SCIENTIFIC OPINION

Pest risk assessment of *Spodoptera frugiperda* for the European Union

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Abstract

EFSA was asked for a partial risk assessment of *Spodoptera frugiperda* for the territory of the EU focussing on the main pathways for entry, factors affecting establishment, risk reduction options and pest management. As a polyphagous pest, five commodity pathways were examined in detail. Aggregating across these and other pathways, we estimate that tens of thousands to over a million individual larvae could enter the EU annually on host commodities. Instigating risk reduction options on sweetcorn, a principal host, reduces entry on that pathway 100-fold. However, sweetcorn imports are a small proportion of all *S. frugiperda* host imports, several of which are already regulated and further regulation is estimated to reduce the median number entering over all pathways by approximately 10%. Low temperatures limit the area for establishment but small areas of Spain, Italy and Greece can provide climatic conditions suitable for establishment. If infested imported commodities are distributed across the EU in proportion to consumer population, a few hundreds to a few thousands of individuals would reach NUTS 2 regions within which suitable conditions for establishment exist. Although *S. frugiperda* is a known migrant, entry directly into the EU from extant populations in sub-Saharan Africa is judged not feasible. However, if *S. frugiperda* were to establish in North Africa, in the range of thousands to over two million adults could seasonally migrate into the southern EU. Entry into suitable NUTS2 areas via migration will be greater than via commercial trade but is contingent on the establishment of *S. frugiperda* in North Africa. The likelihood of entry of the pest via natural dispersal could only be mitigated via control of the pest in Africa. If *S. frugiperda* were to arrive and become a pest of maize in the EU, Integrated Pest Management (IPM) or broad spectrum insecticides currently used against existing pests could be applied.

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Summary

Following a request from the European Commission, the EFSA Panel on Plant Health conducted a partial pest risk assessment of *Spodoptera frugiperda* for the territory of the European Union (EU). *S. frugiperda* is an economically important lepidopteran pest in the Americas and following reports of its first occurrence in Nigeria and Sao Tome and Principe in 2016 (Goergen et al., 2016) it is now reported as a major pest of *Zea mays* and *Sorghum* and as damaging many other crops in sub-Saharan Africa (Cock et al., 2017; Abrahams et al., 2017).

A first phase assessment (pest categorisation) for the EU concluded that *S. frugiperda* could establish in a small area of the southern EU although there were uncertainties (EFSA PLH Panel, 2017). As requested in the Terms of Reference (ToR) from the European Commission, this second phase risk assessment focused on the main pathways for entry, factors affecting establishment, risk reduction options and pest management. *S. frugiperda* is a strong seasonal migrant in the Americas (Johnson, 1987; Nagoshi et al., 2012). The Panel therefore interpreted the main pathways for entry into the EU to be (i) imports of infested plant products from the Americas and sub-Saharan Africa, and (ii) natural migration from Africa. The ToR did not request an assessment of pest spread or impact, were the pest to establish in the risk assessment area. The Panel therefore understood that the ToR requested a partial pest risk assessment (EFSA PLH Panel, 2018).

Entry via trade in five plant commodities was assessed using pathway modelling in @Risk for Microsoft Excel. The five commodities were selected based on the importance of the host (*Zea mays*, sweetcorn) and the history of interceptions associated with the trade: eggplant/aubergine (*Solanum melongena*), peppers (*Capsicum* spp. and *Pimenta* spp.), asparagus and rose cut flowers (*Rosa* sp.). These commodities also well reflect a range of crop husbandry techniques, e.g. crops grown outdoor and crops grown under protection; intensively managed and less intensive; ongoing exposure to pests and short-term exposure to pests.

Information and data were collected using conventional literature searches and hand searching and was compiled into 'evidence dossiers' to support the expert elicitation necessary to estimate model input values for each substep of each pathway model. Stakeholder information sources were contacted to try and fill remaining knowledge gaps.

The partial risk assessment followed the framework provided in recent guidance (EFSA PLH Panel, 2018). The conceptual assessment models for entry pathways are described in detail using flow charts and formalised with algebra.

An estimate for the value of each parameter in each model was determined following EFSA's guidance on expert knowledge elicitation (EFSA, 2014). Elicitations for the 1st, 25th, 50th (median), 75th and 99th percentile were made on the basis of the evidence dossiers and expert knowledge and used a shortened approach based on the Sheffield method (EFSA, 2014).

The risk assessment considered two scenarios. The first scenario (A0) is a baseline scenario representing the regulatory conditions applied to each of the studied pathways when this assessment was initiated in January 2018. At that time *Capsicum*, *S. melongena* and *Rosa* cut flowers were regulated, although not specifically with respect to *S. frugiperda*. Consignments from third countries were subject to phytosanitary inspection on arrival in the EU. Sweetcorn and asparagus were not regulated and consignments were allowed to enter without phytosanitary checks.

The second scenario (A1) is an imagined future situation where the pathways are all specifically regulated with respect to *S. frugiperda*. In principle, a variety of phytosanitary measures, also known as risk reduction options, are available to lower the likelihood that *S. frugiperda* enters the EU on host commodities traded internationally. For example, commodities could be sourced from a pest free area, a pest free place of production or a pest free production site. Prior to export a commodity could be officially inspected to certify that it is free from *S. frugiperda* or has been subjected to treatment to ensure freedom from the pest. In order to guarantee pest freedom within a crop, place of production, place of production and buffer zone, or area, it is necessary to fulfil the requirements outlined in ISPM No. 4 (FAO, 2017) and ISPM No. 10 (FAO, 2016). This would be very challenging for a pest such as *S. frugiperda* that is highly mobile and highly polyphagous. The Panel is not aware of any countries in the Americas or sub-Saharan Africa that could claim such area freedoms for *S. frugiperda.* Given that host commodities such as peppers and eggplant are chill sensitive (CargoHandbook.com, 2012b, 2017b), cold treatments that would be lethal for *S. frugiperda* are not appropriate for such commodities. The possibility that pre-export visual inspection could guarantee consignments are pest free was the remaining risk reduction option evaluated.

Although not a favoured host, outputs from the Scenario A0 pathway model indicate that peppers are by far the most likely pathway for entry of *S. frugiperda* among the five pathways quantified. The 90% probability interval (i.e. the range between the 5th and 95th percentile) for entry via this pathway ranges from a lower estimate of just under 2,000 to an upper estimate of approximately 525,000 infested peppers per year. A less extreme range to consider is the 50% probability interval (i.e. the range between the 25th and 75th percentile). For peppers in A0, the 50% probability interval ranges from 10,000 to just under 100,000 infested peppers per year. (Recognise that in the order of 40 million peppers are imported into the EU annually from core America and sub-Saharan Africa.)

After peppers, eggplant is the next most important commodity responsible for the largest influx of *S. frugiperda* into the EU. An estimated 4,200 to 210,000 infested eggplant fruit enter the EU each year (90% probability interval (5–95%)). For other pathways, the 95th and 5th quantiles are at least a factor of 10 lower than for the peppers pathway. For example, the 90% probability interval for mean annual number of infested sweetcorn entering the EU ranges from a lower estimate of less than 500 to around 18,000.

Regulating *S. frugiperda* on peppers reduces the extreme upper limit of infestation by approximately 20%, falling from around 525,000 to around 440,000, although these levels of infestation are unlikely. However, regulation has little effect on lowering the 50% probability interval for the number of infested peppers entering the EU annually (A0 = 10,000–98,000; A1 = 10,000–90,000). This can be explained because there are already regulations in place for peppers, including import inspection, and *S. frugiperda* is already a quarantine organism. Explicit measures for *S. frugiperda* in peppers are therefore projected to have only minor consequences. In contrast, instigating risk reduction options on sweetcorn reduces entry on that pathway 100-fold. Nevertheless, sweetcorn imports are a small proportion of all *S. frugiperda* host imports, several of which are already regulated. Further regulation reduces pest entry at the extreme upper levels of entry that were generated by the stochastic simulations in @Risk.

Infested imported goods that escape detection at the EU border are assumed to be distributed across the EU in relation to human population. When distributed within the EU NUTS 2 regions, many regions are expected to receive fewer than 50 infested units per year. However, median estimates suggest that for a few NUTS 2 regions, there may be between 1,000 and 4,000 infested units per year.

Older instar larvae of *S. frugiperda* are cannibalistic (Chapman et al., 1999; Andow et al., 2015). It was assumed that any infested transfer units (e.g. individual sweetcorn cob, individual pepper) entering the EU would be infested by a single late instar larvae.

As a seasonal migrant, entry from Africa through migration was assessed. The closest *S. frugiperda* populations to the EU are approximately 3,000 km distant, with the Sahara Desert and Mediterranean Sea posing very significant ecological barriers. There is no evidence that *S. frugiperda* can traverse this distance in a single continuous flight without extraordinarily favourable wind conditions at the appropriate altitude, nor is there a plausible pathway for sequential nocturnal flights across the Sahara, i.e. a realistic scenario in which adults locate parts of the Sahara that are sufficiently vegetated to allow sporadic occurrence of multiple night flights by moths, interrupted by stayovers during daytime in such putative areas. Given the current state of knowledge, entry of *S. frugiperda* directly into the EU from populations in sub-Saharan Africa is therefore judged not feasible and was not quantified.

However, there are multiple examples of Lepidoptera species that migrate from North Africa to Europe on a seasonal basis. Establishment of permanent populations in North Africa in maize and sorghum growing areas would place *S. frugiperda* within a single night flight of the EU, with regional wind patterns conferring a high probability of periodic migration into Europe. Informed by the HYSPLIT trajectory model (Stein et al., 2015), we estimate that from a few hundred individuals to around two million adults could migrate into the southern EU annually (90% probability interval), particularly into Andalucia and Sicily. The wide range around of this estimate indicates the uncertainty of the estimate which is contingent on *S. frugiperda* establishing in North Africa.

Potential for establishment in the EU was carefully considered and drew on evidence from multiple species distribution models. *S. frugiperda* does not diapause and frosty/cold winters are an important limitation on its distribution. Depending on the sensitivity threshold selected, an ensemble model identifies pockets of climatic suitability in Spain (e.g. Andalucia), Italy (e.g. Sicily) and Greece totalling around 94,000 ha; areas in Portugal may also be identified as suitable depending on the threshold selected (Early et al., 2018). Independently, CLIMEX modelling using weather station data identifies points in the same regions where climatic conditions support establishment (i.e. CLIMEX eco-climatic indices are positive). However, when the weather station data are interpolated to provide gridded data over the landscape, CLIMEX ecoclimatic indices are reduced within grid cells such that when projected onto maps for Europe, establishment does not appear possible (du Plessis et al., 2018). Climatic

conditions in Europe are currently at the boundary for *S. frugiperda* to establish. Accurately determining boundaries of a species' potential geographical distribution is often the most challenging aspect of species distribution modelling and further data regarding the presence and especially the absence of the organism in the Americas and Africa would help refine all forecasts.

Spatially combining the results of entry and establishment allows comparisons to be made between entry of *S. frugiperda* via trade and natural migration from North Africa. If *S. frugiperda* were to establish in North Africa, three to thirty times more *S. frugiperda* are likely to migrate into parts of the southern EU than enter their via infested commodities distributed in trade. The most promising option for mitigating the risk of entry of the pest via natural dispersal is via control of the pest in Africa.

If *S. frugiperda* were to arrive and become a pest of maize in the EU, broad spectrum insecticides currently used against existing pests could be applied to control it but may impact on natural enemies and disrupt existing IPM.

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1. Introduction

1.1. Background and Terms of Reference as provided by the requestor

This pest risk assessment for *Spodoptera frugiperda*, the fall armyworm, was requested from EFSA by the European commission DG SANTE, as per a letter to EFSA's director, dated 10 January 2018, reference SANTE.Gl/as Ares (2017) 7158801. The terms of reference were specified as cited below. The opinion had a deadline of 6 months after the request date.

'EFSA is requested, pursuant to Article 29(1) of Regulation (EC) No 178/2002, to provide a scientific opinion in the field of plant health.

EFSA is requested to prepare and deliver a pest risk assessment (step 2 analysis) for *Spodoptera frugiperda.* The opinion should address entry, establishment and risk reduction options. Elaboration on main pathways of entry in the EU territory, the climatic conditions affecting its establishment in the EU, together with an analysis of available control methods is anticipated'.

1.2. Interpretation of the Terms of Reference

The Terms of Reference (ToR) specify that the requested opinion should address entry, establishment and risk reduction options, but it does not cover spread and impact. The Panel therefore understands that a partial risk assessment is being sought in which spread and impact, including impact of any transient populations that spread within the European Union (EU) during seasonal migration, are interpreted to be out of scope. Due to the rapidly developing situation in Africa, where *S. frugiperda* has spread widely in a relatively short time (Abrahams et al., 2017), the Panel determined that a 5-year time horizon was appropriate. Extending the time horizon beyond five years was considered too speculative.

There have been interceptions of *S. frugiperda* in the EU on plant products from the Americas and Africa, and the pest occurs only in these continents. *S. frugiperda* is a strong seasonal migrant in the Americas (Johnson, 1987; Nagoshi et al., 2012). The Panel therefore interpreted the main pathways for entry into the EU to be (i) imports of infested plant products from the Americas and sub-Saharan Africa, and (ii) natural migration from Africa. Recognising that entry of *S. frugiperda* into Africa likely occurred on at least two occasions (Goergen et al., 2016) and that the pathways for entry of *S. frugiperda* into Africa have not been identified, other pathways can be envisaged but are not considered the main pathways for entry into the EU. The baseline scenario, against which future scenarios can be compared, was taken to be the regulatory conditions applied to each of the studied pathways when this assessment was initiated in January 2018.

The Panel selected to examine factors affecting establishment through species distribution modelling. To link pest entry with establishment potential, the distribution of infested plant material entering the EU was to be delineated using NUTS 2 spatial resolution. As *S. frugiperda* is primarily a pest of field crops, establishment in protected cultivation was not assessed.

