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Abstract

A report on how different factors (drought, water logging, heat and cold temperature, co-infestations, host availability, transport, natural enemies) affect the establishment and spread of the five target pests in the PurPest project. Based on D5.1, we compiled information and data related to the potential drivers of the five focus pest species in the PurPest project: the Fall armyworm, the Cotton bollworm, the Brown marmorated stinkbug, the Pinewood nematode, and *Phytophthora ramorum*.

Public introduction[1]

This is a short report on the potential driving factors that are relevant for the establishment and spread of the fall army worm, the cotton bollworm, the brown marmorated stinkbug, the pinewood nematode, and *Phytophthora ramorum*. The most relevant driving factors are climate (temperature, humidity, precipitation), host availability, and means of transport into new areas.

[1] According to Deliverables list in Annex I, all restricted (RE) deliverables will contain an introduction that will be made public through the project WEBSITE

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1 DRIVING AND LIMITING FACTORS FOR FALL ARMYWORM ESTABLISHMENT

Fall armyworm (FAW, *Spodoptera frugiperda*) is a highly polyphagous horticultural pest native to the Americas, with its range recently expanding as an invasive species in Africa, Asia, Australia, and New Zealand (Kenis et al., 2022). FAW has a substantial long-distance dispersal capacity and displays seasonal trans-latitudinal migratory behavior. Wolf et al. (1990) observed clouds of migrating FAW travelling 400km overnight. FAW has been already reported in Europe, with detections on Madeira Island in Portugal, and in Greece (EPPO, 2023a, b). This pest is particularly damaging to maize, rice, and sorghum (Kenis et al., 2022).

High reproductive capacity, high thermal tolerance, pesticide resistance, and the ability to feed on numerous hosts are the driving factors for FAW establishment and spread in Europe. In addition, climate change, increased anthropogenic activities, and an increase in mixed cropping under smallholder farming systems enable FAW to expand its host range (Mlambo et al., 2024). Adan et al. (2025) showed that land use and land cover were the primary contributors to FAW's habitat suitability, together with precipitation patterns during the driest month and elevation. Low annual temperature and the amount of rain during the wet season are the strongest climatic limits to fall armyworm’s year-round distribution. Irrigation allows for permanent populations in Africa, where it would be otherwise too dry (Timilsena et al., 2022). Europe is expected to be too dry for permanent establishment, however, humid-continental or Mediterranean climates could support a few generations per year, similar to the transient populations that occur in North America (Wang et al., 2023). Population dynamics are more influenced by climate than by the number of hosts (Canico et al., 2020). The minimum threshold for FAW development is about 13°C (Ali et al., 1990), but eggs are still surviving at -10C for short periods of time (Foster et al., 1987). Desiccating or drought resistance in FAW varies with larvae stage, age and history of drought experience by the individual specimens. Adults highest critical thermal limit was between 2C and 45C and instars between 4,7 and 52C. Egg and larva development stopped between 12 and 13C and died at temperatures under 0 and -5C or over 40 and 45C (Keosentse et al., 2002, Tao et al., 2023). Flooding or water logging does not appear to restrict FAW considerably, as larvae were still pupating and emerging in the 80% wet soil (Tao et al., 2023).

Presence of host plants (mainly sorghum and maize, and rice) is a driving factor for establishment; however, FAW has a fairly large host range, so its potential distribution will not be limited by host plant availability (Timilsena 2022). Transport with plant material is increasing the invasion risk significantly (EFSA, 2018; Gilioli et al., 2022).

Among the natural enemies of the FAW are egg parasitoids, larval parasitoids, larval endoparasitoids, and predators. There are no reports of effective entomopathogens of this pest.

2 DRIVING AND LIMITING FACTORS FOR COTTON BOLLWORM ESTABLISHMENT

The cotton bollworm (CBW, *Helicoverpa armigera*) is a highly polyphagous horticultural pest with a widespread natural distribution spanning Africa, southern Europe, Asia, and Australasia (Tay et al., 2013), though it has recently invaded South America (CABI, 2023). The trans-latitudinal seasonal migratory behaviour exhibited over long distances by CBW poses only a transient risk to European countries (extending to northern Europe) where the climate is not suitable for its permanent establishment (Baker et al., 2014; Kriticos et al., 2015). As its apparent inability to establish north of southern Europe, the most important invasion pathway is seasonal long-distance migration from southern Europe and North Africa (Keszthelyi et al., 2013; Baker et al., 2014). Long-range movement occurs by migration and by international trade. These movements facilitate high population admixture and genetic diversity, with important economic, biosecurity, and control consequences in agriculture (Jones et al., 2019).

Pesticide resistance is a major problem in CBW management (Downes et al., 2017) and plays an important role in CBW control and spread.

