Updating the UK Rapid Pest Risk Analysis for *Xylella fastidiosa*

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Background

PRAs are kept under review to ensure they are still fit for purpose taking into account new findings and scientific developments. *Xylella fastidiosa* is no exception. Since Version 1 was produced in 2014 (Parkinson & Malumphy, 2014), there have been many new developments and the risks throughout Europe have been extensively assessed by EFSA (2015) in a 262 page scientific opinion. However, because the risks to the UK were considered not to have changed significantly, the focus has been on providing key information to the industry and the public with a Plant Pest Factsheet (Parkinson & Malumphy, 2015), a web-based resource (Forestry Commission, 2017), an information note on high risk hosts (Defra 2017) and guidance for importers (Defra & APHA, 2017) all accessed through the UK Plant Health Portal[1]. This has been supported with webpages provided by the industry[2] and the European Commission that provides a list of susceptible hosts in the EU (European Commission, 2015-2017). Two EU Horizon 2020 research projects (POnTE[3], end date October 2019, and XF-ACTORS[4], end date October 2020) are currently underway and their wide ranging *X. fastidiosa* objectives include a re-evaluation of the risks posed by this species throughout the EU.

This document, provided as a new appendix to the UK PRA (Parkinson & Malumphy, 2014), has been written to determine whether the recent literature has substantially altered the risk ratings given in the PRA and their level of confidence. It provides a detailed evaluation of the evidence that the different *X. fastidiosa* subspecies and strains pose a risk to plant health in temperate climates such as those in the UK.

[1] https://planthealthportal.defra.gov.uk/pests-and-diseases/high-profile-pests-and-diseases/xylella/
[2] https://www.nfuonline.com/sectors/horticulture-and-potatoes/hort-and-pots-news/xylella-what-you-need-to-know/
[3] https://www.ponteproject.eu/
[4] http://www.xfactorsproject.eu/

Appendix 5

<u>*Xylella fastidiosa*: assessing the suitability of the UK climate</u>

1. Summary

This appendix provides a more detailed assessment of the likelihood of *X. fastidiosa* establishment in the UK than that provided in the UK PRA (Parkinson & Malumphy, 2014). The literature has been reviewed and a detailed climatic comparison has been made between southern UK and the northernmost locations (in North America) and the southernmost locations (in South America) where the pathogen has been reported. This study confirms the risk ratings in the original PRA. *Xylella fastidiosa* subsp. *multiplex* provides the greatest likelihood of establishment since none of the other subspecies have been found in temperate climates. The UK has much milder winters and cooler summers than those at the northernmost limits of its distribution in North America. Both the unlikely to moderately likely rating for establishment and the small rating for economic, environmental and social impacts in the UK PRA are still appropriate. However, there is considerable uncertainty since the pathogen has never been recorded from locations that have the mild winters and cool summers of the UK. It is also important to note that *X. fastidiosa* is likely to be more widely distributed than current records suggest because it is difficult to identify on the basis of symptoms and to test for.

2. Introduction

Based on a detailed review of the evidence and the significant areas of uncertainty, the UK PRA (Parkinson & Malumphy, 2014), concluded that *X. fastidiosa* was unlikely to moderately likely to establish and that its potential to cause economic, environmental and social impacts was small. These risk ratings were primarily based on climatic suitability because hosts and vectors are present.

To assess the suitability of the UK climate for *X. fastidiosa* in more detail and confirm whether the previous risk ratings are appropriate, the following methods have been used:

i. <u>Compare climates at the limits of its distribution in the northern and southern hemispheres with those in southern UK</u> using: climatic data from weather stations, gridded climatological data and climatic summaries based on the Köppen-Geiger classification, plant hardiness zones, degree day models and comparisons of monthly maximum and minimum temperatures.
ii. <u>Utilise models</u>, such as MaxEnt and CLIMEX, to assess the potential UK distribution based on its current global distribution.
iii. <u>Utilise published information on its responses to climatic factors</u> such as temperature to strengthen the results of climatic comparisons undertaken under (i) and (ii).

All the methods have their limitations but the interpretation of the results is particularly challenging when, as for *X. fastidiosa*, the limits to a pest's distribution are poorly known and the species not only has a complex taxonomy but the responses to climate for each subspecies may vary. Reflecting this uncertainty, after reviewing all the evidence, EFSA

(2015) concluded that, although the potential for establishment in the EU was very likely with low uncertainty, “at present it is difficult to anticipate precisely the possible distribution of *X. fastidiosa* in Europe owing to uncertainties linked to the optimal and minimal temperature requirement for growth of *X. fastidiosa* subsp. *multiplex* found in Canada and northern USA and it has yet to be verified that the bacteria is able to shelter in roots and larger plants such as forest and ornamental trees (Hennenberger *et al*., 2004)”. The EFSA PRA was published before the outbreaks of *X. fastidiosa* subsp. *multiplex* in Corsica, mainland France, the Balearics and mainland Spain but these findings do not change the conclusions. An additional purpose of this appendix to the UK PRA is to confirm whether the EPPO PRA conclusions are still appropriate for the UK based on an evaluation of any new information available or any new analysis that has been conducted.

3. Compare climates at the limits of its distribution in the northern and southern hemispheres with those in southern UK

3.1 The northernmost records in North America

The complex taxonomy of *X. fastidiosa* was reviewed in section 6 of the UK PRA (Fera, 2014) and section 3.1.1.1 of the EFSA PRA (EFSA, 2015). Although the number of subspecies has now increased to six (Denancé *et al*., 2017), *X. fastidiosa* subsp. *multiplex* remains the subspecies posing the principal risk to the UK since it is found in temperate climates and has been recorded as far north as south-eastern Canada. It has principally been observed as causing bacterial leaf scorch in elm (*Ulmus*), sycamore (*Acer*) and oak (*Quercus*) but the pathogen has been found in many other trees and shrubs. However, “strains isolated from elm are not pathogenic to sycamore, and vice versa” (Gould & Lashomb, 2005) and *X. fastidiosa* subsp. *multiplex* itself has a complex taxonomy and the four clades have different host ranges (Nunney *et al*., 2013).