Phytosanitary measures that may be used to reduce likelihood of pest entry was evaluated by comparing scenarios with and without additional measures in place. Methods for the control of *S. frugiperda*, should it become established in the EU, are to be assessed.

Emergency measures were introduced against *S. frugiperda* on 23 April 2018 (European Commission, 2018b). Scenario A1 (a future scenario which is compared against the baseline A0) has similarities to the emergency measures but the emergency measures were not explicitly assessed in this opinion.

2. Data and methodologies

2.1. Data

Pest information, on host(s) and distribution, was retrieved from the EPPO Global Database (EPPO, 2017a,b) and the CABI Crop Protection Compendium (CABI, 2017b) and further updated with reports compiled in Abrahams et al. (2017). For this opinion the following data were needed:

Data on EU imports of host commodities from third countries. As a highly polyphagous pest, aggregate data using HS/CN customs codes containing key hosts were downloaded from EUROSTAT.

Data on production areas of maize (green maize and grain maize), sorghum, rice and cotton. These data were extracted from EUROSTAT and represented at the Nuts-2 level.

Data on interceptions of *S. frugiperda* and other pests in trade from the Americas and from Africa. This data was sourced from Europhyt (Europhyt, 2018). Additional data were sourced from the Netherlands Food and Consumer Product Safety Authority.

Data on the biology of the pest, in particular its flight behaviour in relationship to weather, was extracted from the scientific literature.

Data and information regarding the transport of commodities were provided by two stakeholders organisations (Freshfel and Union Fleurs) and obtained from CargoHandbook.com.

Data on the ecological requirements of the pest, to map its area of potential establishment in relation to climate factors, was obtained from the scientific literature.

Data on human population at NUTS 2 level was extracted from EUROSTAT.

2.2. Methodologies

Entry via trade in five plant commodities was assessed using pathway modelling in @Risk for Microsoft Excel. These commodities were selected by expert judgement on the basis of host suitability (sweetcorn) or size of the trade and history of interceptions (capsicum, eggplant, rose cut flowers and asparagus) (Table 1). Expert elicitation was used to estimate model input values for each substep of each pathway model. Total entry over the five pathways was calculated.

S frugiperda is a very polyphagous insect that can occur on a vast range of species, including a range of vegetables and ornamental flowers (Appendix C). A multiplier was elicited to account for the contribution of pathways that were not quantitatively assessed in detail.

The trade entry pathways are broken down into substeps and quantitative judgements are made regarding each substep with and without interventions, such as phytosanitary inspection prior to export and on arrival in the EU. The effectiveness of such measures is then assessed by comparing the projections of the pathway model with and without such interventions in place.

Entry via natural dispersal of moths by flight was assessed using data sets on the frequency of weather patterns suitable for long-distance movement of moths from Africa to Europe. While compiling information into an evidence dossier, no studies provided evidence that suggested *S. frugiperda* could migrate across the Sahara in a single flight. Experts agreed that direct entry to the EU from *S. frugiperda* populations migrating from sub-Saharan Africa is not feasible and quantification of this route was therefore not carried out.

Although *S. frugiperda* is not present in North Africa, the potential for migration from North Africa was assessed taking into account data sets on the frequency of weather patterns and estimates of potential pest distribution and population size based on crop distributions at two potential source locations in North Africa (Morocco and Tunisia). Expert elicitation was used to calculate the number of migrant adults of *S. frugiperda* reaching the EU territory during suitable weather events. Consideration of the distribution of potentially suitable areas within NUTS 2 regions and the main host crops was used to inform establishment. No interventions are possible for the migration pathway other than supporting pest management in source areas.

The potential for establishment of *S. frugiperda* in Europe was modelled using ensemble predictions generated with a platform encompassing eight species distribution model (SDM) techniques that assessed the effects of climate and habitat on the distribution of the pest (Early et al., 2018). SDMs are a statistical approach to calculate the environmental conditions suitable for a population of the study species to survive. SDMs use data on the locations where populations of a species do and do not occur. SDMs also use data on the environmental conditions that are thought to affect where the species can and cannot form populations. The relationship between environmental conditions and the species' distribution is calculated. This can also be thought of as distinguishing between the environmental conditions that are found where the species can and cannot live. The result is a map that ranks each site in a geographical region by the relative suitability for the species, based on the combined effects of all environmental variables. The ensemble map of relative suitability was converted to maps of the areas where environment is suitable for *S. frugiperda* populations to establish year-round using multiple suitability thresholds. No single threshold can be said to be most accurate, so four thresholds are presented, which summarise different levels of confidence.

Results of this modelling activity were contrasted with results obtained using meteorological station data in CLIMEX (Kriticos et al., 2015) and the parameters that were used in du Plessis et al. (2018). du Plessis et al. (2018) present maps of *S. frugiperda* potential geographical distribution based on CLIMEX parameters applied to interpolated climate data. Here we present maps for the point source meteorological station data. The assessment of establishment was therefore based on three lines of evidence (ensemble predictions, CLIMEX with gridded/interpolated climate data and CLIMEX with point source climate data).

The assessment of spread of *S. frugiperda* within the EU, and of subsequent potential impacts was outside the scope of this opinion.

The consequences of phytosanitary regulation were assessed by re-estimating relevant model substep inputs where regulation could have an effect in the pathway model that was developed for entry with trade in plant products. Pest management control options in farmer practice in the EU territory were described in a narrative way.

Table 1: Pathways and scenarios assessed

Pathway	Scenario A$_0$ (baseline)	Scenario A$_1$ (with measures)
Plant products from the Americas and sub-Saharan Africa	✔	✔
Sweetcorn (*Zea mays*)	✔	✔
Peppers (sweet peppers and other *Capsicum*)	✔	✔
Asparagus (*Asparagus officinalis*)	✔	✔
Eggplant/aubergine (*Solanum melongena*)	✔	✔
Rose cut flowers (*Rosa*)	✔	✔
Natural migration from sub-Saharan Africa	Migration direct from Sahel judged not feasible	–
Natural migration from North Africa[a]	✔	–

(a): This pathway is speculative because as of June 2018 *S. frugiperda* is not known to have established in North Africa.

The commodities selected for detailed analysis represent a range of crop husbandry techniques, e.g. outdoor crops (sweet corn, asparagus, some peppers and eggplants that are grown outdoors) and crops under protection (roses, and some peppers and eggplants), intensively managed (rose) and less intensive (sweetcorn), ongoing exposure to pests (sweet corn) and short-term exposure to pests (asparagus).

2.2.1. Conceptual models

The conceptual model expresses the key concepts underlying the calculations made to assess a quantity. In this opinion, modelling is used to assess two variables:

1) the yearly number of entries of the pest with trade resulting in infested commodity being distributed to NUTS2 regions where climate is suitable for establishment;
2) the yearly number of entries of the pest via migration from sub-Saharan Africa to NUTS2 regions that are suitable for establishment;
3) which NUTS2 regions in Europe are suitable for establishment.

2.2.1.1. Conceptual model for entry with trade

The central variable in the entry model with trade is the 'transfer unit'. A transfer unit is a unit of product that goes to the consumer as a whole. In the case of *S. frugiperda*, interceptions have occurred on a number of commodities. e.g. asparagus (*Asparagus officinalis*), peppers (*Capsicum* spp.), eggplant/aubergine (*Solanum melongena*) and rose cut flowers (*Rosa*) (See also Appendix D). These commodities have individual CN customs codes allowing import volumes to be determined. Interceptions have also occurred on other commodities such as bitter melon (*Momordica charantia*) but the import volumes are aggregated into CN codes that are shared with other commodities. It is difficult to assess trade flows for an individual commodity for which no specific CN code is publically available.

In the case of asparagus, the transfer unit is a bunch of 10 asparagus spears, while in the other three cases, the transfer unit is the single fruit (corn cob, pepper, aubergine (eggplant)) or flower stem (for roses). The total number of transfers in the European territory depends on:

- the total trade flow;
- the proportion of the transfer units in the trade that are infested with the pest;
- the probability of pest survival during trade and processing by consumers.

Total trade flow is estimated from EUROSTAT data. The proportion of infested transfer units, the probability of pest survival are estimated by expert elicitation.

The trade flow is apportioned to NUTS2 regions to assess how many infested units of plant product arrive in regions that contain areas potentially suitable for establishment. Transfer to hosts within a NUTS 2 region is not considered.

The climatic suitability for pest establishment in each NUTS2 region is assessed using separate models. The apportioning of imported plant products to NUT2 regions is done on the basis of human population in each region, on the assumption that consumer demand is proportional to population size. Human population data were sourced from EUROSTAT.

The entry model with trade is made in detail for five commodities. Furthermore, for each commodity, five regions or origin are considered: core America and sub-Saharan Africa, where the pest is present, north Africa and the Middle East, where the pest is currently absent, but where it may establish in the foreseeable future, and the rest of the world, where the pest is absent and not expected to establish within the time horizon of this assessment (Figure 1). Core America is defined as all of the Americas except Canada and the USA in the Northern hemisphere and Chile, Argentina and Uruguay in the southern hemisphere. The entry model with trade of one commodity is summarised in a graphic (Figure 2).
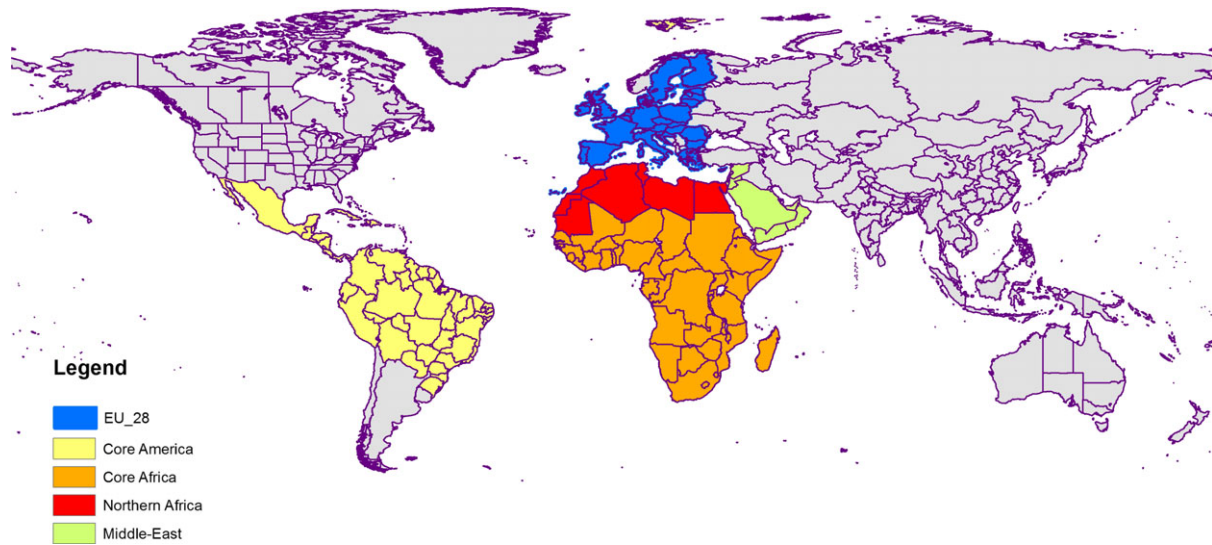
Figure 1: Regions of interest in this assessment. Immediate sources of *S. frugiperda* occur in 'core America' and 'core Africa' (sub-Saharan Africa). The EU 28 is the risk assessment area. North Africa and the Middle East are future potential sources of *S. frugiperda* spreads from core Africa. The focus of this partial assessment is on plant products from core-America and sub-Saharan Africa
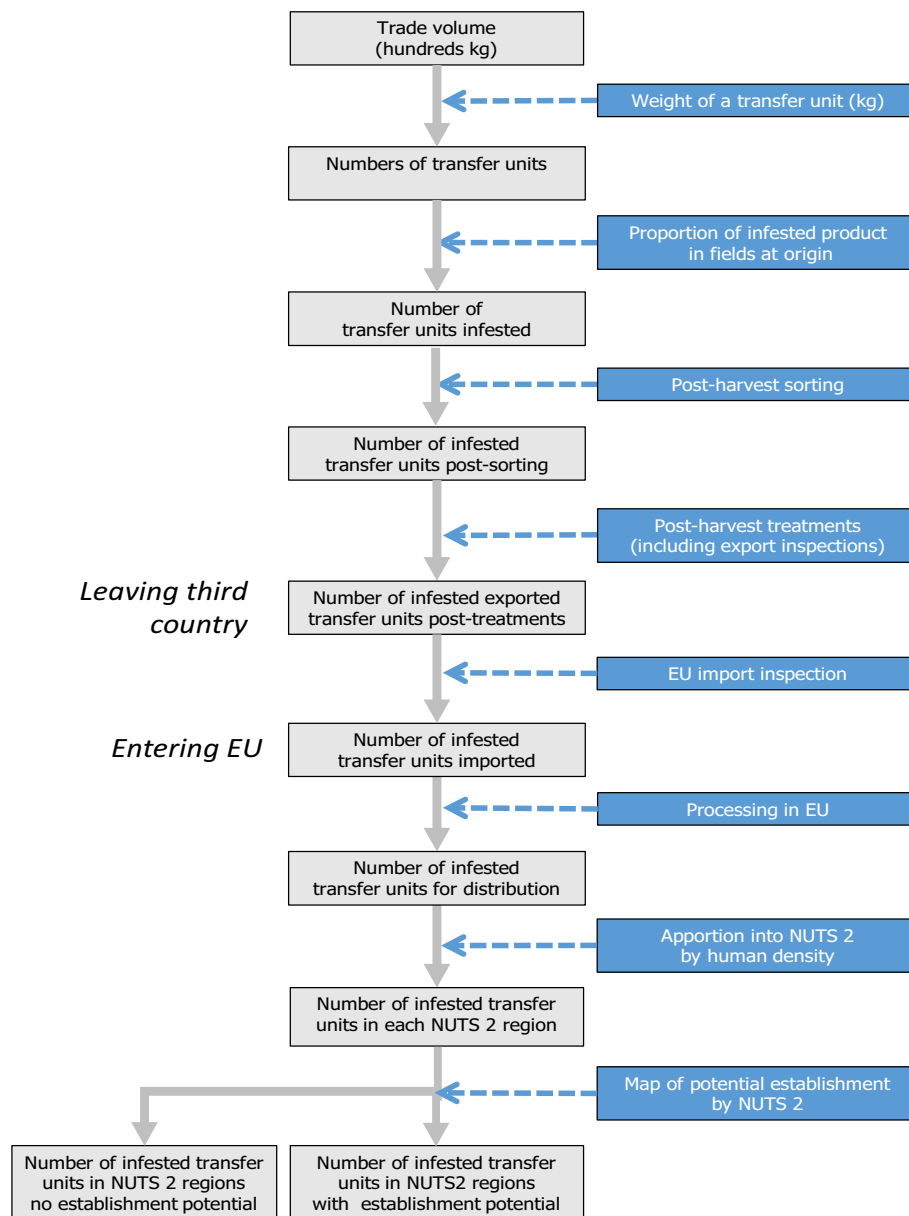
Figure 2: Graphical depiction of an example entry model pathway of *Spodoptera frugiperda* via sweetcorn trade. Such a pathway model was made for five commodities. Results were summed to obtain total entry over five pathways. Furthermore, expert knowledge elicitation was used to account for entry via pathways that were not quantitatively assessed

In Figure 2, grey boxes and solid arrows indicate the flow of the commodity and any associated pests. The flows are calculated using @Risk in Excel. Blue boxes and broken arrows represent model parameters that were obtained by expert knowledge elicitation.