Temperature is an important driving and limiting factor for CBW. A study of CBW from Greece showed that 16 °C is required for termination of diapause (Mironidis et al., 2010). Minimum developmental thresholds are ca 11–12°C. The optimum temperature for development is around 31–34°C, with an upper threshold of ca 37–42°C (Kriticos et al., 2015). Mean adult longevity fluctuated from 34 days at 15ºC to 7-8 days at 35ºC (Mironidis et al. 2008). CBW requires warm winters to survive (Mironidis et al., 2014). The population of the cotton bollworm was lower on cotton plants growing under drought conditions than on plants growing under irrigation, when observed in the field (Noor-ul-ane et al., 2015. Jokar et al. 2022 investigated cotton bollworm populations in Iran after major floodings and showed a drastic reduction in moth populations in the areas that were flooded in spring for the earlier generations of this target pest. However, there is not information on the lower and upper limits of soil moisture on CBW development and spread.

Host plants of CBW include tomatoes, chickpea, cotton, maize, sunflowers, peas, and soybean (Baker et al., 2014). Viability of CBW larvae was highest on cotton (46.1%), followed by millet (39.5%), sorghum (31.2%), soybean (24.2%), and maize (21.1%). Noncotton C_3 hosts served as the major source of CBW moths, and C_4 hosts were a food source of CBW mainly in regions where winter maize is typically cultivated (Dourado et al., 2021). Crops expressing *Bacillus thuringiensis* (Bt) toxins are planted over vast areas to suppress CBW, but resistance to this approach in CBW has been described (Jones et al., 2019)

Biological control of CBW includes *Bacillus thurengiensis*, *H. armigera* nucleopolyhedrovirus and the release of arthropod natural enemies, such as predators and parasitoids.

3 DRIVING AND LIMITING FACTORS FOR THE BROWN MARMORATED STINKBUG ESTABLISHMENT

The Brown marmorated stinkbug (BMSB, *Halyomorpha halys*) is a highly polyphagous pest native to Asia and is invasive in North America and Europe (CABI, 2023). This pest was accidentally introduced into Europe (Switzerland) around 2004 (Haye et al., 2015) and is now widespread across the majority of mainland Europe (CABI, 2023). BMSB is known to spread rapidly into new areas when moved through human activity and movement of goods (Haye et al., 2015).

Temperature is one of the limiting and driving factors for BSMB establishment. The BSMB does not develop below 11-15°C (Kriticos et al., 2017) or over 36ºC (Govindan et al., 2020). It overwinters in dead or standing forest trees or residential and commercial buildings (Wallner et al., 2014). Egg-adult development takes 76 to 81 days at 20°C and about 33 days at 30°C (Haye et al. 2014; Nielsen et al. 2008). *H. halys* can loose water rapidly under dry air conditions and can have difficulties feeding on drought-stressed plants (Grisafi et al., 2021). As this pest is not living in the soil, short-term flooding does not affect it much.

More than 300 host plants have been recorded for the BMSB (Kriticos et al., 2017), though in Europe, extensive damage has predominantly been reported from fruit-growing regions in Italy (Moraglio et al., 2020). Due to its broad host range, it is unlikely that BMSB establishment will be limited in its distribution by host availability

All life-stages can be associated with contamination of agricultural goods, in particular when adults overwinter (Gariepy et al. 2014). As such, it can be frequently transported by human movement across large distances and country borders.

Natural enemies of BSMB include egg parasitoids, egg and adult predators, but very few parasitoids of adults and nymphs (Abram et al., 2017).

4 DRIVING AND LIMITING FACTORS FOR *PHYTOPHTHORA RAMORUM* ESTABLISHMENT

Phytophora ramorum is an oomycete plant pathogen with a very wide host range (Sansford et al., 2009), well known for causing sudden oak death and sudden larch death. These devastating diseases emerged in the US in the 1990s and in the British Isles in the late 2000s, respectively (Rizzo et al., 2002; Brasier & Webber, 2010; Jung et al., 2018). In Brittany, France sudden larch death was detected in 2017 (http://ephytia.inra.fr/fr/C/24935/Forets-Phytophthora-ramorum). *Phytophora ramorum* originates from East Asia where eight new lineages were discovered (Jung et al., 2021). There are numerous *Phytophthora* species that are severely damaging to forest ecosystems (Jung et al., 2018; Brasier et al., 2022, 2025). Programs to manage these pathogens in or eradicate them from natural ecosystems have largely been unsuccessful as demonstrated by all 43 globally known Phytophthora epidemics of natural ecosystems are still spreading (Jung et al., 2018; Brasier et al., 2022). Consequently, preventing their initial introduction to a new area has the highest potential of success in limiting their further spread (Hansen, 2015; Jung et al. 2016, 2018).

When grown at different temperatures, the growth curves for the EU1 and EU2 lineages are similar with the EU2 lineage growing faster than the EU1 lineage, as were the lower limit and optimal range. However, the upper limiting temperature is higher for EU2 (29 °C vs 28 °C) (Harris et al., 2021; Jung et al., 2021).