The northernmost record from the Niagara Peninsula in southern Ontario, Canada, is of the strain affecting elms. It was found in leaves of *Ulmus americanum* with leaf scorching symptoms near a vineyard (Virgil), by a roadside in a small town (Niagara-on-the-Lake), and in a park (Fort Erie) by the Niagara River (Goodwin & Zhang, 1997). There have been no subsequent records from this area and this may be due to the mortality caused by Dutch elm disease on the elm population. Elms infected with *X. fastidiosa* are very susceptible to Dutch elm disease (Gould and Lashomb, 2005). The greatest damage to elm by *X. fastidiosa* subsp. *multiplex* has been observed much further south in the mid-Atlantic United States, e.g. Washington, D.C, where 30% of 3000 trees were affected in 2001 (Gould & Lashomb, 2005).

The strain affecting oak has been studied extensively in New Jersey where it is found in every county (Zhang *et al*., 2011) and “up to 35% of oaks planted as street trees and in landscapes are affected” (Gould & Lashomb, 2005). Harris *et al*. (2014) showed that *X. fastidiosa* subsp. *multiplex* is responsible for significant crown dieback on *Quercus palustris* and *Q. rubra* in Washington DC. It is associated with oak decline as far south as Florida (Barnard *et al*., 1998) but no records could be found in the literature of the oak strain in states to the north of New Jersey. The sycamore strain is also most common in street trees in the south-eastern and mid-Atlantic United States.

Elsewhere in Canada, there are records of *X. fastidiosa* from:

- Vancouver Island and the Gulf Islands, British Columbia on *Acer macrophyllum* (Callan, 1992). However, prior to 1997, when PCR-based diagnosis became available, records are considered unreliable because symptoms are easily confused with water stress, early senescence and other diseases, e.g. Dutch elm disease.
- Alberta on elm, though this is considered to be unreliable (Goodwin & Zhang; 1997). It was reported as *Xylemella fastidiosum*, an illegitimate name but this could also have been a major typing error (Jean-François Dubuc, personal communication, 28th June 2017).
- Saskatchewan on seven samples of elm (*Ulmus*) submitted to the Canadian Crop Protection Laboratory (Northover & Dokken-Bouchard, 2012).

In the USA, there are records from:

- Washington State but this is incorrectly listed in EPPO PQR since Huang (2004) refers to Washington DC.
- Oregon on blueberries (*Vaccinium* spp.) causing a leaf scorch disease (EPPO RS 2008/074).
- Illinois, Indiana, Kansas, Michigan, Missouri and Oklahoma based on a survey of leaves primarily from trees with symptoms sent in by foresters and other volunteers from North Central and Plains states (Adams *et al*., 2013). Precise locations and hosts are not given but a map of positives and negatives is provided from which the northernmost finding Michigan state can be approximately located to the town of Petersburg in the south east of the state.
- Alabama, Arizona, Arkansas, California, Delaware, District of Columbia, Florida, Georgia, Indiana, Kentucky, Louisiana, Maryland, Mississippi, Missouri, Montana, Nebraska, New Jersey, New Mexico, New York, North Carolina, Oklahoma, Pennsylvania, South Carolina, Tennessee, Texas, Virginia, West Virginia (EPPO PQR, 2014).

3.2 Interpreting the northernmost records in North America

It is not possible to determine the precise northernmost limit of *X. fastidiosa* in North America from the literature because:

- Old records, especially those prior to 1997, are unreliable because they pre-dated PCR-based diagnosis.
- Infected trees are often symptomless unless stressed. Hopkins (1989) stated that: "Except for a few host-pathogen combinations like Pierces's disease of grapevine and phony disease of peach, *X. fastidiosa* could be considered a weak or opportunistic pathogen. Strains of *X. fastidiosa* often appear to survive as residents of the xylem vessels in symptomless hosts, but accumulate and produce disease symptoms only if the host is weakened by some other stress factor. Stress factors favouring *X. fastidiosa* diseases include drought, other diseases, root pruning with cultivation equipment, overproduction of fruit, normal fruit maturation, and senescence".
- Leaf scorch symptoms are insufficiently distinctive because they tend to become visible only in autumn when the tree leaves are already senescing and are difficult

to distinguish from the symptoms caused by other tree diseases and stressors. Moreover, Hopkins (1989) stated that “nonlethal infection by the bacteria also may predispose its hosts to other pathogens and stresses”.

- Elm populations, the tree host at the northernmost location for *X. fastidiosa* in North America, have been greatly reduced by Dutch elm disease and so the continued presence of the pathogen is difficult to determine.
- Surveys have not been comprehensive and have focused on street trees particularly in New York and Washington DC and particular states, e.g. New Jersey where *Quercus rubra* is the state tree. Very few wider surveys, such as Goodwin & Zhang (1997) in southern Ontario and Adams *et al*. (2013) in North Central and Plains states have been undertaken and no investigations in the US Atlantic states north of New Jersey have been reported.
- Surveys based on symptomatic leaves may not reveal the bacterium. The likelihood of false negatives is increased in trees near the northern limits of the distribution because their xylem vessels may have low titres of the bacterium and *X. fastidiosa* is unlikely to be evenly distributed throughout the plant. Higher concentrations can be expected in the roots. Adams *et al*. (2013) outlined some of the improvements in the sampling and detection methodology that are needed.