2.2.1.2. Conceptual model for entry by migration

Other than supporting pest management in source areas, no interventions are possible for the migration pathway and a different approach to that used when assessing trade pathways was adopted. First information was gathered concerning long-distance migration of *S. frugiperda* and related Lepidoptera. Information regarding spread of Lepidoptera from Africa to Europe was also collected. The information in the dossier, together with input from expert opinion was used during an expert elicitation to estimate what would be the average annual number of *S. frugiperda* that arrive in a NUTS 2 region suitable for establishment were *S. frugiperda* to establish in North Africa, specifically Morocco or Tunisia.

The Panel considered evidence regarding the migration of butterflies and moths from sub-Saharan Africa to the European territory (Appendix L). While there is evidence that some lepidoptera species can make this long-distance migration, the available evidence indicates that such migration is not possible for *S. frugiperda* because of the presence of the Sahara as a barrier for successful migratory flight. Details are given in the evidence dossier. Because of the lack of evidence that the moth can cross the Sahara directly into the EU, this pathway was not quantitatively assessed. On the other hand, were *S. frugiperda* to be introduced in northern Africa in the future, then entry by flight would be a realistic possibility (Appendix M). This pathway was quantitatively assessed to obtain quantitative estimates of the number of moths arriving per year and to compare the size of this entry with the size of entry by trade pathways. The pathway model is visualised in the flow chart as Figure 3.
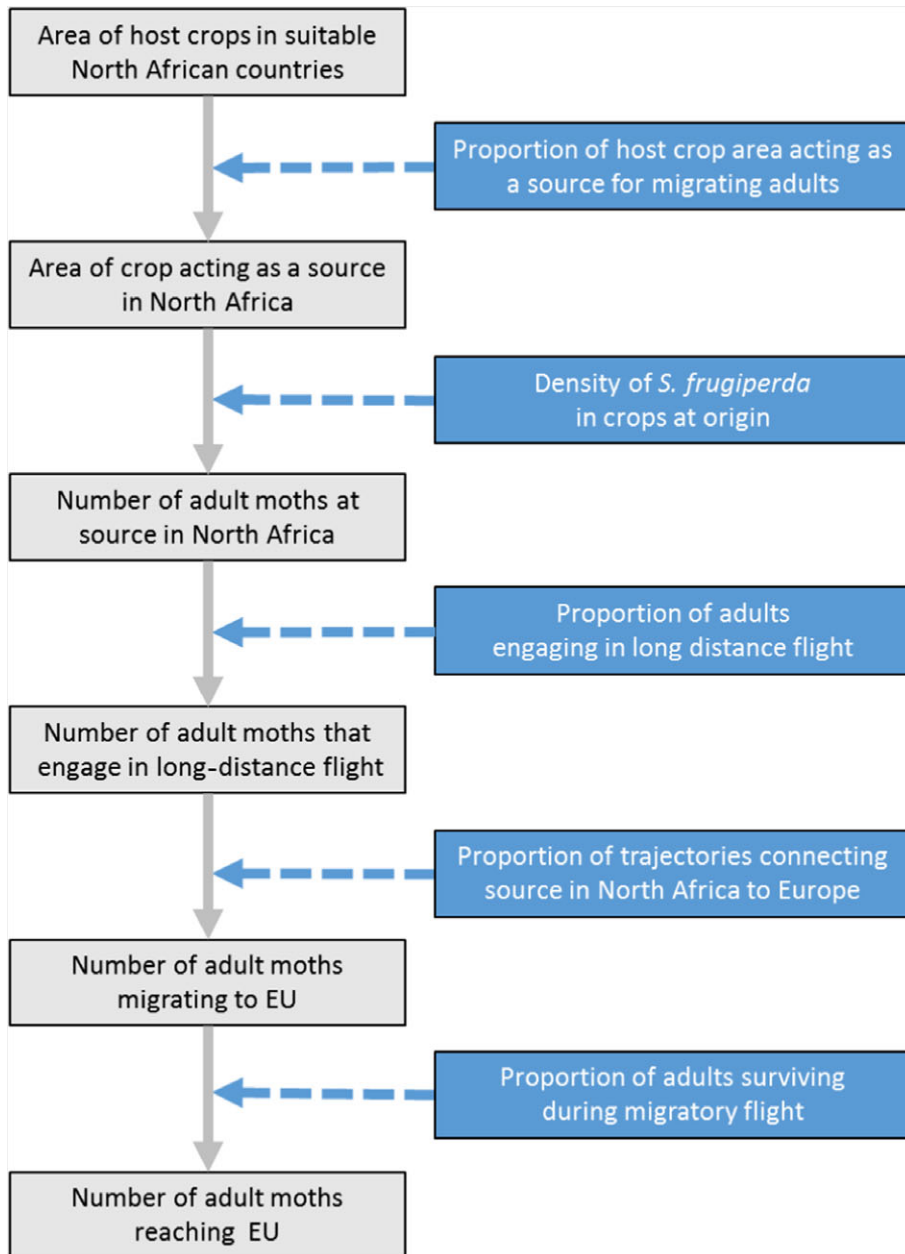
Figure 3: Graphical depiction of the entry model of *Spodoptera frugiperda* by migratory flight from northern Africa (contingent on *S. frugiperda* establishing in northern Africa)

Assessment of *S. frugiperda* migratory potential was based on seasonal wind patterns and projections of air transport trajectories. Wind vector maps were generated from monthly average wind velocity (vector mean wind speed and wind direction) using the 1981–2010 base period derived from NCEP-NCAR reanalysis of monthly zonal (i.e. westerly) and meridional (i.e. southerly) wind velocity components at a

pressure-height of 925 mb (hPa) (source: National Oceanic and Atmospheric Administration (NOAA) and the National Centers for Environmental Prediction (NCEP)). The analysed maps were obtained online from the International Research Institute for Climate and Society (Earth Institute, Columbia University, New York, NY; http://iridl.ldeo.columbia.edu/maproom/Global/Climatologies/Vector_Winds.html).

Air transport trajectories for various locations in North Africa were estimated using the Hybrid Single Particle Lagrangian Integrated Trajectory Model at the Air Resources Laboratory (ARL) READY web site run by NOAA (http://ready.arl.noaa.gov/HYSPLIT.php; (Stein et al., 2015). Potential sources for *S. frugiperda* migration into Europe were identified based on host plant availability and geographical proximity. Morocco source locations were Kenitra (34.26101, -6.5802), El Jedidah (33.25492, -8.50602) and Beni Mellal (32.33725, -6.34983). Tunisia source site was at Bizerte (37.26442, 9.87391). Projections were made for the 150-day period from April to August, 2017, which based on the agricultural growing season should encompass the highest *S. frugiperda* populations. Because *S. frugiperda* migrates nocturnally, the duration of continuous flight is limited. Estimation of maximum flight time was based on length of night during the April–August time frame in North Africa, which ranged from 9 to 11 h with an average of 10.3 h. In addition, there are indications that moth flights over water can be extended for a limited time into the day period, presumably due to the absence of landing sites (Mikkola, 1970). Based on these observations HYSPLIT projections used 12-h flight durations beginning at 18:00 h. Daily trajectories were calculated for starting altitudes of 500 m AGL and 1,500 m AGL, then displayed as a frequency distribution with percentages reflecting the proportion of trajectories entering a given grid.

2.2.1.3. Conceptual model for establishment

Species distribution modelling informed the assessment of whether and where establishment of *S. frugiperda* in the EU is possible based on climatic conditions. As *S. frugiperda* is primarily a pest of field crops, establishment in protected cultivation was not assessed. Results were adapted from Early et al. (2018). Initially host distribution was not considered because the host range of *S. frugiperda* is very wide, and establishment at the NUTS2 region level is not likely constrained much by the presence of hosts.

Environmental data

Annual minimum temperature is important for *S. frugiperda*, as the species cannot enter diapause and so die below a certain temperature. The minimum temperature for development was variously reported as 13.8°C (Hogg et al., 1982), 9.5–10.9°C (Busato et al., 2005) and 10°C (Wood et al., 1979). Growing degree days have an important effect on *S. frugiperda* population growth rate (Wood et al., 1979; Isenhour et al., 1985; Busato et al., 2005). Unfortunately, the number of growing degree days is so strongly correlated with annual minimum temperature that both variables could not be included in models together. Minimum temperature was chosen, as this has the more direct effect on *S. frugiperda* survival.

Precipitation and excessive irrigation have a direct negative effect on larval and pupal survival by causing drowning. However, indirect effects of moisture are likely more important for *S. frugiperda* population sizes than direct effects. Abundance tends to peak during rainy seasons, particularly in drier sites, possibly because of increased host plant growth (Silvain and Ti-A-Hing, 1985). There is considerable variation in the length and timing of rainy seasons across Africa (Leff et al., 2004). Several precipitation variables were therefore chosen to accommodate variation in the timing and length of the rainy season, or even multiple rainy seasons.

The following climatic variables were selected:

- SumWet, total amount of precipitation in wettest 3 months of year (intensity of rainy season, when most food available and population growth is fastest);
- LenWet, number of months when rain is greater than average (length of rainy season, when most food available and population growth is fastest);
- SeasPpn, seasonality of precipitation (difference in rainfall between rainy and dry season);
- MinTemp, mean temperature of the coldest month of the year (the lowest limit for growth).

Climatic variables were calculated from monthly averages for the period 1961–1990, derived from the climatic research unit (CRU) data set at 10 arc-minute resolution (New et al., 2002).

In addition to climatic variables 'Forest' was also used, the proportion of each 10-minute grid cell that is covered by trees. This is because *S. frugiperda* is only reported from agricultural areas, though there may be many areas covered by forest that are climatically suitable for the species, but from which it is not reported, or is absent due to a lack of host plant. We would therefore expect a negative relationship between Forest and probability of *S. frugiperda* occurrence. Forest was used, rather than crop or pasture land, as forest is relatively easier to delineate than grassland using satellite data.

Forest cover was drawn from the European Space Agency's Global Land Cover 2000 project at 1 km (https://www.esa-landcover-cci.org/) and aggregated to 10-arc minute resolution.

Spodoptera frugiperda distribution data

The presence records of *S. frugiperda* for the Americas were obtained from three sources: (1) Global Biodiversity Information Facility (www.gbif.org) in November 2016. Records that did not have coordinates but did have location descriptions were georeferenced with accuracy equal to the climatic grid data. (2) A review of literature on *S. frugiperda* in the region. (3) CABI and local experts in Colombia. In the southern USA, occurrences from south of 27 degrees in Florida and south of 31 degrees in Texas were considered to be year-round populations and were included as presence data points. Other USA populations were considered to be seasonal/transient migratory populations and were not included as presence data points. A total of 876 presence locations were found. Distribution data for Africa were obtained from four sources: (1) a survey of farming households in Ghana and Zambia, conducted in July 2017 (Abrahams et al., 2017). The countries were stratified into geographical regions, within which survey locations were chosen randomly. Surveys yielded 466 incidences of farming households experiencing *S. frugiperda* infestation. (2) Published literature (Goergen et al., 2016; Nagoshi et al., 2017a,b). (3) Infestations of *S. frugiperda* reported to CABI's Plantwise clinics from July 2016 to June 2017. (4) Seven pheromone traps managed by the USAID Agricultural Development and Value Chain Enhancement (ADVANCE) project, from April 2017 to July 2017.

Distribution data were filtered so that only one presence was recorded in each climatic grid cell resulting in 240 presences in Africa and 167 presences in the Americas.

The majority of SDMs operate by contrasting environmental conditions at sites from which the species is present and absent. Exhaustive surveys are required to ascertain if a species is absent, so in most situations true absence is not known. Instead, pseudo-absences can be randomly assigned to grid cells from which the species is not recorded. It is prudent to fit the models using several independently generated sets of pseudo-absence data, in order to be confident that results are not driven by unusual conditions in the randomly generated locations. The placement of pseudo-absences was repeated 20 times, and the number of pseudo-absences was the same as the number of presences used.

Pseudo-absences should be drawn from a background region within which the species could reasonably be expected to disperse naturally and establish if the regional was suitable for establishment (Van Der Wal et al., 2009). The geographical background from which *S. frugiperda* pseudo-absences were drawn is all of South and Central America, and the lower 48 states of the USA. American countries were excluded from the backgrounds if they did not have records of *S. frugiperda* but *S. frugiperda* is known to be present (determined using CABI's Crop Protection Compendium, https://www.cabi.org/cpc/about/, and internet searches), or if the country is surrounded by countries in which *S. frugiperda* is recorded. Pseudo-absences were randomly placed in climatic grid cells within the background region, but outside occupied grid cells.