This may not have a major effect on potential establishment in Europe, as Ireland et al. (2013) showed that the main limiting factors in Europe were temperature, cold/heat stress and moisture availability or drought. However, regarding the actual sporulation and damage potential, the temperature and humidity requirements for infection and sporulation need to be considered. A study in Oregon showed that there was a 2-year delay between the introduction of *P. ramorum* at a certain site and tree mortality at that site (Peterson et al., 2015). Flooding supports sporulation of soil born *Phytophthoras* and can increase the risk of root infections (Mestas et al., 2022), while drought will reduce this risk.Temperatures of 37.5-40C over several hours were lethal to *P. ramorum* hyphae growing in pure culture, while different isolates of this oomycete survived -5C for 24 hours, very few survived even -25C for 24 hr. Low humidity (41-48%) at 28C over 2hr or at 20C over 8hr was lethal to this pathogen (Browning et al., 2008).

P. ramorum exhibits a very wide host range, with the European pest risk analysis listing 133 species (though with differing levels of certainty and susceptibility) (Sansford et al., 2009). Host plant availability would therefore not limit its potential distribution within Europe. However, as establishment should be regarded in the context of infection and sporulation, only leaf hosts that support sporulation are truly relevant for the damage potential of this pathogen.

Grünwald et al. (2012) showed that imported nursery plants infected with *P. ramorum* facilitated the invasion to the US by this pathogen. The nursery trade appears to be the main source of long-distance spread (Jung et al. 2016, 2021), as planting of infested, often symptomless, nursery stock is a major driving factor in *P. ramorum* spread, establishment, and plant losses. Ornamental nurseries across Europe show very high infestation rates with *P. ramorum* (Jung et al. 2016). In those nurseries, *P. ramorum* is almost ubiquitously associated with *Rhododendron*, which is the most transmissive host plant contributing to the spread of the pathogen throughout Europe (Vercauteren et al., 2013; Jung et al., 2016; Thomsen et al., 2023). Several biocontrol agents, such as Bacillus brevis, Bacillus subtilis, Paenibacillus subtimyxa, Pseudomonas fluorescens, and Streptomyces lydicus (Cohen et al., 2008; Linderman & Davis 2006, Elliott & Shamoun 2008) or Trichoderma asperellum have been tested against P. ramorum (Elliott & Shamoun, 2008; Widmer, 2008, 2014) but not used to much effect.

5 DRIVING AND LIMITING FACTORS FOR PINEWOOD NEMATODE ESTABLISHMENT

The pinewood nematode (PWN, *Bursaphelenchus xylophilus,*) is native to North America, where it does not cause disease in native healthy hosts. It invaded Asia more than 100 years ago and, more recently Europe, where it is currently present in Portugal and Spain (Mallez et al., 2015). It is transmitted by beetles of the genus *Monochamus*, which are widespread in Europe (GBIF, 2023). The nematode is the causative agent of pine wilt disease (PWD) in the invaded areas. As a vectored disease-causing agent, there are multiple factors that influence the distribution of disease expression, such as climate influencing disease expression, the distribution of suitable host plants, and the presence of *Monochamus* spp. vectors (Sousa et al., 2001; Evans et al., 2009; Gruffud et al., 2016). Without its vector, PWN cannot be transmitted to its tree hosts.

Climate PWN/vector: PWN is not likely to develop below 9-10°C (Evans et al., 2009; Futai 1980). Mean temperature of 20° C in July is one of the major drivers in PWD expression, while the vector beetle needs a mean temperature above 10°C in winter and at least 21°C in July. The PWN can survive drought, heat and cold for extended periods of time in a dauer stage. Under low osmotic pressure, metabolic activity is greatly reduced and life is suspended (Robinet et al., 2011, Wang et al., 2024). The average survival rates were 1.7% after −80 °C treatment for 30days (Pan et al., 2021). The minimum lethal temperature is 56 °C for 1 min. However, embryonic development is disrupted at 35 °C, and sharp declines in survival occur after 48 hours at 30 °C and 24 hours at 35 °C. Only dauer stages are likely to survive longer at higher temperatures under cryptobiosis (Pan et al., 2021, Uzunovic et al., 2013, Wang, 2012)

The PWN causes serious damage to both natural and managed pine ecosystems. The PWN is threatening European pines, such as maritime pine (*Pinus pinaster*), *P. sylvestris, P. uncinata, P. nigra, P. peuce,* and to some extent *Pinus halepensis* (Bonifácio et al., 2015; Nunes et al., 2015). Seasonal drought and high temperature, causing water stress in the host trees, are factors that predispose the host to infection (Estorninho et al., 2022).

The vector is not a long-distance flyer, but accidental introductions of the nematode or its vector by humans can effectively spread PWD over long distances (Robinet et al., 2011). The nematode can easily be transported in wood-based packaging material to new areas. However, if the insect-vector is not present, this is unlikely to cause the establishment of this pest.

The endoparasitic fungi *Esteya vermicola* appears to be a promising biological control agent of the PWN (Wang et al., 2015). This entomopathogenic fungi and the bacteria *Bacillus licheniformis* strain MH48 have shown some effect against PWN under laboratory conditions (Jeong et al., 2015). *Beauvaria pseudobassiana* has been isolated from the PWN vector *M. galloprovincialis* and seemed to be highly virulent against this beetle, serving as another potential biocontrol agent (Álvarez-Baz et al., 2015).

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