The northernmost limits to the distribution of *X. fastidiosa* in North America are thus highly uncertain. The records from Alberta and British Colombia are unreliable. The positive samples from Saskatchewan on elm (Northover *et al*., 2012) do not have a precise location. Therefore only those records from: the coolest areas of New Jersey (USA), the Petersburg area of Michigan (USA) and the Niagara peninsula (Canada) have been selected to represent the northernmost limits for comparison with the UK since they are the most clearly documented.

The following weather stations were selected to represent these areas:

Area	**Weather station**	**Co-ordinates**	
New Jersey	West Milford:	41.1311° N	74.3673° W
New Jersey	Mount Olive	40.8515° N	74.7329° W
New Jersey	Sparta	41.0335° N	74.6364° W
New Jersey	Vernon	41.1947° N	74.4938° W
New Jersey	Dover	40.8840° N	74.5621° W
Petersburg area	Petersburg	41.9012° N	83.7149° W
Niagara peninsula	Fort Erie	42.9018° N	78.9722° W
Niagara peninsula	Niagara-on-the-Lake	43.2550° N	79.0773° W

Climatic data were modelled from weather data[5] collected between 1982 and 2002.

3.3 Comparison of the northernmost records in North America with the southern UK climate

[5] https://en.climate-data.org/info/sources/

EFSA (2015) mapped the global locations where *X. fastidiosa* has been found in relation to the Köppen-Geiger climate classifications, annual minimum temperatures and the hardiness zones concluding that large areas of Europe were similar and thus potentially vulnerable. In this document, similar comparisons have been made but with southern UK rather than the whole of Europe.

3.3.1 Köppen-Geiger climates

The Köppen-Geiger 1951-2000 climate classifications for the northernmost and southernmost locations where *X. fastidiosa* has been reliably recorded were compared with locations in southern UK based on maps and downloads provided by Kottek *et al*., (2006). Table 1 shows that none of the locations have a similar climate to southern UK which is defined as warm temperate, fully humid and with a warm summer. Two locations in New Jersey also have a warm temperate and fully humid climate but with a hot summer. The other North American locations all have snow in winter, are fully humid and have either a warm or hot summer.

3.3.2 Winter temperatures, Isotherms and Hardiness Zones

The following methods have been applied in an attempt to define the limits to the distribution of *X. fastidiosa* based on cold winter temperatures:

- Minimum winter temperatures have been used to identify areas of the USA where Pierce's disease of grapevine could occur. Engle and Margarey (2008) used a cold temperature exclusion model for NAPPFAST based on thresholds of –12.2°C for two days and –9.4°C for four days previously applied by Anas *et al*. (2008).
- Isotherms of January winter temperatures were used by Purcell and Feil (2001) to identify zones where Pierce's disease impacts on grapes are severe (4.5 °C), occasional (1.7 °C) or rare (–1.1 °C).
- EFSA (2015) mapped the annual minimum temperatures and the hardiness zones where *X. fastidiosa* is known in North America and compared these with Europe concluding that large areas of Europe were similar and thus potentially vulnerable.

Although minimal winter temperatures occasionally plummet to very low levels, the daily minimum winter temperature thresholds of ≤ -12.2°C for 2-3 days or ≤ -9.4°C for 4-5 days and used by Anas *et al*. (2008) as a cold temperature exclusion model only occur very exceptionally in southern UK. At Heathrow Airport[6] between January 1st 1960 and August 31st 2017, they occurred 4 and 7 times respectively with a decadal mean of less than one day per winter for both thresholds since 1990. Figure 2 shows that January mean minimum temperatures for coastal southern England and Wales for 1981-2010 are within 2 - 3°C, the majority of southern England has January minima of 1 - 2°C and only the high ground in southern England and much of eastern and central has an average of 0.5 - 1°C. While Pierce's disease is caused by a different subspecies, *X. fastidiosa fastidiosa* rather than *X. fastidiosa multiplex*, this gives no support to arguments that suggest that southern UK has winters that are too cool for the pathogen to survive.

[6] http://www.ecad.eu/dailydata/index.php

Hardiness zones are based on average annual minimum winter temperatures, divided into 10-degree Fahrenheit zones and converted into centigrade (see Table 1). The southern UK is in zone 11 with a mean minimum winter temperature of 4.4 to -10°C. The locations in New Jersey, Petersburg and Canada are in zone 9 (-6.7 to -15.6°C).

Clearly *X. fastidiosa* can overwinter in areas with much colder winters than those found in southern UK. However, as reflected in the Köppen-Geiger classifications, unlike in the UK, the northern North American locations will generally be covered in snow during the winter insulating the roots from the lowest temperatures.

3.3.3 Monthly maximum and minimum temperatures and degree-day accumulations

Figure 3 compares monthly maximum and minimum temperatures for 1982-2002 representative of the coolest locations in New Jersey where *X. fastidiosa* has been reliably recorded with climate data for 1981-2010 from Heathrow Airport[7] showing that all the New Jersey locations have a very similar annual pattern. Figure 4 plots the same data for one of the New Jersey locations (West Milford), Petersburg (Michigan) and Fort Erie (Canada) with those from Heathrow Airport and St Mary's[8] (Isles of Scilly). These two UK locations were chosen to represent locations with the hottest summer temperatures (Heathrow Airport) and mildest winters (St Mary's) in the UK.

The following conclusions can be made:

- The five locations in New Jersey (West Milton, Mt. Olive, Vernon, Sparta and Dover) and Petersburg in Michigan have almost identical mean monthly maximum and minimum temperatures throughout the year. Compared to southern UK, they have much hotter summers (a mean July maximum temperature of 27 - 28°C which is approximately 5°C warmer than Heathrow Airport) and colder winters (a mean January minimum temperature of -9°C which is approximately 10°C cooler than Heathrow Airport).
- The two locations in the Niagara Peninsula (Fort Erie and Niagara-on-the-Lake) have almost identical mean monthly maximum and minimum temperatures throughout the year. The minimum temperatures are very similar to the locations in New Jersey and Michigan but the summer maximum temperatures are approximately 2°C lower than the other North American sites (and thus approximately 3°C warmer than Heathrow Airport).