Species distribution modelling

An ensemble SDM was created, which included eight modelling techniques: artificial neural networks (ANN), classification tree analysis (CTA), flexible discriminant analysis (FDA), generalised additive models (GAM), generalised linear models (GLM), multivariate adaptive regression splines (MARS), random forest (RF) and surface range envelope (SRE, note this does not use pseudo-absence data in model calibration but does in validation). The CLIMEX technique (Kriticos et al., 2015) was not included in the ensemble of SDM techniques. Although CLIMEX uses distribution data, the model uses data in a different way and provides a different format of output than SDMs (see below). Maxent was not used due to time constraints. Results from CLIMEX and Maxent have been shown to not differ systematically from results from other SDM techniques used here, and there is no evidence that CLIMEX and Maxent perform better than other SDMs in any given situation (Shabani et al., 2016).

The accuracy of *S. frugiperda* predictions globally can be assessed by calculating how accurately SDMs constructed with a subset of distribution data predict the presence and pseudo-absence in the rest of the distribution data ('internal validation'). The statistics used to do this are the area under receiver operating curve (AUC) and true skill statistic (TSS) (Allouche et al., 2006). Each of the 20 distribution data sets were split randomly so that 70% of the presence and pseudo-absence points were used to calibrate the models. These models were used to predict the suitability at the 30% remaining validation distribution data points.

No single SDM technique is thought to be most accurate. Instead, it is thought that each technique gives a different and potentially valid representation of the relationship between species and

environment. It is tempting to select the single model that is found to have the most accurate cross-validation score. However, a high internal validation score can mean that a model fits only the precise conditions in the species' observed distribution and cannot be generalised to make predictions for other places. Additionally, because pseudo-absence data are randomly placed, no single data set will represent locations where *S. frugiperda* does and does not occur entirely accurately. Therefore, an ensemble of a representative range of model types and 20 pseudo-absence data sets was used (Shabani et al., 2016). An ensemble forecast was therefore constructed for the global terrestrial surface. Ensembles were made using models (from the eight modelling technique × 20 distribution data sets) for which validation TSS > 0.4. Models with TSS ≥0.4 are considered to have 'moderate' performance (greater than 'fair', but less than 'substantial', Landis and Koch, 1977). All presence and pseudo-absence points in each of the 20 data sets were used to calculate the final models to be included in the ensemble (i.e. not just the 70% of the data used in calibration). To construct ensembles, the selected models were rescaled so that projections were on the same numerical scale, and the mean suitability predicted by all retained models was calculated, weighted by the accuracy (TSS) of each model. This method has been shown to be the most accurate of the 'traditional' ensembling methods that could be applied to these data (Gritti et al., 2013). In order to visualise the uncertainty of the prediction in any given grid cell, the variance between models in the ensemble was calculated.

The ensemble map of relative suitability was converted to maps of the areas where environment is suitable for *S. frugiperda* populations to establish year-round. This was done by comparing the relative suitability map against presence and pseudo-absence data, and selecting suitability thresholds where a certain proportion of presence and pseudo-absence data were accurately predicted to be suitable or unsuitable, respectively. No single threshold can be said to be most accurate (Liu et al., 2005; Jiménez-Valverde and Lobo, 2007; Nenzén and Araújo, 2011), and we present the results of four thresholds that summarise different levels of confidence.

To calculate the thresholds, 407 presences were used and 100 sets of 407 pseudo-absences were generated, using the same technique as for constructing SDMs. 'Sensitivity' is the percentage of presences predicted to be in a suitable environment. 'Specificity' is the percentage of pseudo-absences predicted to be in an unsuitable environment. The first threshold was set to be the suitability value at which sensitivity was 95%. The second threshold was set to be the suitability value at which sensitivity was 90%. The third threshold was the suitability value that maximises the sum of sensitivity and specificity. The fourth threshold was the suitability value that minimised the difference between sensitivity and specificity.

The importance of environmental variables determining the range for *S. frugiperda* range was calculated using all of the distribution data in a given data set, and using all models, regardless of TSS score. For any given environmental variable, that variable was randomised; an SDM was made with the shuffled data set. The Pearson's correlation (r) calculated between the SDMs with original data and shuffled data for each variable. Importance is calculated as 1-r, so a value 0 indicates the variable has no influence on the SDM.

2.2.2. Formal models

Formal models are provided in Appendix A.

2.2.3. Specification of the scenarios

Two scenarios were elaborated:

Scenario A0, the baseline. It is the situation representing the regulatory conditions applied to each of the pathways when this assessment was initiated in January 2018.

Scenario A1, is an imagined future situation where the pathways are all specifically regulated with respect to *S. frugiperda*, i.e. risk reduction options (RROs) (pre-export inspection and EU import inspection) are applied to regulated pathways.

Scenario A1 presumes the introduction of additional regulations of pest freedom from consignments in specific commodities, such as sweetcorn, whereas such a regulation was not present previously. Such a regulation would have direct and indirect effects. Direct effects would include increases in inspection effort for those commodities that were not previously subject to inspection requirements, such as sweetcorn. Indirect effects would result from the deterrent effect of such requirements and inspections on producers. To safeguard their market, they are expected to make all feasible adjustments in the production system, including improved control of the pest in the field, as well as

pre-export sorting, grading and treatments (e.g. cold treatment of harvested product where this is compatible with the cold hardiness of the product) to try and ensure that the product meets the standards before export. Effectiveness of measures was parameterised at the level of substeps in the pathway models. Experts evaluated the evidence and discussed the effectiveness of the measures using expert knowledge elicitation. Effects on entry were calculated using the pathway model in @Risk. The calculations in @Risk show the total effect of all actions resulting from a regulation of pest freedom in consignments of pathways of *S. frugiperda*.

No interventions are possible for the migration pathway other than supporting pest management in source areas; hence, migration from North Africa is only modelled within Scenario A0.

2.2.4. Definitions

2.2.4.1. Definition of the pathways

Currently, *S. frugiperda* is confirmed as present (established year round) in the USA and Mexico and in several countries in Central and South America and in sub-Saharan Africa (Abrahams et al., 2017). Within the USA *S. frugiperda* has a limited year-round distribution in southern Florida and southern Texas. However, the exact overwintering locations are uncertain. Small populations may exist in coastal pockets of southern US states bordering the Gulf of Mexico (Louisiana, Mississippi and Alabama). Two types of pathway are quantified for these areas of pest presence: (i) import via trade in fresh host commodities, and (ii) natural migration from Africa.

Trade pathways are further elaborated. Because trade data is available on a country scale and *S. frugiperda* has only a limited distribution year round in USA, exports from USA are not included in the analysis. Recognising the recent introduction and rapid expansion in Africa, it is feared that the pest may extend its geographical range further to include regions in northern Africa and/or the Middle East. If this happened, there would be additional pathways. As of 1 June 2018, *S. frugiperda* was not known to have established in Africa north of the Sahara in countries bordering the Mediterranean nor in the Middle East. These potential pathways are therefore hypothetical. Nevertheless, the consequences of a geographical range extension into North Africa will be considered in the light of these possible future pathways and following feedback from the European Commission during a presentation of interim findings (PLH Plenary meeting 16–17 May 2018).

2.2.4.2. Definition of different units used

Trade is expressed in units of plant products. Depending on the product, the units are hundreds of kg of commodity (consistent with how EUROSTAT provides data). These can be converted to individual pieces using standard European conversion factors (EFSA unpublished data).

Dispersal by flight is expressed in numbers of moths migrating from a source area to a target area during a single dispersal event.

2.2.4.3. Definition of abundance of the pest

The abundance of the pest is expressed as the proportion of traded units that are infested, starting in the field and progressing along the pathway (Figure 2).

2.2.4.4. Potential RROs of the steps and identification of the RROs for the substeps

In principle a variety of phytosanitary measures, also known as risk reduction options, or RROs, are available to lower the likelihood that *S. frugiperda* enters the EU on host commodities traded internationally. For example, commodities could be sourced from a pest free area (PFA), or a pest free place of production (PFPP) or a pest free production site (PFPS). Prior to their export a commodity could be officially inspected to certify that it is free from *S. frugiperda* or had been subjected to treatment to ensure freedom from the pest. PFA, PFPP and PFPS are among the measures listed in the EU emergency measures (European Commission, 2018a,b) but were not considered feasible by the EFSA PLH Panel. In order to guarantee pest freedom within a crop, place of production, place of production and buffer zone, or area, it is necessary to fulfil the requirements outlined in ISPM No. 4 (FAO, 2017) and ISPM No. 10 (FAO, 2016). Considering the biology of the pest (multivoltine, polyphagous, highly mobile adults), it would be very challenging for any NPPO to fulfil the requirements necessary. The Panel is not aware of any countries in core America or sub-Saharan Africa that could claim such area freedoms.

Another possible RRO option is to produce (grow) the hosts liable to be infested with *S. frugiperda* in complete physical protection, e.g. in glasshouses or polytunnels with appropriate screens over vents. It is not economic to grow field crops such as sweetcorn under such conditions. High value

crops such as cut flowers are already grown under protection in Africa and the Americas and are therefore already considered within the baseline scenario (A0). Given that host commodities such as peppers and eggplant are chill sensitive (CargoHandbook.com, 2012b, 2017b), cold treatments that would be lethal for *S. frugiperda* are not appropriate for such commodities. A remaining RRO is consignment freedom, based on pre-export visual inspection. Recognising that pre-export official inspection would occur within Scenario A1, with potential loss of market access if consignments were found infested, scenario A1 also assumed growers would implement additional pest control within production sites, e.g. additional scouting for pest symptoms and subsequent additional chemical treatments where necessary.

2.2.4.5. Ecological factors and conditions in the chosen scenarios

Evidence dossiers for commodity pathways describe relevant ecological factors and pathway conditions (Appendices E–I).

2.2.4.6. Temporal and spatial scales

Due to the rapidly developing situation in Africa, where *S. frugiperda* has spread widely in a relatively short time (Abrahams et al., 2017) the Panel considered that a 5 year time horizon was appropriate. The quantitative model uses an annual time step.

Establishment is considered within NUTS 2, the spatial scale at which commodities entering the EU are apportioned into. SDM uses a finer scale with grid cells of 10-arc minutes (approximating to 14 km^2 each).

2.2.5. Summary of the different scenarios

Scenario A0 is a baseline scenario representing the regulatory conditions applied to each of the pathways when this assessment was initiated in January 2018. At that time, *Capsicum*, *Solanum melongena* and *Rosa* cut flowers were already regulated (although not specifically with respect to *S. frugiperda*) and consignments from third countries were subject to phytosanitary inspection on arrival in the EU. Sweetcorn (*Zea mays*) and *Asparagus* were not regulated and they were allowed to enter without phytosanitary checks.

Scenario A1 is an imagined future situation where the pathways are all specifically regulated with respect to *S. frugiperda* (see Section 2.2.3).

3. Assessment

3.1. Pest biology

The biology and life cycle of *S. frugiperda* is summarised in the first phase assessment (a pest categorisation) by EFSA PLH Panel (2017). A summary is provided here for ease of use. *S. frugiperda* (Smith, Lepidoptera: Noctuidae) is a polyphagous pest with hosts in 27 plant families. Favoured hosts include maize, rice and sorghum (Poaceae). Hosts also include crops within the Brassicaceae, Cucurbitaceae, Rutaceae, Solanaceae and other families (de Silva et al., 2017). *S. frugiperda* is native to tropical and subtropical regions of the Americas where winter temperatures rarely fall below 10°C (Sparks, 1979; Ashley et al., 1989; Nagoshi and Meagher, 2008). It migrates to temperate regions in North and South America during the relevant hemispheres summer. In southern Florida, *S. frugiperda* can breed year round (Abrahams et al., 2017). There are continuous generations in Central and South America (Johnson, 1987) where there can be four to six generations per year (CABI, 2017b).

In 2016, *S. frugiperda* was reported for the first time in Africa with outbreaks in Benin, Nigeria, Sao Tome and Principe and Togo (Goergen et al., 2016; IITA, 2016). Subsequent reports suggest that it spread rapidly across Africa.

Eggs are usually laid on the underside of hosts' leaves although at high population densities oviposition can occur on almost any surface. Eggs are laid in clusters of 100–300 and are protected with a covering of abdominal scales (CABI, 2017a,b). 1,000 eggs being laid per female (Johnson, 1987). Eggs hatch in 2–4 days at 21–27°C (Sparks, 1979). First and second instar larvae feed together on the host where eggs were laid (Pannuti et al., 2015). Young leaves and tender growing tips of hosts are preferred. Third instar larvae disperse away from each other but generally do not go far unless they are at a high larval density and hosts are depleted (Pannuti et al., 2016). In such circumstances, larvae will 'march' in search of food. There are five or six larval instars. Mature larvae burrow into the soil to pupate. Overall, egg to adult development takes around 66 days at 18.3°C and

18 days at 35.0°C (Barfield et al., 1978). A threshold temperature of 10.9°C and 559 day-degrees above the threshold is required for development of the complete life cycle. Adult females are relatively short-lived (13–19 days at 26.8°C) (Johnson, 1987). All stages are usually killed by freezing temperatures (Smith et al., 1997; CABI, 2017a,b).

3.1.1. Assessment of entry via plant commodities under given scenarios

3.1.1.1. Summary – Entry into the EU in Scenario A0 (baseline)

Table 2 presents the results of model outputs under Scenario A0. Results have been rounded to avoid the impression of very great precision. Outputs from the pathway models indicate that peppers (*Capsicum* and *Pimenta*) are by far the most likely pathway for entry of *S. frugiperda* among the five pathways quantified (Table 2). The 90% probability interval for entry via this pathway ranges from a lower estimate of just under 2,000 to an upper estimate of approximately 525,000 infested peppers per year. After peppers, eggplants provide the next highest numbers of infested commodities, with the 90% probability interval between approximately 4,200 and 210,000 infested transfer units (i.e. individual peppers). For other pathways, the 95th and 5th quantiles are at least a factor of 10 lower than for the peppers pathway.

