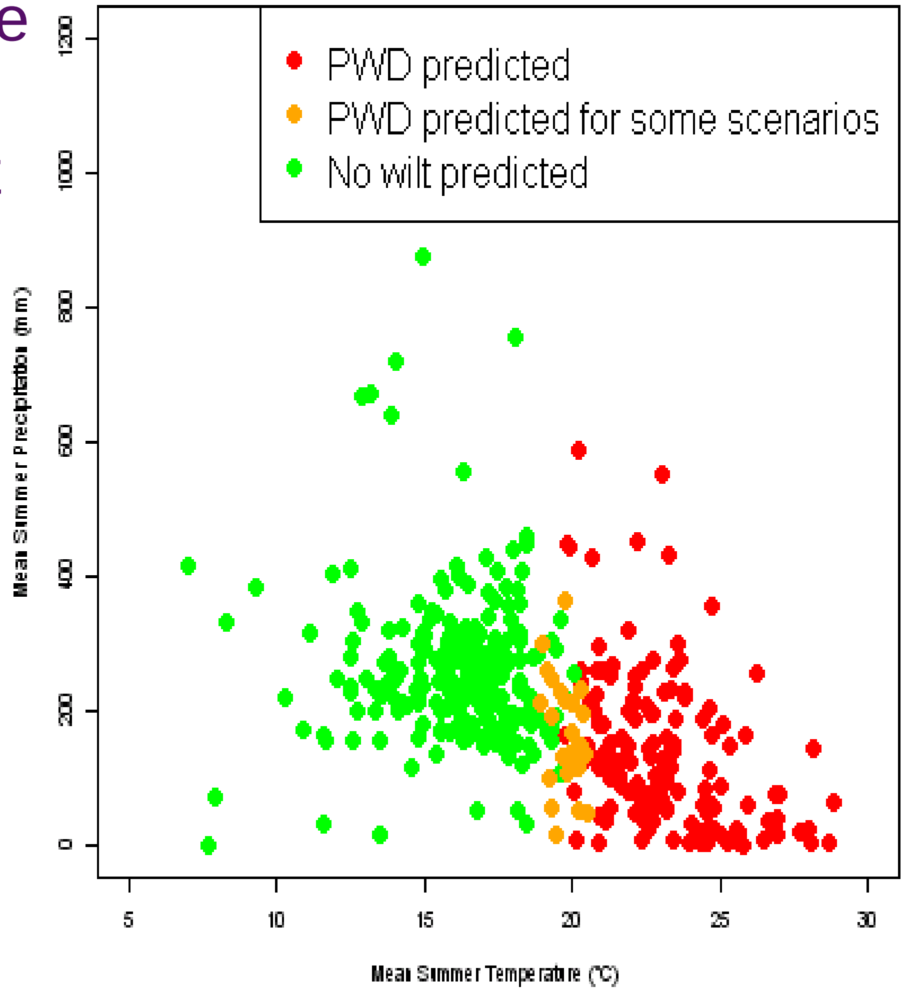
Model output for over 400 locations across Europe. Red points are within or very close to the region predicted by Evans *et al.* (2002)

Thresholds for Wilt

T-tests yield significant differences in the Mean Summer Temperature and Mean Summer Precipitation between locations expressing wilt and those that don't.