It can therefore be concluded that, at the northernmost limits to its distribution in North America, *X. fastidiosa multiplex* survives much colder winters than those which occur in southern UK, though snow cover may insulate the pathogen in the roots. However, summer temperatures are much warmer than in southern UK.

The additional warmth can also be seen very clearly in Table 1, where the annual degree days above 10°C for 1961-2000 based on New *et al*., (1999) in North America are at least 50% higher than that in southern UK (Heathrow Airport).

3.3.4 Relationship between *Xylella* and host distribution

[7] http://www.metoffice.gov.uk/public/weather/climate/gcpsvg2yz
[8] http://www.metoffice.gov.uk/public/weather/climate/gbgebz4kn

Xylella fastidiosa multiplex has a very wide host range and distribution maps of major hosts, such as for *Quercus rubra*[9], show that these species are found much further north than the northernmost known limits of the pathogen.

3.4 The southernmost records

The southernmost records of *X. fastidiosa* are from Argentina: Aimogasta (La Rioja province; 28.5508°S, 66.8152°W) and Cruz del Eje (Córdoba; 30.7219°S, 64.8086°W), where *X. fastidiosa* subsp. *pauca* was found on olives in December 2013 (Haelterman *et al*., 2015).

3.5 Comparison of the southernmost records with the southern UK climate

Table 1 shows that the Argentinian records are from desert Köppen-Geiger climate classes and are thus very different to those in the UK. They are in cooler hardiness zones and have much higher annual degree day accumulations.

Transposing the 1982-2002 modelled[10] climate data for Cruz del Eje[11] and Aimogasta[12] so that cold and hot seasons in the northern and southern hemispheres align, Figure 5 shows that, in comparison with climate data for 1981-2010 from Heathrow Airport, mean monthly maximum temperatures are approximately 10°C higher throughout the year with minimum temperatures similar only in the coldest months. The relatively consistent 15°C difference between the mean monthly maximum and minimum temperatures at the two Argentinian locations throughout the year implies that there is a large diurnal temperature range. Clearly there are considerable differences in the climates between the Argentinian locations and Heathrow Airport. Coupled with the finding that only *X. fastidiosa* subsp. *pauca*, a subspecies not known to be established in temperate climates, has been found in Argentina, it can be concluded that the Argentinian *X. fastidiosa* records are not relevant to the potential establishment of *X. fastidiosa* in the UK.

4. Utilise models, such as MaxEnt and CLIMEX to assess the potential UK distribution based on its current global distribution

4.1 MaxEnt

Based on the distribution of *X. fastidiosa* in Italy, the MaxEnt species distribution model has been used to predict the potential distribution in Italy under current (1960-1990) climates (Bosso *et al*., 2016a) and in the Mediterranean under climate change (Bosso *et al*., 2016b). The authors caution the reader not to use their results as a risk map and indeed there are dangers in projecting from the distribution of a pathogen that is still spreading (White *et al*., 2017).

4.2 CLIMEX

Hoddle (2004) modelled and mapped the potential North American and global distribution of *X. fastidiosa* subsp. *fastidiosa* and one of its vectors, *Homalodisca vitripennis,* using the

[9] https://pubs.usgs.gov/pp/p1650-a/pages/qurufix2.pdf
[10] https://en.climate-data.org/info/sources/
[11] https://en.climate-data.org/location/19861/
[12] https://en.climate-data.org/location/19798/

CLIMEX species distribution model. Parameter variables were based not only on studies by Feil and Purcell (2001) who showed that the optimum temperature for growth *in vitro* for the bacterium is 28°C with no development at 12°C but also from the distribution of Pierce's disease in California. The ecoclimatic indices calculated by CLIMEX showed a very southerly potential distribution both in the USA, with the projected northernmost limit of *X. fastidiosa* subsp. *fastidiosa* only reaching North Carolina, and in Europe, where, as admitted by the author, the finding of this subspecies in Kosovo was also not predicted.

Since the species is so variable, is still spreading and the limits to its distribution are so poorly known, it is not surprising that neither model has so far shown to be helpful in assessing the potential distribution of *X. fastidiosa*.

5. Utilise the known information on its responses to climatic factors such as temperature to strengthen the results of climatic comparisons

Low temperatures have been shown experimentally to eliminate *X. fastidiosa* in grapes (Purcell, 1977) and plums (Ledbetter *et al*., 2009). Low winter temperatures increase the rate of host recovery (Purcell, 1980) and Hopkins and Purcell (2002) considered that this "cold curing" limits the northern spread of Pierce's disease caused by *X. fastidiosa* subsp. *fastidiosa*, in western USA. In the field, recovery happens more often when infections occur in the summer or autumn than during the spring (Feil and Purcell, 2001). However, the occurrence of *X. fastidiosa* in areas with very cold winter conditions in Canada and New Jersey suggests either that over wintering survival in *X. fastidiosa* subsp. *multiplex* is not affected by low temperatures in the same way as other subspecies such as *X. fastidiosa* subsp. *fastidiosa* or that other factors such as the tree host or the vector might be responsible for the differences. Henneberger *et al*. (2004) showed that the bacterium overwintered in sycamore trees with minimum air temperatures of –5°C, probably being protected in the roots.