Older instar larvae of *S. frugiperda* are cannibalistic (Chapman et al., 1999). It was assumed that any infested transfer units (e.g. individual sweetcorn cobs, individual peppers) entering the EU would be infested by a single late instar larvae; hence, the number of infested units entering the EU equates to the number of *S. frugiperda* larvae entering the EU.

Table 2: Outputs (rounded) of pathway models for entry of *S. frugiperda* into the EU via the trade in peppers, sweetcorn, eggplants, cut roses and asparagus. Calculations with the pathway model were made assuming current regulations as at January 2018 (Scenario A0)

Percentile[a]	5th	25th	Median (50th)	75th	95th	90% Prob interval[b]	50% Prob int[c]
Peppers	1,800	10,000	30,500	98,000	525,000	523,200	88,000
Eggplant	750	4,200	13,500	42,000	210,000	210,000	38,000
Sweetcorn	150	1,000	2,500	6,000	18,000	17,850	5,000
Cut roses	50	200	500	1,200	4,500	4,450	1,000
Asparagus	> 0	50	100	500	3,200	3,200	450

(a): Descending cumulative probability.
(b): 90% probability interval between 95th and 5th percentile.
(c): 50% probability interval between the 75th and 25th percentile.

3.1.1.2. Summary – Entry into the EU in Scenario A1 (all pathways regulated)

Table 3 presents the results of model outputs under Scenario A1. Like Table 2, the results have been rounded to avoid the impression of very great precision. Measures against *S. frugiperda*, such as a requirement for inspection against this pest, are anticipated to have an effect at the upper end of the level of infestation. Overall, there are minor effects on entry for the three out of the five pathways that are already regulated. For peppers, eggplant and cut roses there are already requirements against other quarantine pests and on entry into the EU these consignments are inspected; some at a reduced frequency, e.g. rose cut flowers from Kenya. The similarity of quantiles for these pathways in Table 2 (current regulations) and Table 3 (with specific measures for *S. frugiperda*) attests to the limited effects of further regulation.

In contrast, specific measures for *S. frugiperda* would result in a substantial reduction in the entry via the sweetcorn pathway (Figure 4), because under current regulations, there is no requirement for inspection of this commodity. Inspection is expected to increase the pressure on importers to produce pest free product at origin and is expected to therefore likely lead to several improvements in the operations before export to ensure product quality.

Table 3: Outputs (rounded number of infested fruits/flowers) of pathway models for entry of *S. frugiperda* into the EU via the trade in peppers, sweetcorn, eggplants, cut roses and asparagus. Calculations with the pathway model were made assuming specific measures against *S. frugiperda* (Scenario A1)

Percentile[a]	5th	25th	Median (50th)	75th	95th	90% prob int[b]	50% prob int[c]
Peppers	1,800	10,000	30,500	90,000	440,000	438,200	80,000
Eggplant	900	4,500	13,500	40,000	190,000	190,000	35,500
Sweetcorn	> 0	50	100	200	600	600	150
Cut roses	50	200	500	1,200	4,500	4,450	1,000
Asparagus	> 0	50	100	450	2,800	2,800	400

(a): Descending cumulative probability.
(b): 90% probability interval between 95th and 5th percentile.
(c): 50% probability interval between the 75th and 25th percentile.

Details on the data and parameters that underlie these modelling results are given in the Appendices E–I. Individual pathways are considered further below.

3.1.2. Assessment of entry via sweetcorn

With regulation, scenario A1 shows a marked shift of the distribution to the left, representing a reduction in projected entry of infested cobs. The 5th percentile of this distribution (i.e. the level of entry that is exceeded with a 5% chance) is reduced from a value of about 17,000 sweetcorn cobs per year for the whole of the EU to less than 1,000 cobs per year. Only a few of these cobs would end up in regions with potential for establishment (see Section 3.2).

Figure 4: Descending cumulative probability distributions for the entry of *S. frugiperda* with trade in sweetcorn under two scenarios A0 (current measures- hatched lines) and when regulated (A1, solid line)

3.1.3. Assessment of entry via peppers

In Scenario A0, the mean rate of entry of infested peppers has a 90% probability interval of between 1,800 and 525,000 peppers per year, whereas in Scenario A1 the 90% probability interval is from 1,800 to 440,000 (Tables 2 and 3). Hence with further regulation of peppers, it is the extreme

upper levels of infestation that may be reduced although such levels of infestation are expected to occur less often than lower levels.

Figure 5 plots the descending cumulative probability distributions for the entry of *S. frugiperda* in peppers for both scenarios. In the central region of the distribution, between the 25th and 75th percentile, there is little difference between the two distributions. This can be explained because there are already regulations in place for peppers, including import inspection, and *S. frugiperda* is already a quarantine organism. Explicit measures for *S. frugiperda* in peppers are therefore projected to have only minor consequences for entry of the insect.

Figure 5: Descending cumulative probability distributions for the entry of *S. frugiperda* with trade in peppers under two scenarios: (A0) current measures (hatched lines) and (A1) specific requirements for *S. frugiperda* in peppers

3.1.4. Assessment of entry via asparagus

Asparagus is not regulated in Scenario A0 yet regulation of the pathway in Scenario A1 appears to have little effect (Figure 6), perhaps because of the difficulty in detecting what is already low levels of infestation. Entry on the asparagus pathway is two orders of magnitude smaller than entry on the pepper pathway.

Figure 6: Descending cumulative probability distributions for the entry of *S. frugiperda* with trade in asparagus under two scenarios: (A0) current measures (hatched lines) and (A1) specific requirements for *S. frugiperda* in asparagus

3.1.5. Assessment of entry via eggplants

It is clear that in Figure 7 there is little difference between the two distributions. This is because there are already regulations in place for eggplant, including import inspection, and *S. frugiperda* is already a quarantine organism. Explicit measures for *S. frugiperda* in eggplant are therefore projected to have only minor consequences for entry of the insect. As in the case of peppers, further regulation of eggplants has an effect at the extreme upper levels of mean infestation rate reducing it from approximately 220,000 to 190,000 infested fruit per year. Such levels of entry are thus expected less frequently. Entry on this pathway is approximately half that of entry on the pepper pathway.

Figure 7: Descending cumulative probability distributions for the entry of *S. frugiperda* with trade in eggplant under two scenarios: (A0) current measures (hatched lines) and (A1) specific requirements for *S. frugiperda*

3.1.6. Assessment of entry via rose cut flowers

Following what is seen with the other commodities that are already regulated, there is almost no difference between the distributions of mean rate of entry via rose cut flowers in Scenarios A0 and A1 (Figure 8). Explicit measures for *S. frugiperda* in cut roses are therefore projected to have only minor consequences for entry of the insect. Entry on this pathway is two orders of magnitude smaller than entry on the pepper pathway.
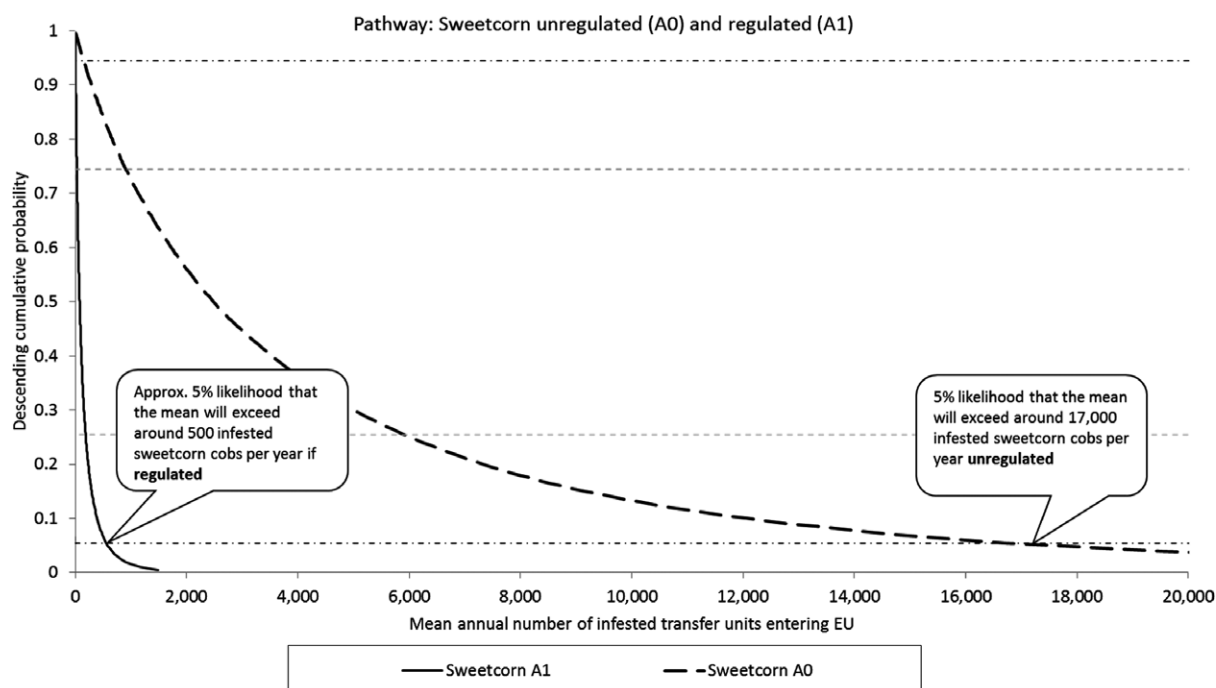

Figure 8: Descending cumulative probability distributions for the entry of *S. frugiperda* with trade in rose cut flowers under two scenarios: (A0) current measures (hatched lines) and (A1) specific requirements for *S. frugiperda*

3.1.7. Aggregate assessment of entry (detailed pathways)

Figure 9 shows the descending cumulative probability distributions for the entry of *S. frugiperda* with aggregate trade in the five commodities detailed above. Further regulation appears to reduce likelihood of the mean number of annual entries of infested commodities. At the 75th percentile it reduces from approximately 38,000 to 32,000 and at the 25th percentile from approximately 190,000 to 165,000 (Figure 9). At the 95th percentile regulation reduces mean entry by around 150,000 from approximately 735,000 to 585,000 (the long tails of each distribution are not shown in Figure 9).

Pathway: Aggregate of pathways baseline (A0) and with RROs (A1)

In Scenario A0 there is approximately 50% probability that the mean number of infested units annually entering the EU is between 38,000 and 190,000

In Scenario A1 there is approximately 50% probability that the mean number of infested units annually entering the EU is between 32,000 and 165,000

Mean annual number of infested transfer units entering EU

—— Aggegate A1   — – Aggregate A0

Figure 9: Descending cumulative probability distributions for the entry of *S. frugiperda* with aggregate trade in the five commodities detailed above under two scenarios: (A0) current measures (hatched lines) and (A1) specific requirements for *S. frugiperda*

The explanation for this projection is a combination of the component pathways. Three pathways are already regulated in A0 (peppers, eggplant and rose cut flowers). Thus, exporters already have an incentive to produce product that is pest free, and hence free from *S. frugiperda.* Additional specific measures for *S. frugiperda* would not change this situation by much. Additional specific measures against the pest in these commodities were therefore judged to have only minor consequences for the entry process. There is a significant reduction in sweetcorn but the significance is lost in the aggregate trade due to the much larger volumes of peppers imported.

Details on the data and parameters that underlie these modelling results is given in the Appendices E–I.

3.1.8. Assessment of entry with other commodities

Recognising that other vegetable and cut flower hosts could provide pathways, Table 4 indicates the estimated range in mean number of infested transfer units entering on pathways represented in Appendix K. While Appendix K lists additional potential pathways and associated import quantities, Appendix D indicates interceptions of *S. frugiperda* notified on Europhyt to May 2018.

Table 4: Outputs (rounded) of pathway models for entry of *S. frugiperda* into the EU via the trade in other vegetable and cut flower hosts

Percentile[a]	5th	25th	Median (50th)	75th	95th	90% prob int[b]	50% prob int[c]
Scenario A0	6,000	18,000	45,000	120,000	600,000	595,000	100,000
Scenario A1	4,000	15,000	38,000	100,000	500,000	495,000	85,000

(a): Descending cumulative probability.
(b): 90% probability interval between 95th and 5th percentile.
(c): 50% probability interval between the 75th and 25th percentile.

Many of the commodities listed in Appendix K are not regulated in either Scenario A0 or A1. The reduction in mean number of infested commodities in Table 4 is a reflection of the estimated changes between A0 and A1 in the detailed pathway analyses where there is also little regulatory change although greater awareness of pathways and inspection efforts pre-export and post EU entry could reduce the number of infested items entering the EU.

3.1.9. Combined assessment of entry via trade (detailed pathways plus other vegetables and cut flowers)

Combining entry via the pathways assessed in detail (Appendices E–I) and other vegetable and cut flower pathways (Section 3.1.8; Appendix K), Table 5 and Figure 10 indicates the estimated range in mean number of infested transfer units entering on all trade pathways considered for each scenario.

Table 5: Outputs (rounded) of pathway models for entry of *S. frugiperda* into the EU via the trade in all vegetable and cut flower hosts considered

Percentile[a]	5th	25th	Median (50th)	75th	95th	90% Prob int[b]	50% Prob int[c]
Scenario A0	25,000	75,000	160,000	385,000	1,560,000	1,535,000	310,000
Scenario A1	20,000	61,000	142,000	338,000	1,230,000	1,210,000	277,000

(a): Descending cumulative probability.
(b): 90% probability interval between 95th and 5th percentile.
(c): 50% probability interval between the 75th and 25th percentile.