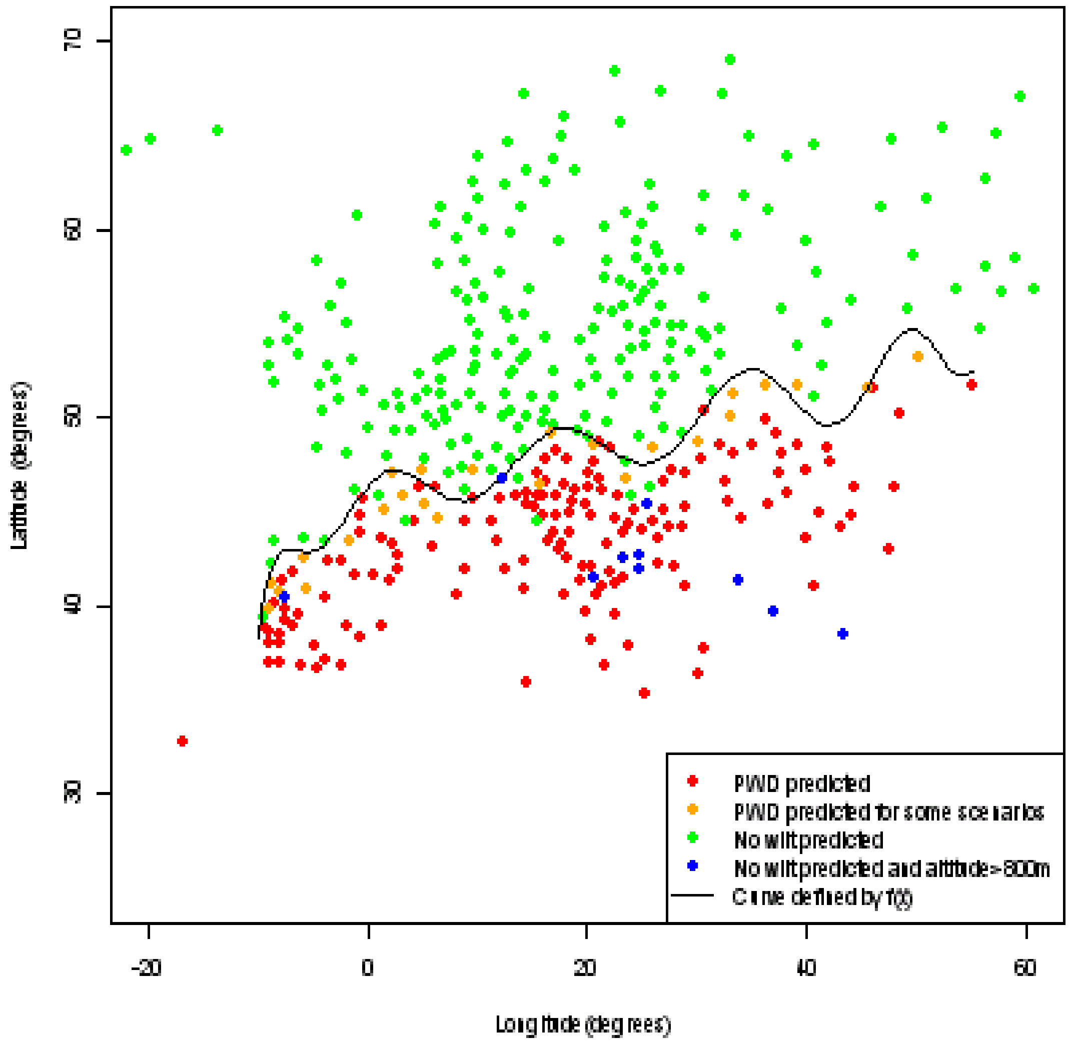
The graph shows a clear split of points at around MST = 20°C. The ETpN model predicts:

- **Wilt** for 99% of locations with MST $\geq$ 20°C
- **No wilt** for 100% locations with MST<19.31°C
- **Wilt for some parameters combinations** for 83% locations with 19.31°C $\leq$ MST<20°C



Further Simplified Model

- MST can be used to predict the locations for which the model predicts wilt.
- If climate data is unavailable a users location can be used to give a relatively good prediction of likelihood of wilt.
- **Green** points - locations where model predicts no wilt.
- **Red** points - locations where model predicts PWD.
- **Amber** points - possible locations for PWD.
- **Blue** points - locations with altitude>800m and where model predicts no wilt.
- We can estimate locations where model predicts wilt, for x=longitude and f(x)=latitude with:

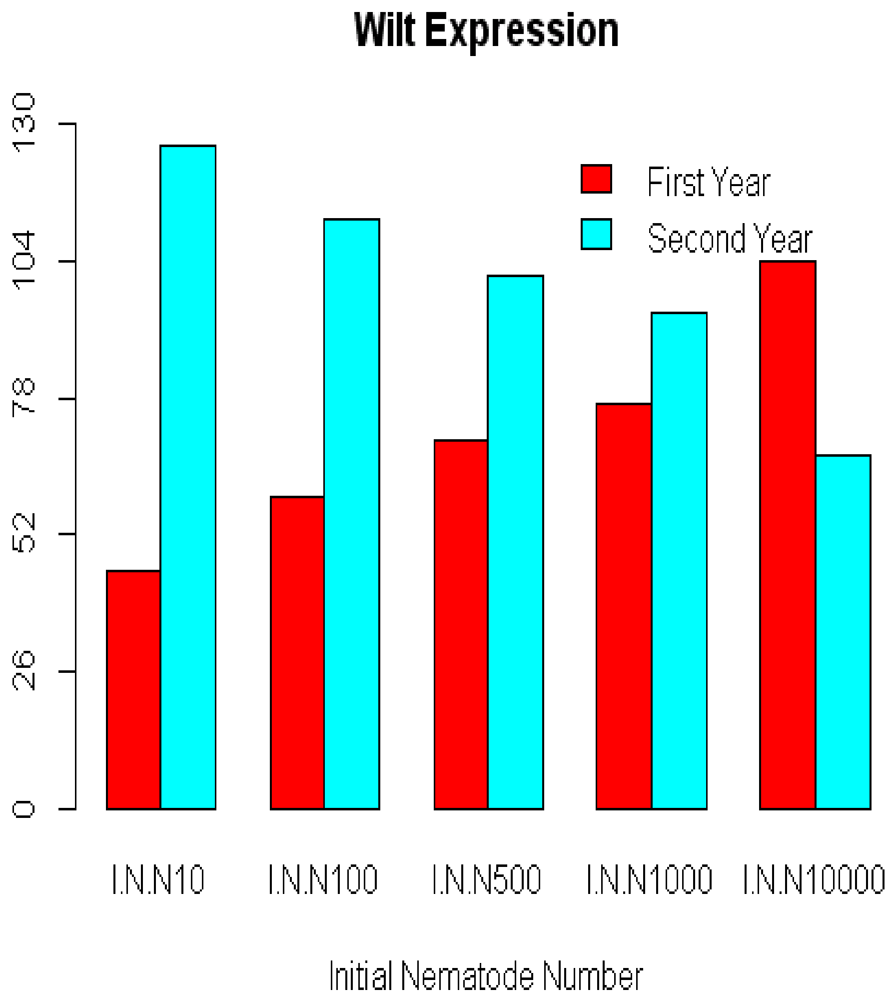


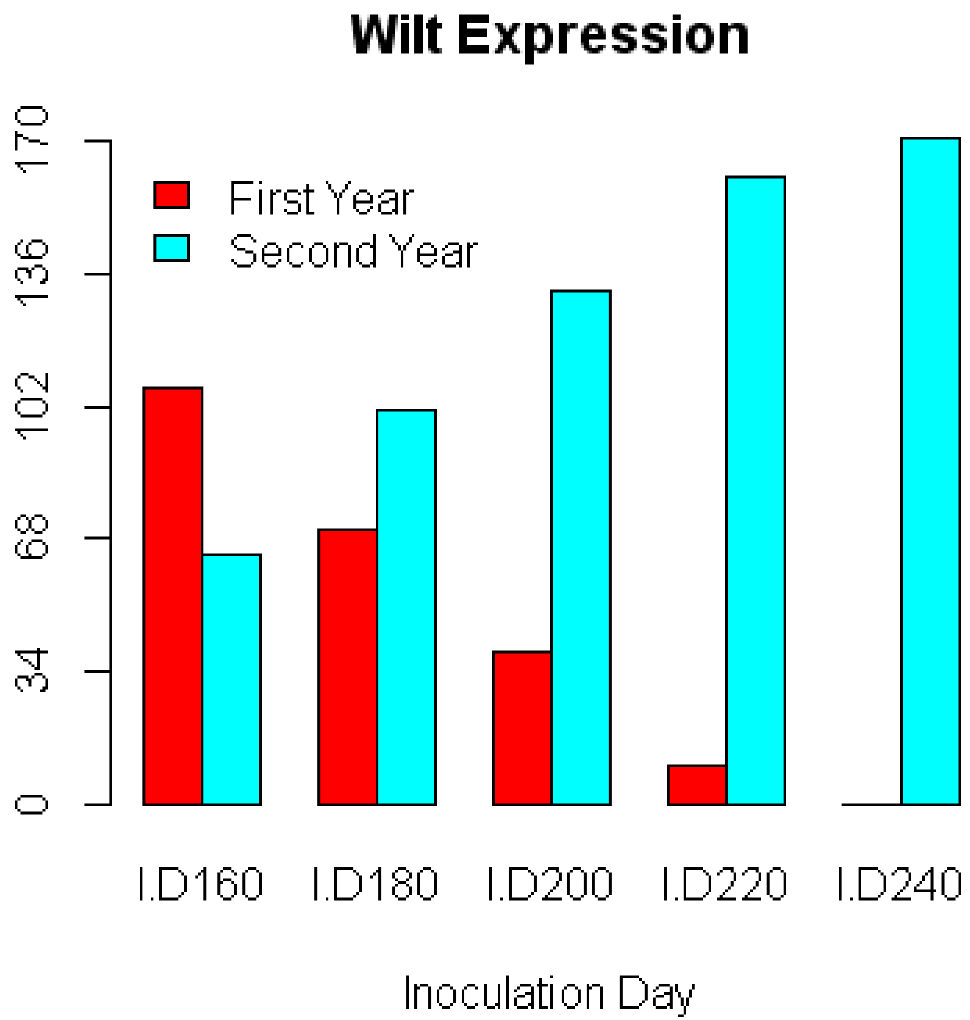
$$f(x) \leq a_{13}x^{13} + a_{12}x^{12} + \cdots + a_2x^2 + a_1x + a_0$$