To determine the minimum temperatures that would represent the overwintering challenge if *X. fastidiosa* can survive in the roots (as soil provides a buffering effect), January soil temperature data were obtained. A location representative of the northernmost sites where *X. fastidiosa* has been found in North America was compared with soil temperature data from the same month at sites in southern England. The daily minimum temperatures in the air, at the soil surface and at 5, 10, 20, 50 and 100 cm below the soil surface[13] were obtained from Chatham (46°20′52″N 86°55′44″W) in Michigan, a location with a Dfb Köppen-Keiger climate (snow, fully humid, hot summer), comparable to several locations in Table 1. This showed that in January 2012, although the mean air and soil surface temperatures (-7.7° and -9.9°C) were very cold and fluctuated wildly, below the soil surface they remained relatively constant at 1.2°, 1.6°, 2.4°, 3.2° and 3.4°C at 5, 10, 20, 50 and 100 cm respectively. Demonstrating the greater warmth of the English winter and the buffering effect of the snow blanket in North America, the temperatures at two English sites were much warmer and subject to much greater daily variation at 10 cm depth than the North American location. At Wisley in January 1999, they varied between 0.8° and 9.6°

[13] https://www1.ncdc.noaa.gov/pub/data/uscrn/products/daily01/2012/CRND0103-2012-MI_Chatham_1_SE.txt

with a mean of 5.2°C. At Kew in January 2003, temperatures were very similar, varying between 1.0° and 9.1° with a mean of 4.3°C. With the snow cover at Chatham (Michigan) there was much smaller variation: 1.0° – 1.9° around the mean of 1.6°C. If *X. fastidiosa* can overwinter in tree roots, the stable, relatively warm temperatures below ground and the snow blanket would help explain its presence in North America.

In North America, the sharpshooter (Cicadellidae, Cicadellinae) vectors overwinter as adults and, if infected, they can maintain *X. fastidiosa* over winter. In contrast, the European sharpshooters and most of the European spittlebugs (Aphrophoridae and a few Cercopidae) are generally considered to overwinter as eggs (Nickel and Remane, 2002). Since *X. fastidiosa* cannot be transmitted transovarially, in Europe it therefore cannot overwinter in its vectors. However, there is some uncertainty because *Philaenus spumarius* adults are occasionally found in the winter in the UK, although the significance of this in terms of overwintering is unclear (Chris Malumphy, personal communication, 8th September 2017) and Yaghmaee (2008) has reported overwintering adults in the Mashad Region of north-eastern Iran. .

6. Conclusions

- A comparison of the climate in southern UK with that at the northernmost known limits of *X. fastidiosa* in North America and the southernmost limits in Argentina shows that the UK has much warmer winters and much cooler summers.
- *Xylella fastidiosa* subsp. *multiplex* causes bacterial leaf scorch at the northernmost limits of the pathogen's distribution in North America where winters are cold. Unlike the *X. fastidiosa* subsp. *fastidiosa* subspecies, the causal agent of Pierce's disease of grapes, plants have not been observed to recover from *X. fastidiosa* subsp. *multiplex* infection following cold temperatures. *Xylella fastidiosa* subsp. *multiplex* thus provides the greatest risk of establishment to the UK.
- Since the UK has much milder winters than those at the northernmost limits of its distribution in North America, *X. fastidiosa* subsp. *multiplex* would appear to be able to survive overwinter. However, North American winters have a much more reliable snow cover than the UK which insulates the roots from hard frosts. Unlike the UK, the North American vectors can maintain the pathogen over winter. Since *X. fastidiosa* subsp. *multiplex* has never been recorded from locations with the mild winters and cool summers in the UK, the likelihood of establishment and the magnitude of impacts remain highly uncertain.
- The southernmost locations of *X. fastidiosa* in Argentina are of *X. fastidiosa* subsp. *pauca.* These are in arid areas with similarly mild winters but much hotter summers than in the UK.
- None of the published attempts to model the potential distribution of *X. fastidiosa* contribute to reducing the uncertainty related to the establishment of this species in the UK.
- The lower summer temperatures in the UK are likely to have a negative effect on the development of *X. fastidiosa*, symptom expression, the vector population and transmission. However, since *X. fastidiosa* has never been found in such climates, the extent of this effect is highly uncertain.

- The conclusions of the UK PRA (Parkinson & Malumphy, 2014) were that *X. fastidiosa* is unlikely to moderately likely to establish and that its potential to cause economic, environmental and social impacts is small. This appendix shows that these risk ratings continue to be appropriate.
- The conclusions in EFSA (2015) that: "at present it is difficult to anticipate precisely the possible distribution of *X. fastidiosa* in Europe owing to uncertainties linked to the optimal and minimal temperature requirement for growth of *X. fastidiosa* subsp. *multiplex* found in Canada and northern USA and it has yet to be verified that the bacteria is able to shelter in roots and larger plants such as forest and ornamental trees (Hennenberger *et al*., 2004)" are also still valid.

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Table 1 Kőppen-Geiger Climate Classifications, Hardiness Zones and Degree Days base 10°C for the southernmost and northernmost locations of *Xylella fastidiosa* in comparison with two locations in the UK representative of the hottest summers and the warmest winters