Eggs or larvae entering the EU on host commodities would be able to complete their development if environmental conditions were suitable.
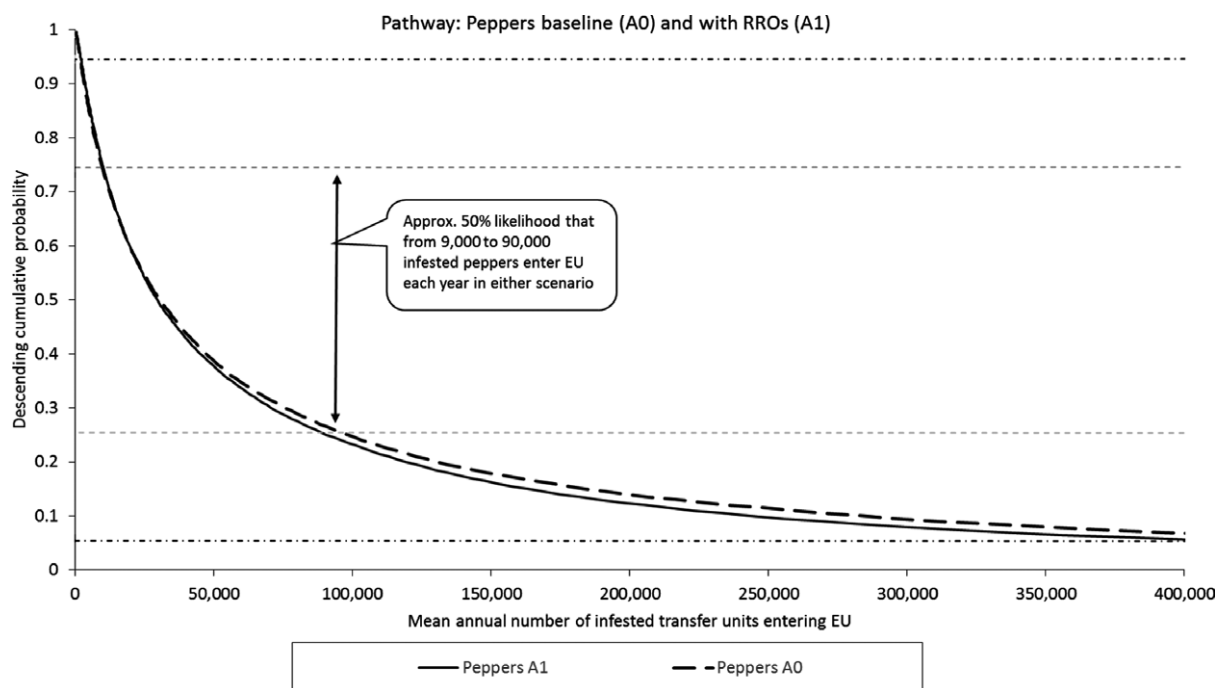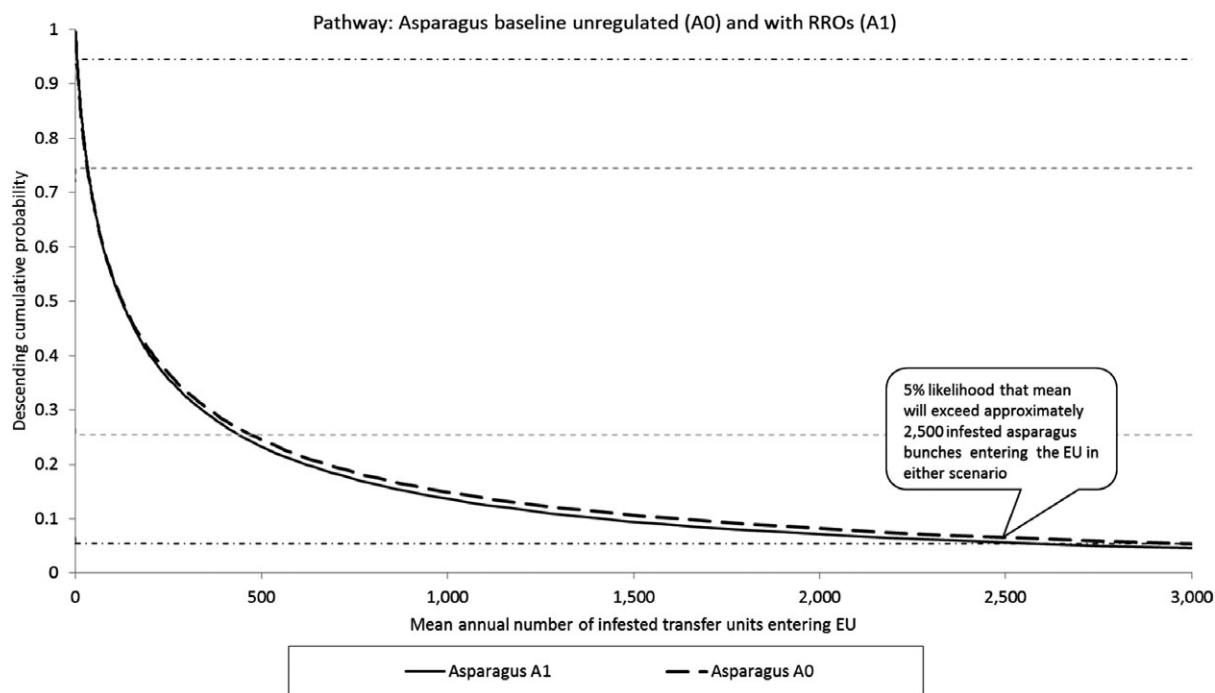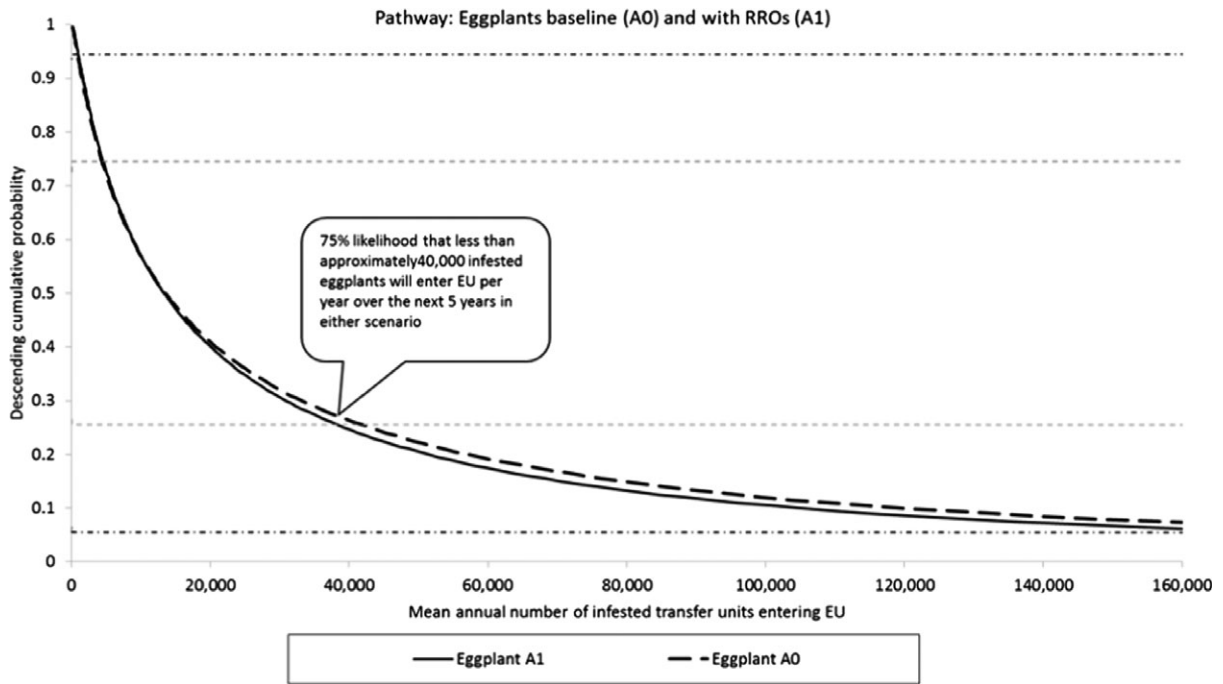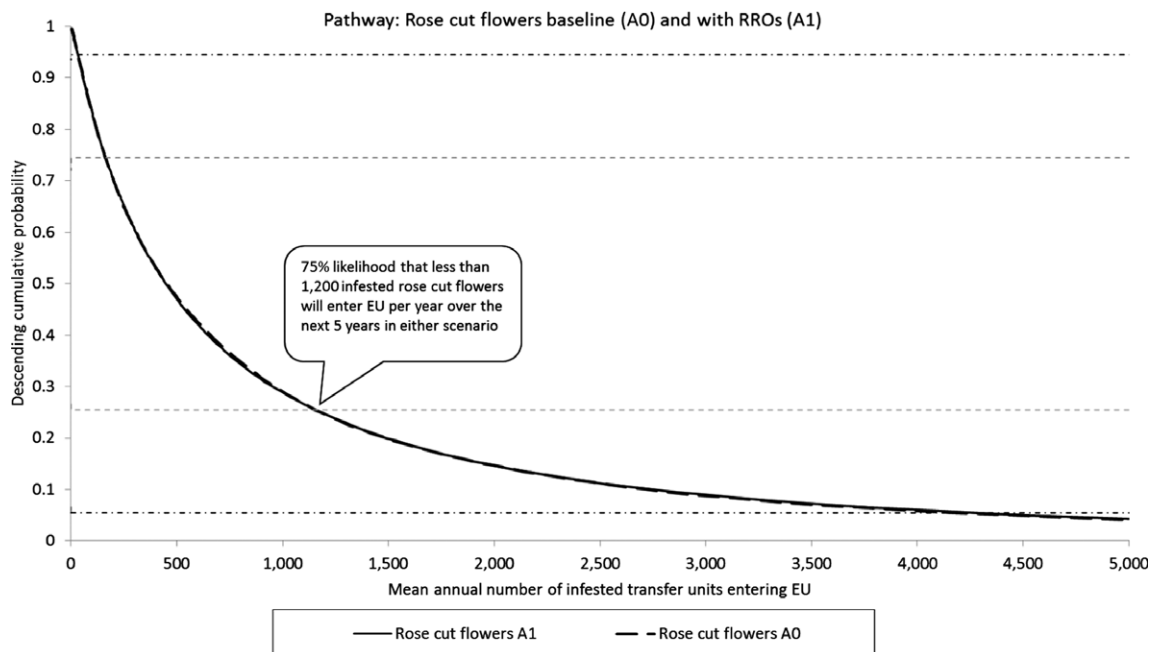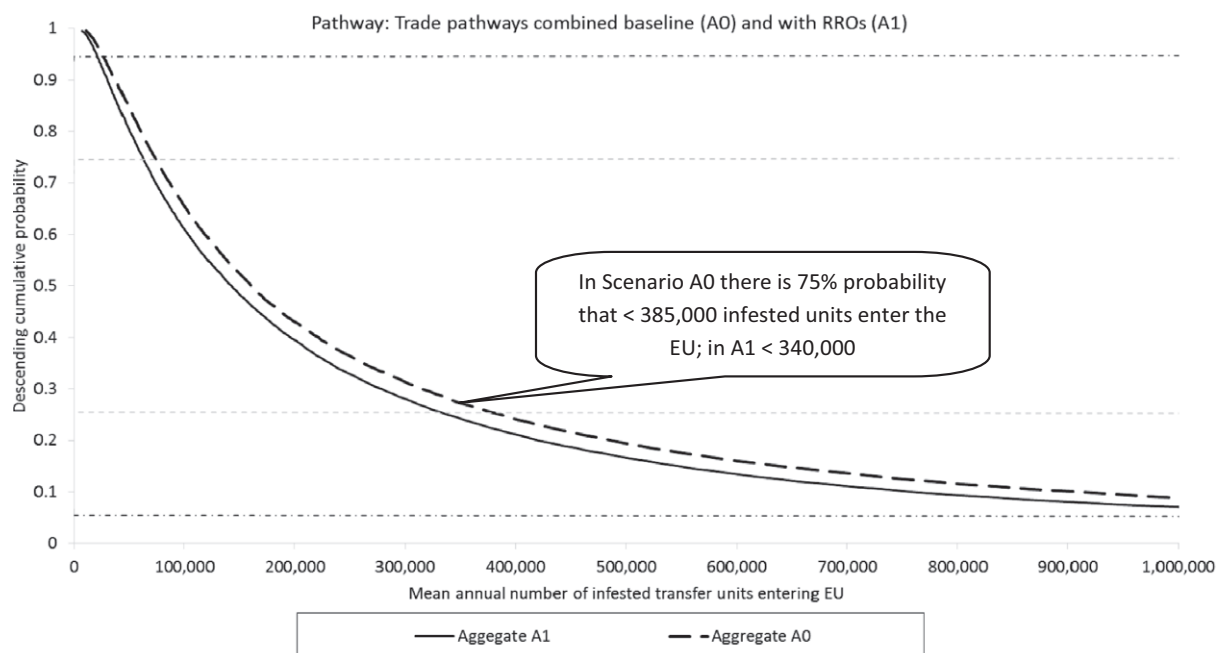
Figure 10: Descending cumulative probability distributions for the entry of *S. frugiperda* with trade in all hosts considered under two scenarios: (A0) current measures (hatched lines) and (A1) specific requirements for *S. frugiperda*