Latency in Wilt Expression

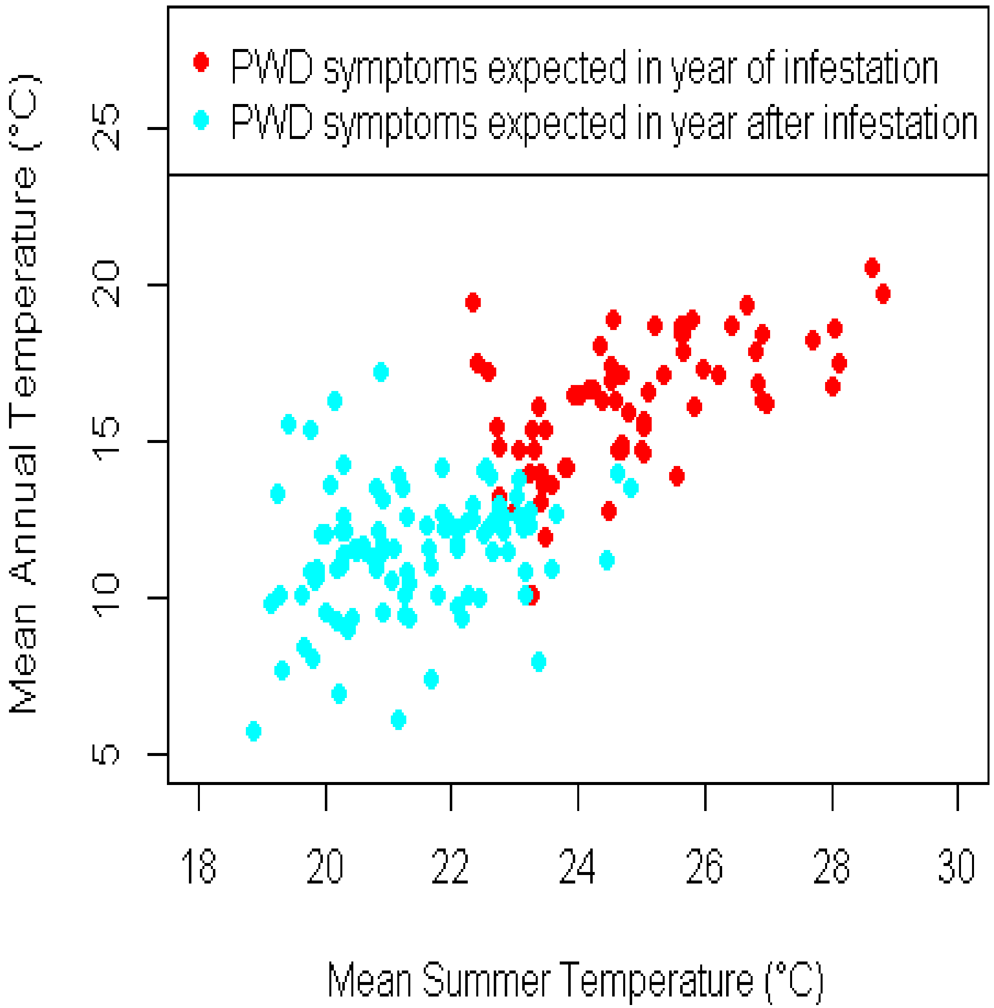
- Latency in wilt expression has been observed in the field as well as experiments. *B. xylophilus* can persist in living pine trees without inducing PWD.
- Latency in symptom development is an important feature in management and eradication of PWD.
- Understanding what factors cause latency will allow better management
- We evaluate the affect that the model parameters and climate data have on timing of wilt expression.