Location	Country	Kőppen-Geiger Climate Classification: Main Climates, Precipitation, Temperature	Hardiness Zone: Mean winter temperature	Degree Days base 10°C
Aimogasta	Argentina	Bwk: Arid, desert, cold arid	10: -1.1°C to 4.4°C	2685
Cruz del Eje	Argentina	Bsh: Arid, desert, hot arid	10: -1.1°C to 4.4°C	3140
Fort Erie	Canada	Dfb: Snow, fully humid, warm summer	9: -6.7°C to -1.1°C	1233
Niagara-on-the - Lake	Canada	Dfb: Snow, fully humid, warm summer	9: -6.7°C to -1.1°C	1290
West Milford	USA	Dfa: Snow, fully humid, hot summer	8: -12.2°C to -6.7°C	1224
Petersburg	USA	Dfa: Snow, fully humid, hot summer	9: -6.7°C to -1.1°C	1430
Mount Olive	USA	Cfa: Warm temperate, fully humid, hot summer	8: -12.2°C to -6.7°C	1300
Sparta	USA	Dfb: Snow, fully humid, warm summer	8: -12.2°C to -6.7°C	1258
Vernon	USA	Dfa: Snow, fully humid, hot summer	8: -12.2°C to -6.7°C	1328
Dover	USA	Cfa: Warm temperate, fully humid, hot summer	8: -12.2°C to -6.7°C	1333
Heathrow Airport	UK	Cfb: Warm temperate, fully humid, warm summer	11: 4.4°C to -10°C	827
St Mary's	UK	Cfb: Warm temperate, fully humid, warm summer	11: 4.4°C to -10°C	665

Figure 1. Weather stations representing the northernmost locations where *X. fastidiosa* has been recorded North America