3.1.10. Entry across the EU specified at NUTS2 level

Although the majority of fruit and vegetables enters the EU via the Netherlands and Germany, all host commodities, including infested hosts that escape detection at the EU border, are assumed to be distributed across the EU in relation to human population. Working at a spatial resolution of NUTS 2 (see Section 2.2.4.6), fresh produce for consumption was distributed across the EU is proportion to the number of consumers in NUTS 2 regions. While food consumption does vary regionally, Blandford (1984) found the differences in food consumption between OECD countries were decreasing, suggesting diets were converging and are become increasingly similar in the overall structure of their diet. When comparing diets within Europe, Elsner and Hartmann (1998), Mauracher and Valentini (2006) and Schmidhuber and Traill (2006) found European diets were also converging. Within the EU diets have become more homogeneous, there has been increased intakes in Mediterranean countries of saturated fats, cholesterol and sugar, while there has been reductions in saturated fat and sugar in Northern European countries (Schmidhuber and Traill, 2006). Figure 11 delineates the apportionment by NUTS 2 regions (Appendix L). It is noteworthy that Andalucia is among the NUTS 2 regions receiving the higher amounts of commodities (50% probability interval that 1,200–6,400 infested units enter annually; median value 2,600 infested units enter annually) (see also Section 3.2 establishment).
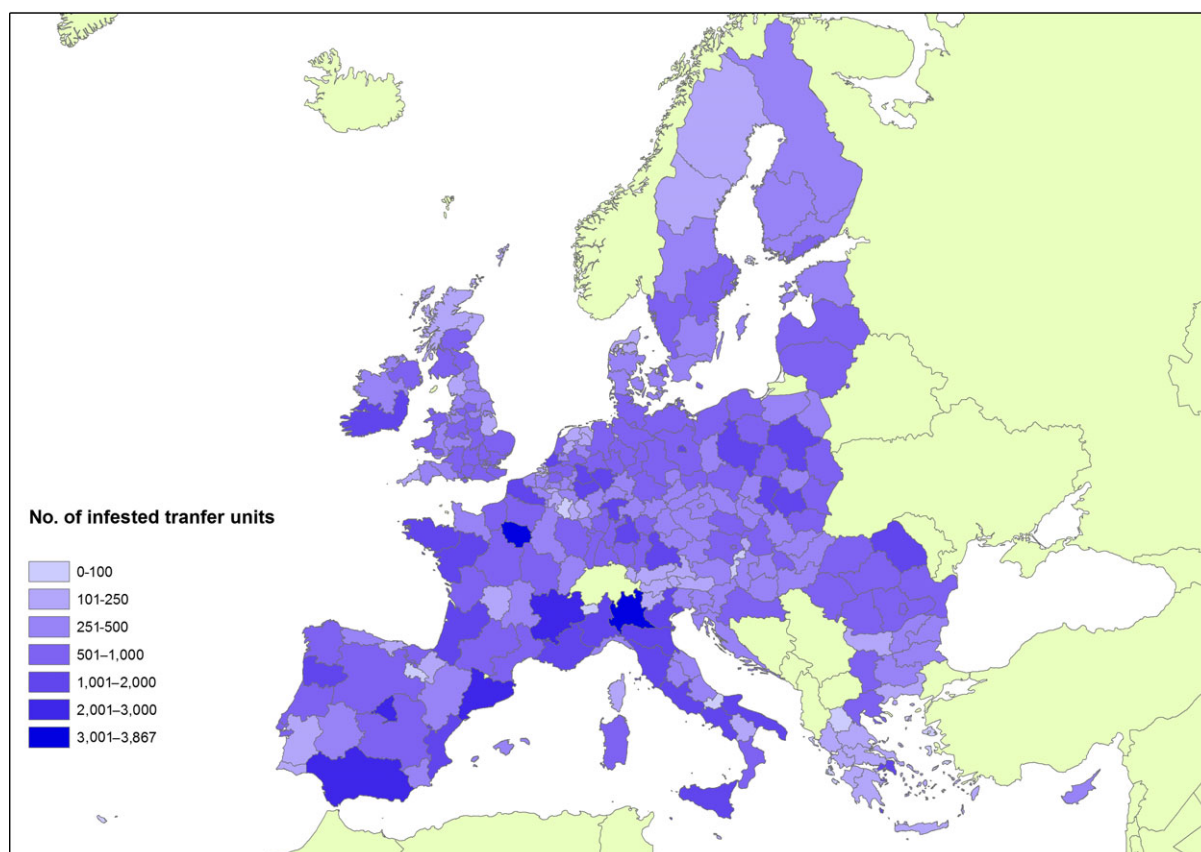
Figure 11: Allocation of median values of all infested vegetable and cut flower host commodities entering the EU via trade then apportioned to NUTS 2 region in relation to human population

3.1.11. Assessment of entry via natural migration from sub-Saharan Africa

After considering the information in the evidence dossier (Appendix M) and taking expert knowledge into account, the entry of *S. frugiperda* directly into the EU from populations in sub-Saharan Africa is judged not feasible and was therefore not quantified.

3.1.12. Potential for entry via migration from northern Africa

Assuming *S. frugiperda* were to establish in North Africa, Figures 12 and 13 represent potential trajectories from source host crop growing regions in Morocco and Tunisia. There is considerable uncertainty regarding the number of moths that could reach the EU each year from North Africa, with estimates ranging from a few hundred individuals to around two million although it is more likely that in the range of tens to hundreds of thousands would enter each year, many arriving into Andalucia (Table 6 and Figure 14).
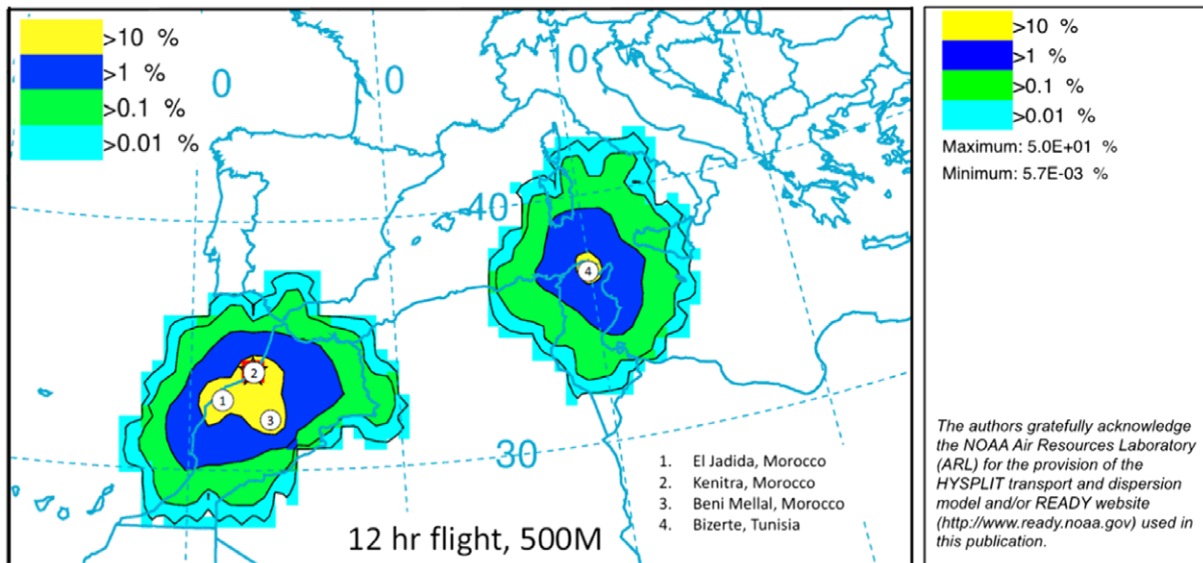
Figure 12: HYSPLIT trajectory projections for a 12-h flight at 500 m. Origins in Morocco are marked 1, 2, 3; in Tunisia 4. Different colours indicate the percentage of trajectories originating in the source area that cross the coloured zones. For instance: yellow areas are crossed by more than 10% of the 1,500 m height wind trajectories that originate in the source areas during a travel time of 12 h. Blue areas are crossed by 1–10% of those wind trajectories, etc. Further information is given in Stein et al. (2015)
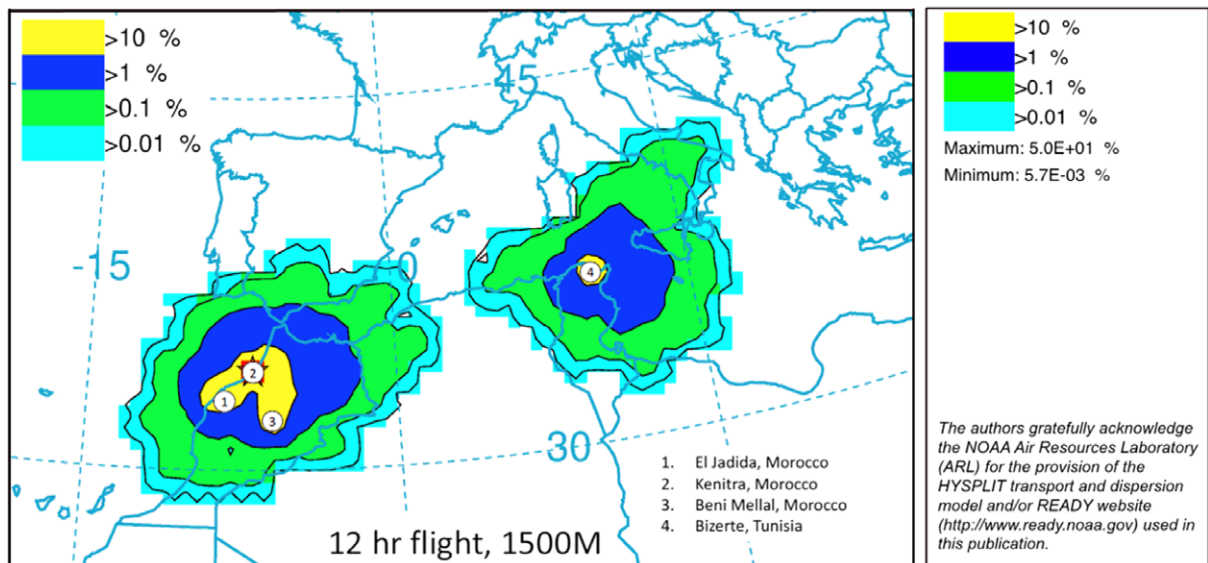
Figure 13: HYSPLIT trajectory projections for a 12-h flight at 1,500 m. Origins in Morocco are marked 1, 2, 3; in Tunisia 4

Table 6: Distribution of estimated mean annual number of adult *S. frugiperda* migrating into the EU from NorthAfrica. This pathway is contingent on *S. frugiperda* establishing in Africa, north of the Sahara, specifically in Morocco and Tunisia

Percentile[a]	5th	25th	Median (50th)	75th	95th	90% prob int[b]	50% pro bint[c]
Scenario A0	100	4,000	32,000	200,000	2,400,000	2,400,000	195,000

(a): Descending cumulative probability.
(b): 90% probability interval between 95th and 5th percentile.
(c): 50% probability interval between the 75th and 25th percentile.
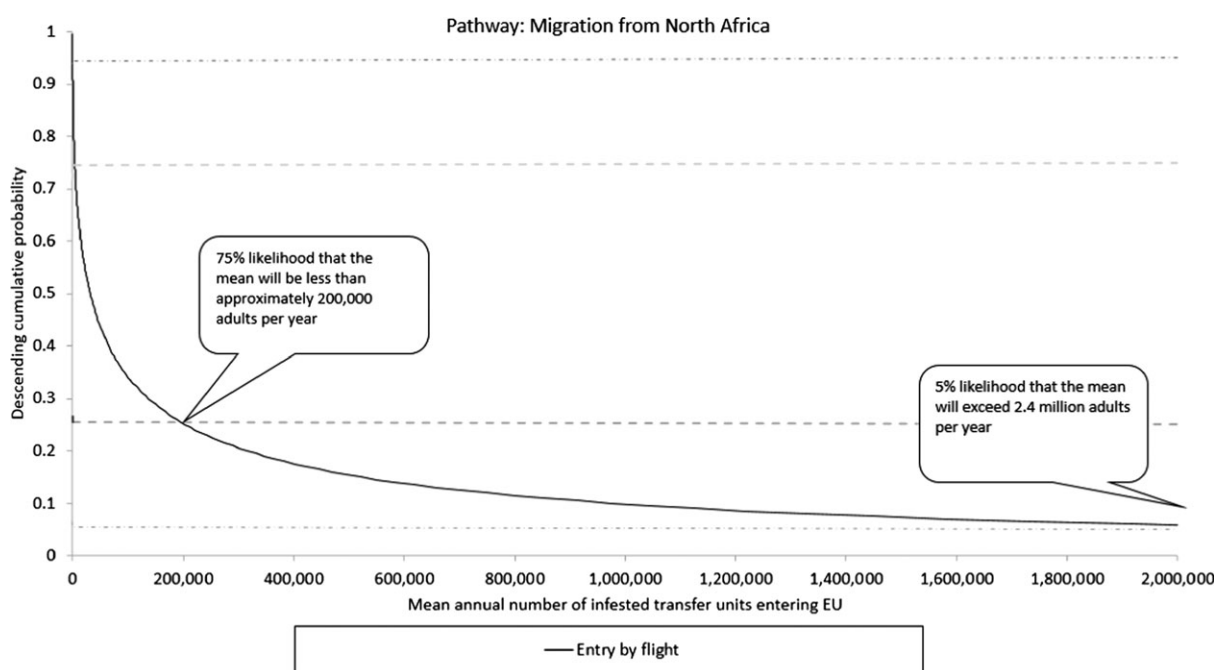
Figure 14: Descending cumulative probability distributions for mean number of *S. frugiperda* reaching the EU via natural migration from locations in North Africa each year. No phytosanitary measures are anticipated against this pathway; hence, only one curve appears

Small pockets in isolated areas north of the Sahara, even if not in the maize or primary host areas, provide sources from which populations can spread to reach maize, and then subsequent populations can spread further afield, including into the EU, where further spread could occur.

Details on the data and parameters that underlie these modelling results is given in Appendix N.

3.1.13. Uncertainties affecting the assessment of entry

3.1.13.1. Entry via trade

S. frugiperda is highly polyphagous (CABI, 2017a,b). Within the constraints dictated by the resources available for this assessment, the assessment focussed on five broad pathways, aggregating each individual commodity to core-America and sub-Saharan Africa. There are differences between production systems within and between countries. Appendices E–I try to capture such variation. Other host commodities can also provide pathways for the entry of *S. frugiperda.* Europhyt interception data to May 2018 are shown in Appendix D.