Affect of parameters on Latency





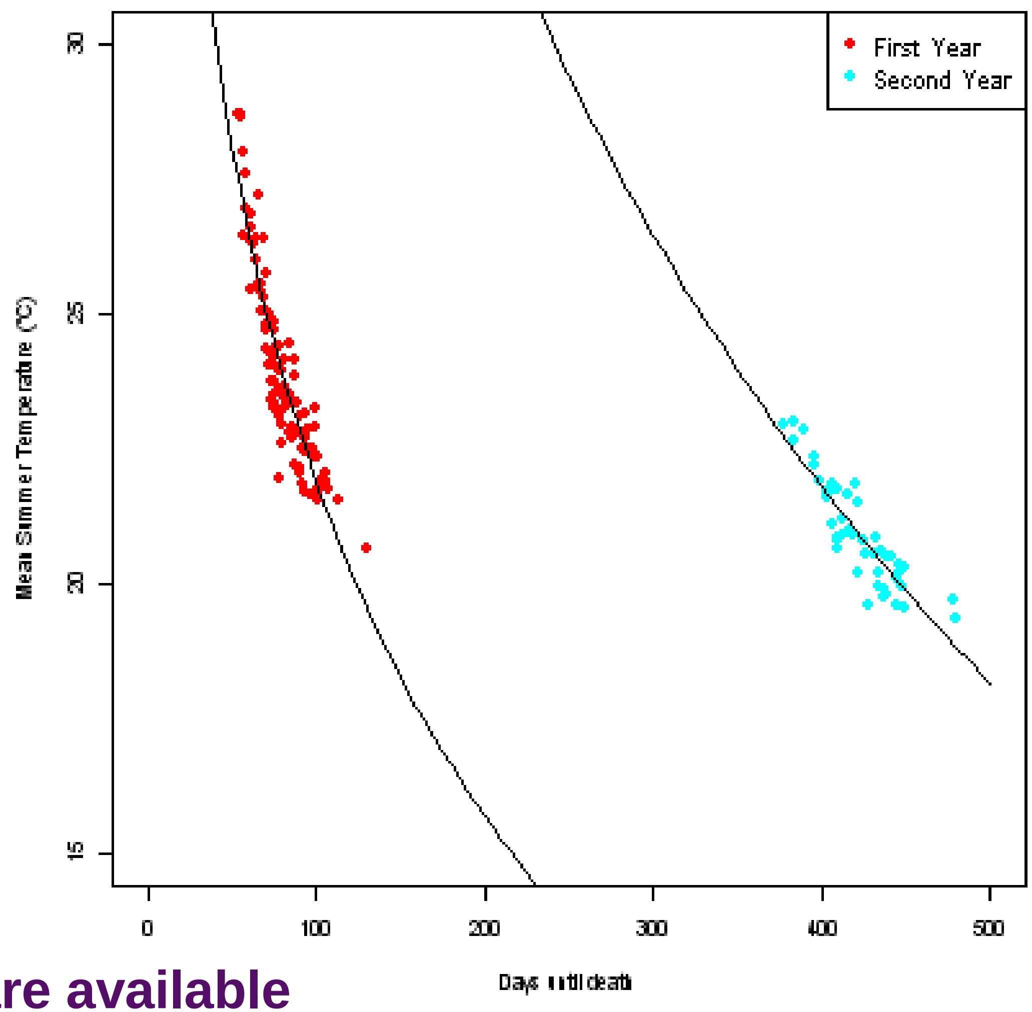
Latency Model



- T-tests comparing climatic data between locations where the model predicts wilt in the year of infestation and locations where the model predicts wilt in the year after infestation show a significant difference between MST and MAT.
- There is a **higher chance of wilt** in the **year of infestation** at locations where MST>23°C.