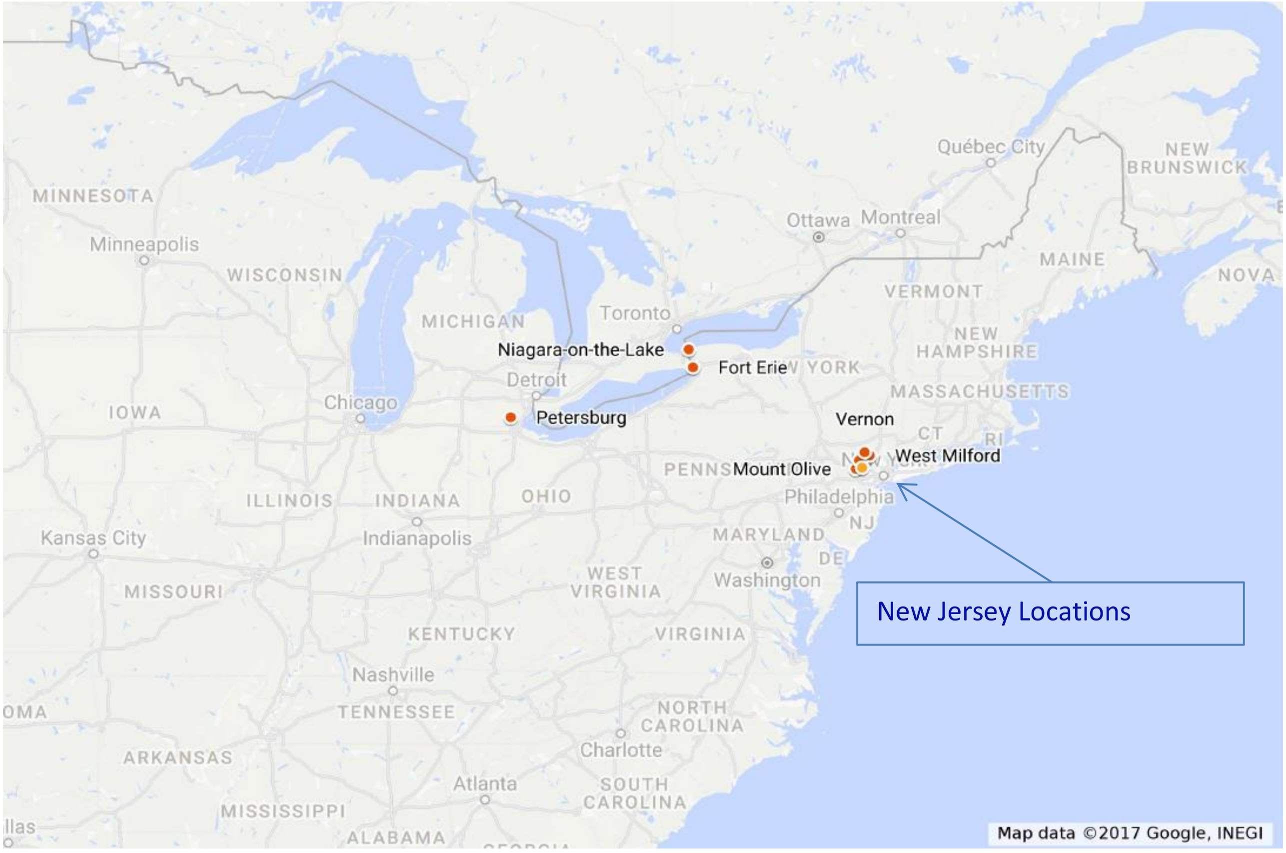

Figure 2. Mean minimum temperatures for the UK in January in 1981-2010

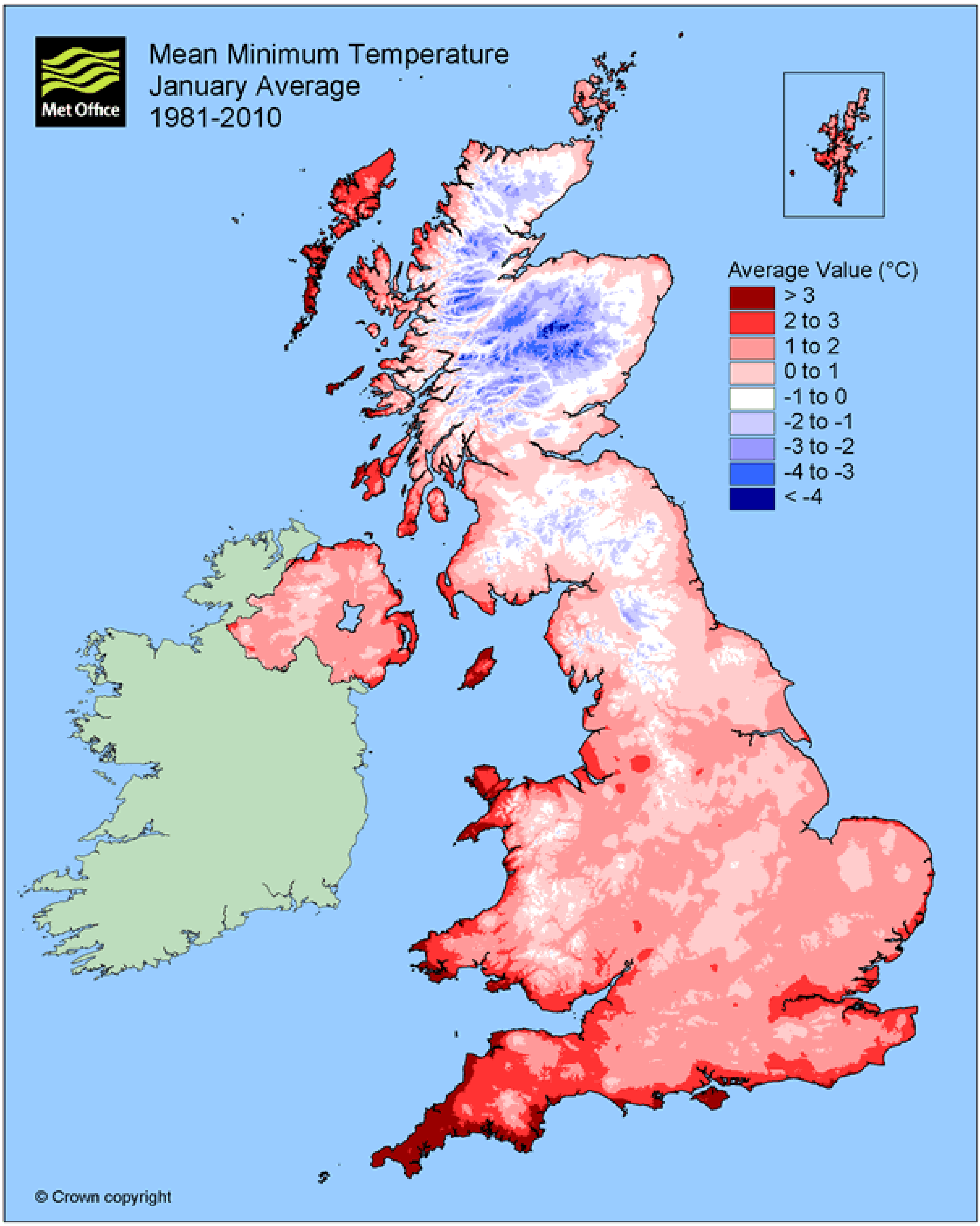

Figure 3. Monthly mean maximum (solid lines) and minimum (dashed lines) temperatures (°C) for five locations in New Jersey (USA) (1982-2002) and Heathrow Airport (UK) (1981-2010)