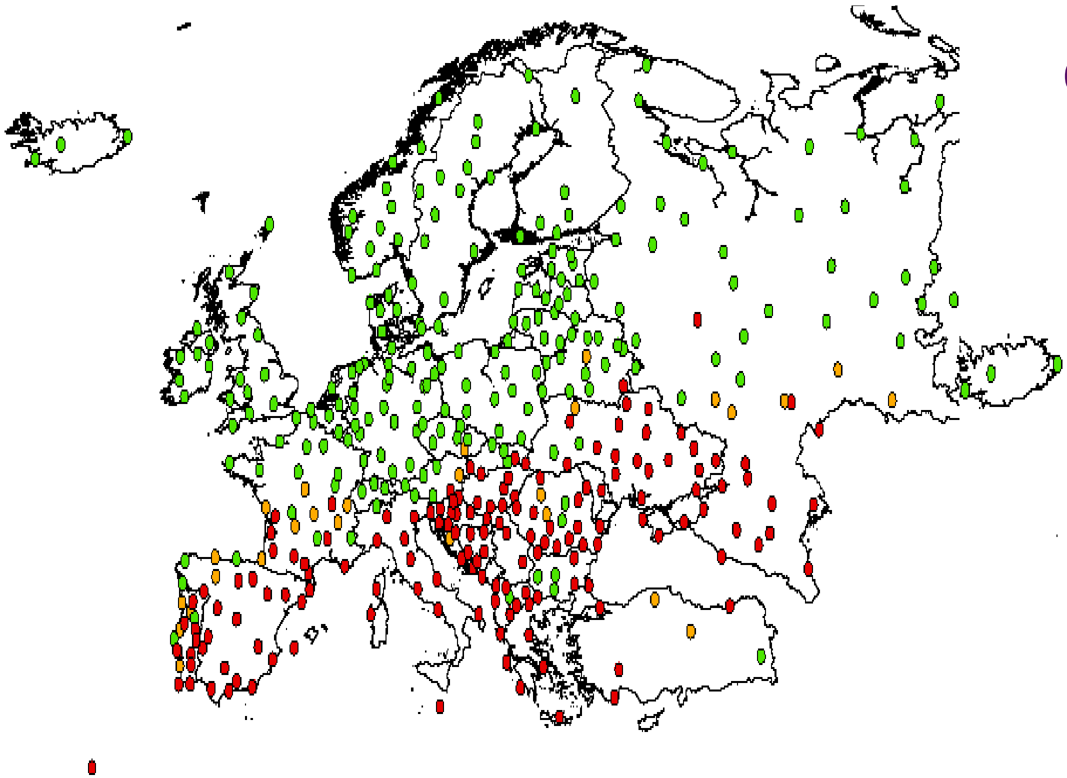
Wilt Expression

- There is a strong relationship between MST and the number of days/months it takes an infested tree to die of PWD.
- We can use these relationships to predict the year of wilt and also the number of days (for death in year of infestation) or months (for death in year after infestation) from infestation until death.



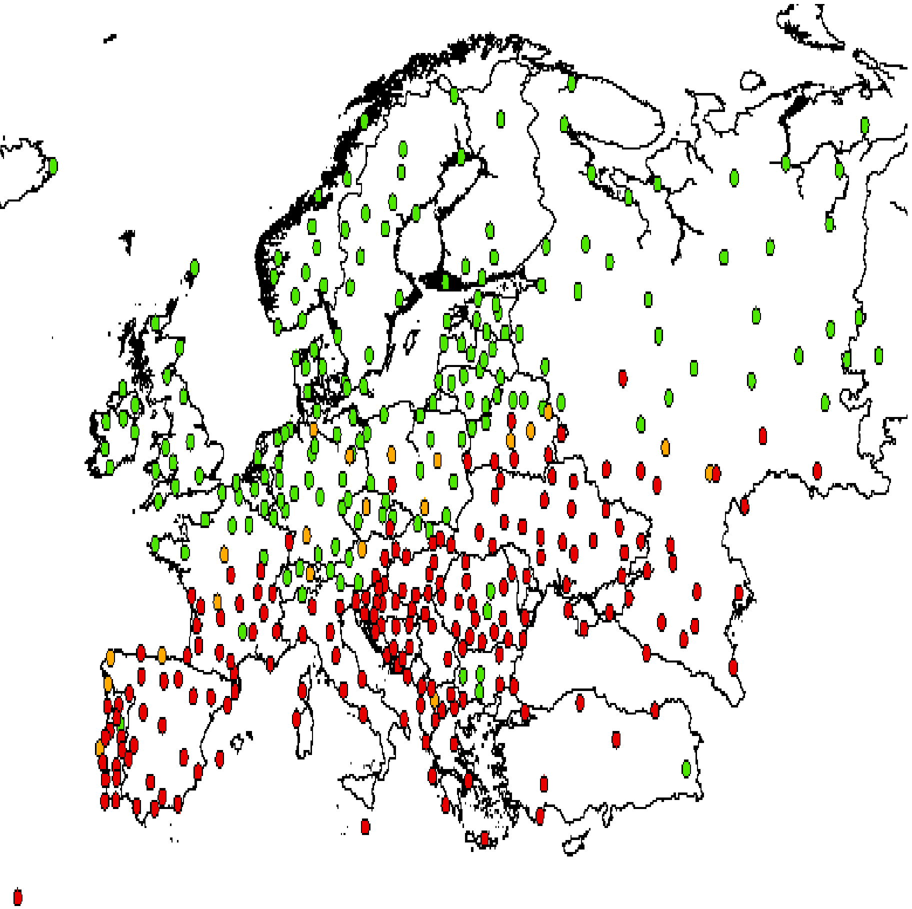
The Latency and "lite" models are available on: http://www.rephrame.eu