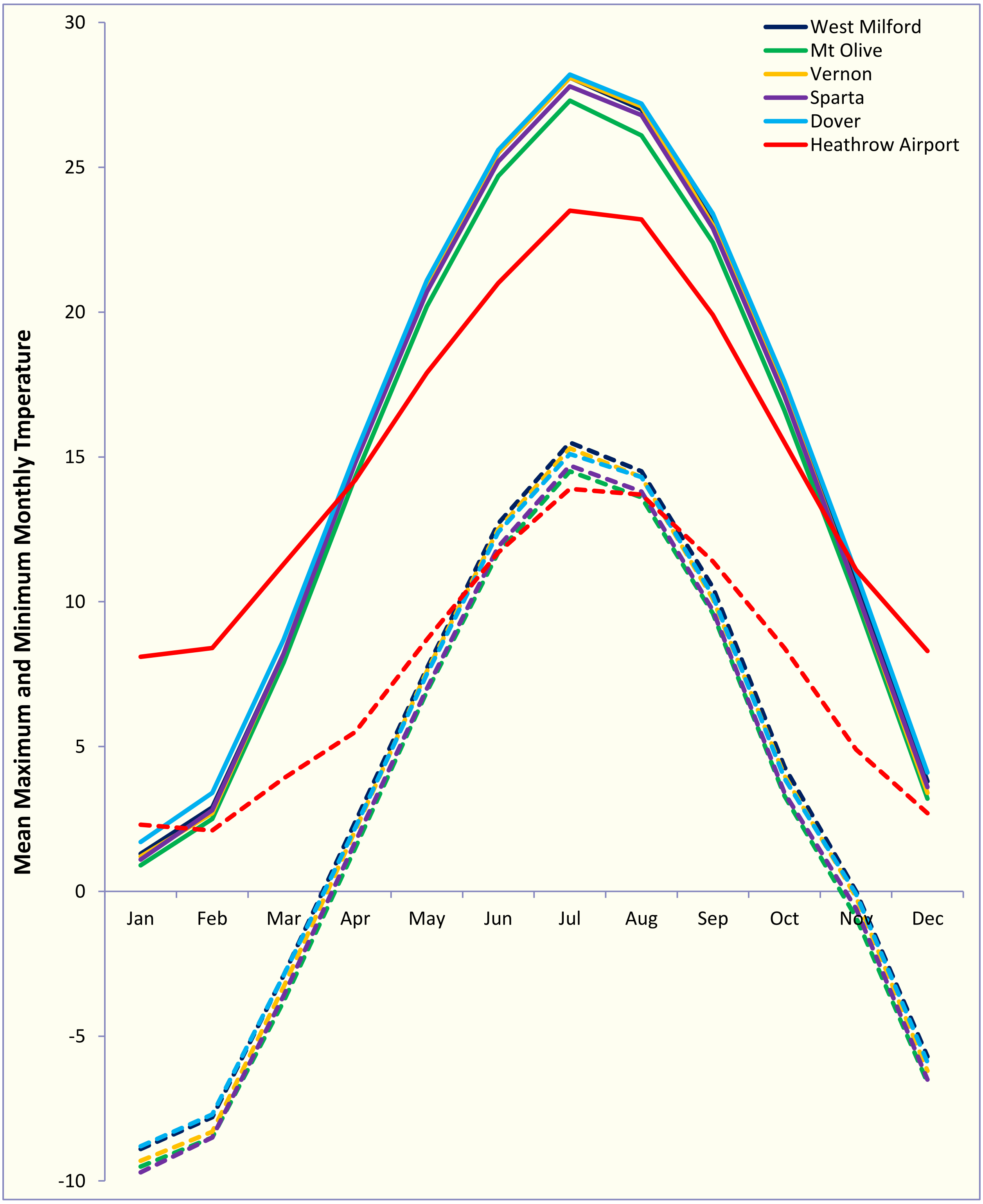

Figure 4. Monthly mean maximum (solid lines) and minimum (dashed lines) temperatures (°C) for West Milford (New Jersey, USA), Petersburg (Michigan, USA) and Fort Erie (Canada) representing the northernmost limits of the *Xylella fastidiosa* distribution in North America compared with Heathrow Airport and St Mary's, Isles of Scilly (UK)

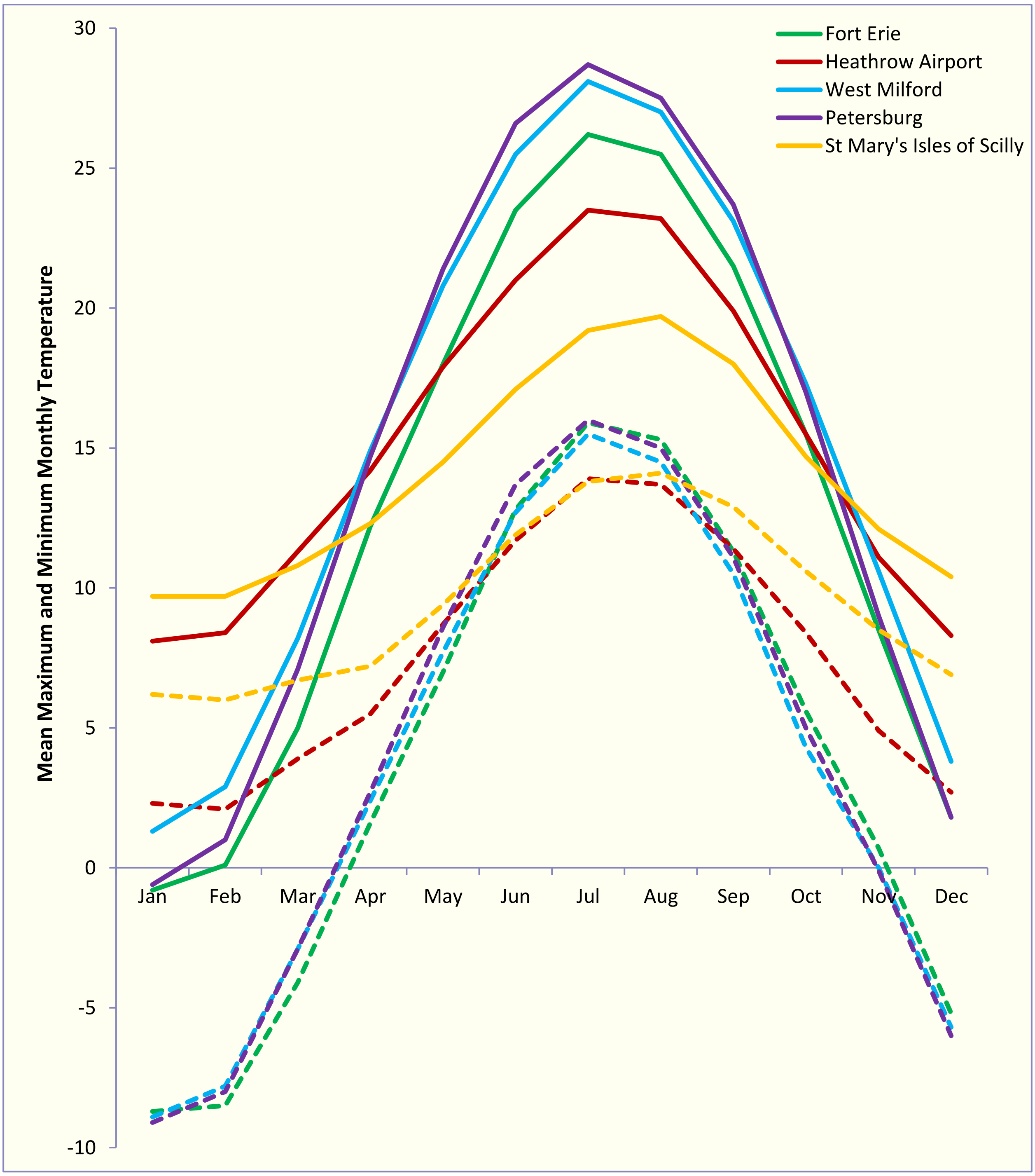

Figure 5. Monthly mean maximum and minimum temperatures (°C) representing locations in Argentina where *Xylella fastidiosa* has been recorded and Heathrow Airport (UK). The data from Argentina have been shifted so that the seasons in the different hemispheres coincide. Mean monthly temperatures: solid lines are maximum, dashed lines minimum.