Potential Spread - Climate Change

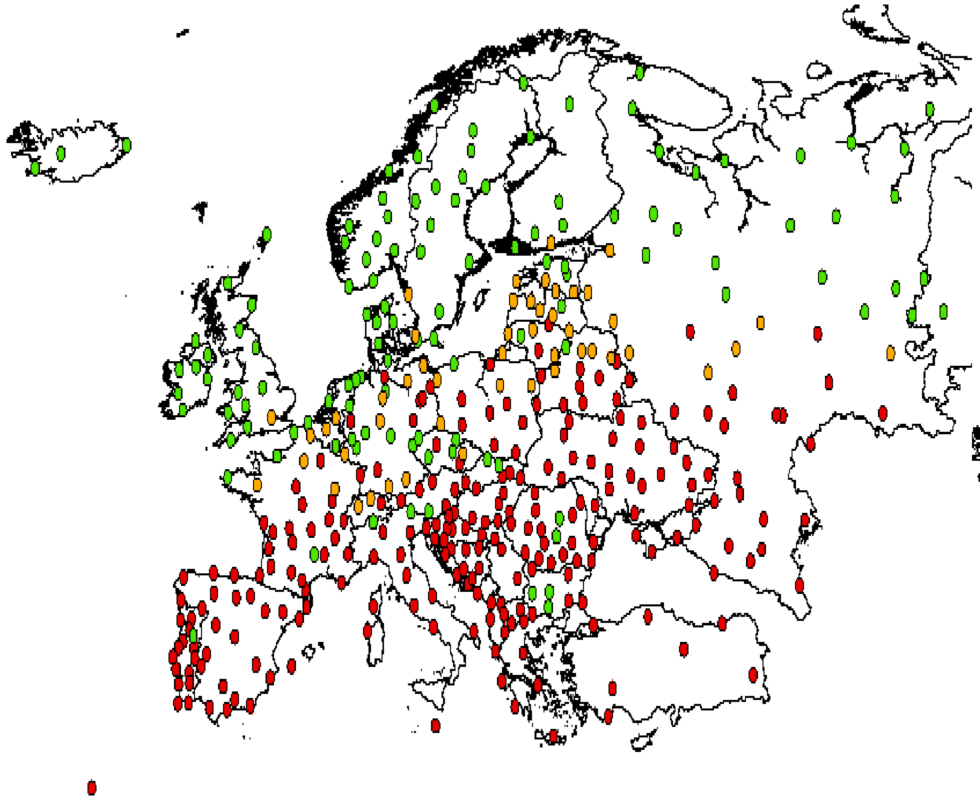


Model output for current climate.

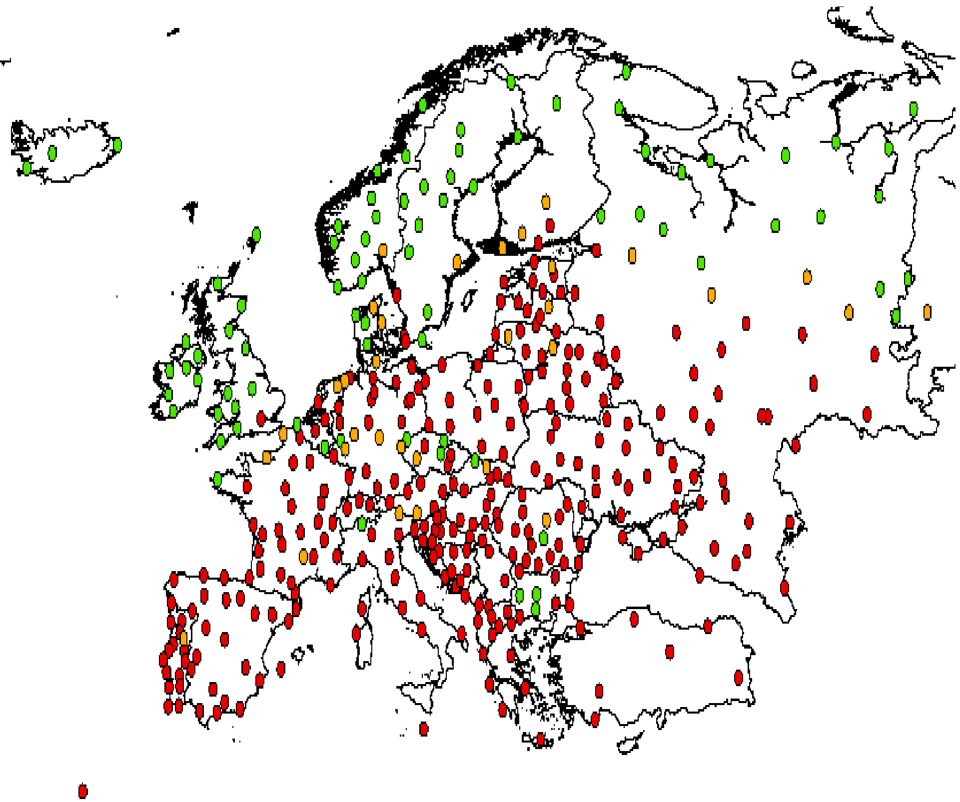
Model output for current climate +1°C



Potential Spread - Climate Change



Model output for current climate +2°C



Model output for current climate +3°C

Conclusions

- We have modified an Evapo-Transpiration model by adding elements that model the population growth of nematodes and link it to a reduction in photosynthesis and energy.
- This model requires extensive climate data and parameters which a general user would not have access to.
- We have tested model output against climate data and parameters and have developed a “lite” model where **wilt is predicted** for locations where **MST>20°C**. Furthermore, when no climate data is available we can **predict PWD from location** (latitude, longitude and altitude).
- We developed a latency model linking wilt expression to tree resistance, infestation day and MST.
- There is likely to be a northward shift in the current climatic limit of PWD in Europe due to climate change.

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Questions?

Acknowledgements

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