For modelling purposes commodities entering the EU were apportioned into NUTS 2 regions by human population. However, noting historical and cultural links between some source countries and individual EU MS some consignments may be destined to be distributed within only a limited area of the EU (Dyke et al., 2013).

3.1.13.2. Entry via migration

HYSPLIT trajectories used Morocco and Tunisia as possible sources for *S. frugiperda* were it to establish in North Africa. Alternative locations for possible sources include Egypt, particularly from along the Nile and irrigated lands around it. Migration from North Africa to the EU first requires *S. frugiperda* to be introduced into the region. There is variation between establishment models regarding the extent to which *S. frugiperda* could establish north of the Sahara (see Section 3.2).

3.1.13.3. Other pathways

Although the pathway(s) that *S. frugiperda* took to enter Africa have not been identified, genetic analysis of populations show that it was introduced into Africa on at least two occasions (Goergen et al., 2016). This assessment of entry focussed on entry via trade in host plant material from the Americas and sub-Saharan Africa. Entry via migratory flights from North Africa is contingent on future establishment there. However, other potential pathways could be considered. This is because although egg masses are normally laid on host plants, they can be laid on other surfaces indiscriminately, particularly when populations are high (Sparks, 1979; Thomson and All, 1984). Hence, egg masses could conceivably enter on a wide range of articles that move internationally if exposed at to adult *S. frugiperda* seeking an oviposition site. Egg masses of *Lymantria dispar* have been found on shipping containers (Gray, 2010). Porter and Hughes (1950) reported that 0.86% of surveyed aircraft entering Miami from the Caribbean and South America had at least one lepidopteran egg mass attached. *S. frugiperda* egg masses were the most common individual species. Larvae that emerge from introduced egg masses would need to fairly quickly locate a food source. Hence articles carrying egg masses would need to be close to, or upwind from, *S. frugiperda* host plants so that larvae could transfer (Cock et al., 2017).

Entry on material in passenger baggage or with military hardware moved internationally is also possible additional pathways for entry.

3.1.14. Conclusion on the assessment of entry for the different scenarios

S. frugiperda can enter the EU via traded host plant commodities. Interceptions have been reported from core America and sub-Saharan Africa. Expert knowledge elicitation was used to inform inputs to quantitative pathway models so as to estimate mean numbers of infested units of host commodities that could enter the EU over the next 5 years.

Although not a favoured host, more *S. frugiperda* are likely to enter the EU on peppers than on other commodities. The 90% probability interval (i.e. the range between the 5th and 95th percentile) for entry via this pathway ranges from a lower estimate of just under 2,000 to an upper estimate of approximately 525,000 infested peppers per year. A less extreme range to consider is a 50% probability interval such as the range between the 25th and 75th percentile. For peppers in A0, this 50% probability interval ranges from 10,000 to just under 100,000 infested peppers per year. (Recognise that in the order of 40 million peppers are imported into the EU annually from core America and sub-Saharan Africa.) Regulating *S. frugiperda* on peppers reduces the extreme upper limit of infestation by approximately 20%, falling from around 525,000 to around 440,000, although these levels of infestation are unlikely. However, regulation has little effect on lowering the 50% probability interval for the number of infested peppers entering the EU annually (A0 = 10,000–98,000; A1 = 10,000–90,000). This can be explained because there are already regulations in place for peppers, including import inspection, and *S. frugiperda* is already a quarantine organism. Explicit measures for *S. frugiperda* in peppers are therefore projected to have only minor consequences.

After peppers, eggplant is the commodity likely to be responsible for entry. In Scenario A0, the 90% probability interval is that the mean number of infested eggplants entering the EU is from less than 1,000 to 210,000 per year; in Scenario A1, the upper limit is reduced by just under 10% to 190,000. Like peppers, eggplants are regulated in both A0 and A1, and additional regulation has a limited effect. In contrast, instigating risk reduction options on sweetcorn reduces entry on that pathway approximately 100-fold (A0 90% probability interval = approximately 150 to 18,000 infested sweetcorn cobs per year, median = 2,500; A1 90% probability interval = less than 50 to 600 infested sweetcorn cobs per year, median = 100).

When distributed within the EU NUTS 2 regions, many regions are expected to receive less than 50 infested units per year. However, median estimates suggest that for a few NUTS 2 regions, there may be between 1,000 and 10,000 infested units per year (Figure 11). Model outputs indicate that Andalucia is one of the NUTS 2 regions that receive the most infested commodities. Being close to

Morocco, Andalucia is also the NUTS 2 region where *S. frugiperda* migrating from North Africa could enter the EU. The 90% probability interval for entry via migration is between 100 individuals and 2.4 million individuals. The wide range around this estimate indicates the uncertainty of the estimate which is contingent of *S. frugiperda* establishing in North Africa.

3.2. Establishment

3.2.1. Assessment of establishment

3.2.1.1. SDM and ensemble modelling

Using SDM and ensemble modelling, the suitability threshold that maximises the sum of sensitivity and specificity, 67 10 arc-minute grid cells (each approximately 14 km^2) in Europe are classed as suitable for year-round *S. frugiperda* populations. These grid cells are found in Spain, Italy, and Greece (Appendix O) and collectively represent approximately 94,000 ha or approximately 0.5% of the EU maize area. However, the areas suitable for establishment do not occur in the same locations as the main maize growing regions of the EU, which lies further north. In 2016, maize was harvested from approximately 17.7 million ha (FAOSTAT, 2018) (Figure 15).
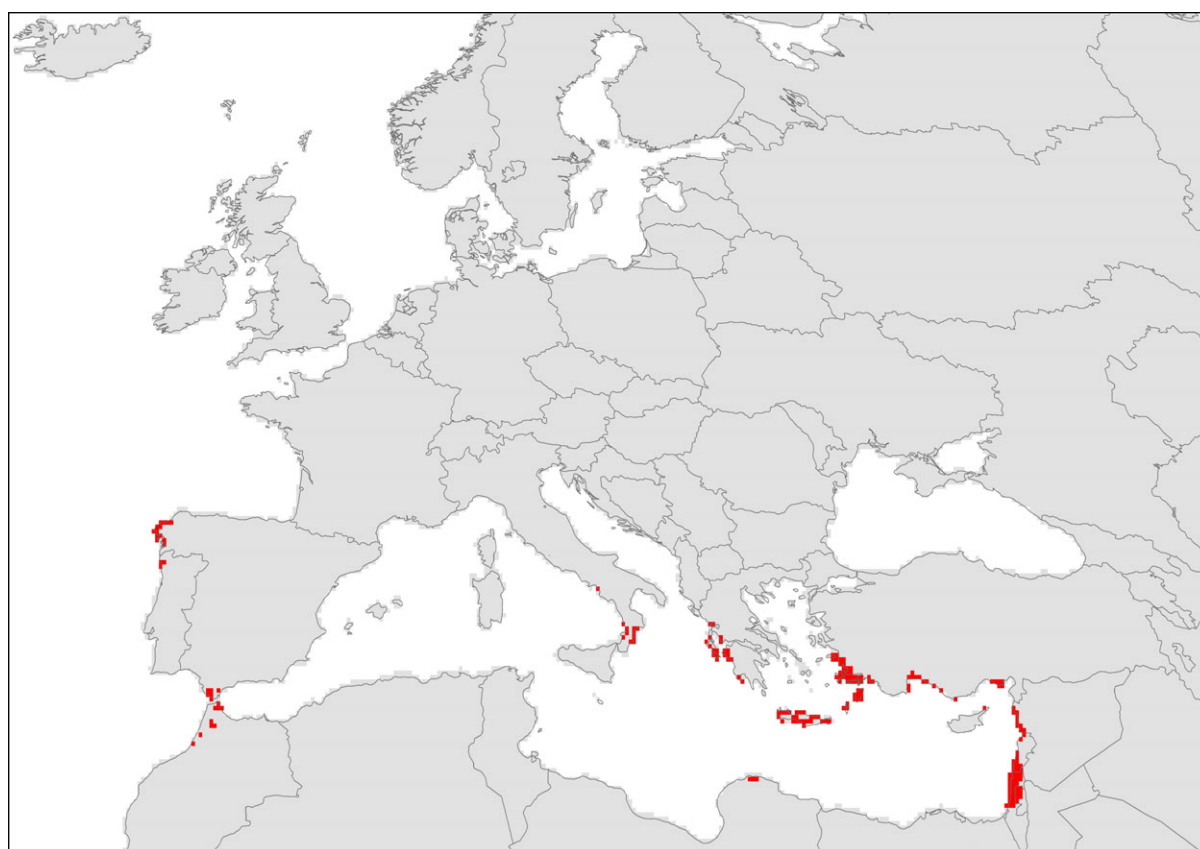
Figure 15: SDM ensemble model result showing locations of 10 arc-minute grid cells suitable for establishment of *S. frugiperda*. These grid cells are found in Spain, Italy and Greece (Appendix O) and collectively represent approximately 94,000 ha

The areas on the Iberian Peninsula that are found suitable in the SDM ensemble predictions (Figures 15 and 16) are not contiguous. This is due to differences between those regions in the explanatory factors that drive the ensemble prediction, i.e. rainfall in the three wettest months of the year, length of the rainy season, difference in rainfall between the wet and dry season, minimum temperature in the coldest month of the year, and land cover (Section 2.2.1.3). Suitable areas show greater contiguity when a lower threshold is chosen for the establishment index. However, choosing a lower threshold increases the rate of false positives (Appendix O.3). Furthermore, the possible effects of averaging of weather variables over space should be considered. This can result in inaccuracies near the sea where weather gradients are steep.

In presenting Figure 15, a trade-off is made between under-representing locations where climate is suitable for establishment and over-representing locations where SDM suggests establishment is possible when it is not (see Section 3.2.2 Uncertainties). Visualising uncertainty in maps is a challenge. Figure 16 provides establishment likelihoods using a range of 'thresholds'. Cells coloured red represent climate suitability with greatest confidence.
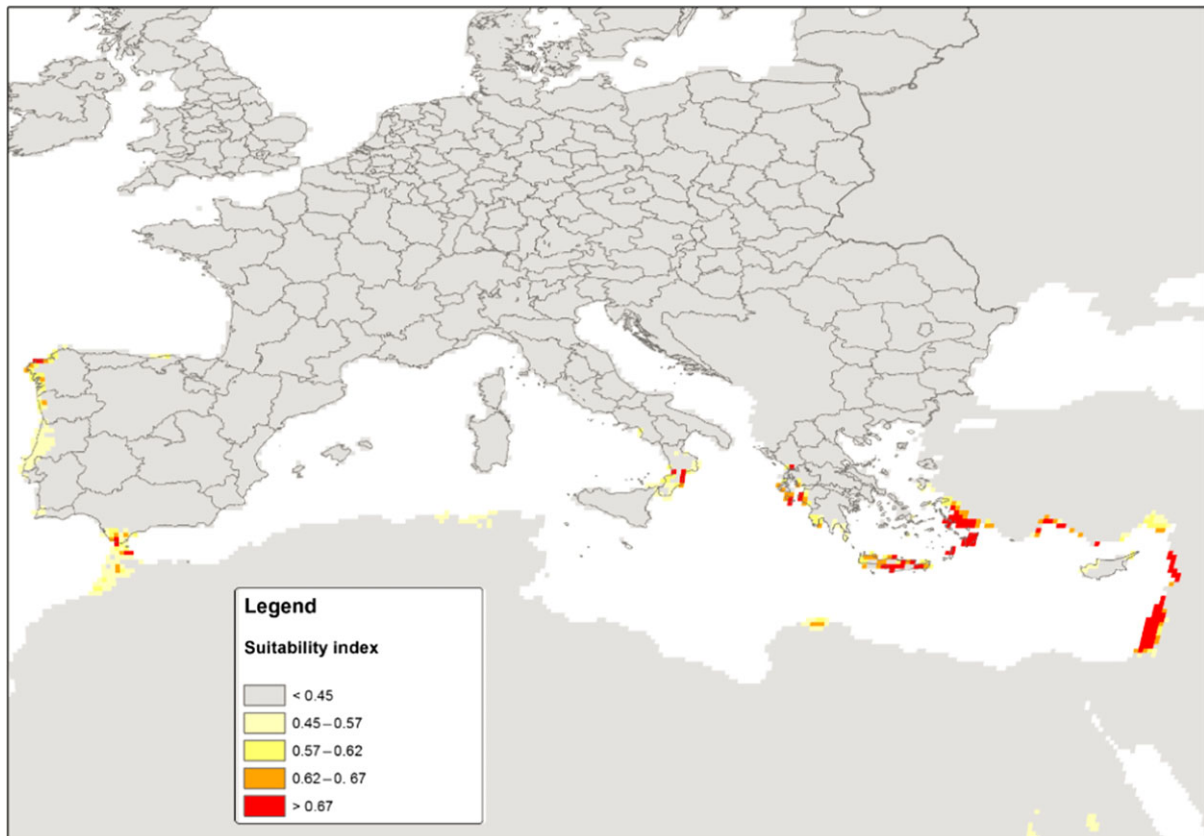
Figure 16: SDM ensemble model result showing locations of 10 arc-minute grid cells suitable for establishment of *S. frugiperda* with different thresholds (see Appendix O)

3.2.1.2. Environmental factors affecting establishment

MinTemp (coldest annual temperature) and Forest (proportion of each 10 min grid cell that is covered by trees) were consistently identified as the environmental variables that most affected *S. frugiperda* distribution. SumWet (rainfall during the wettest 3 months), LenWet (rainy season length) and SeasPpn (the contrast between the rainy and dry seasons) were less important than Forest and MinTemp. *S. frugiperda* is most commonly found in areas with very little forest cover, a minimum annual temperature of 18–26°C, and with 500–700 mm rainfall in the three wettest months. The importance of 'Forest' is likely because it indicates the availability of crops on which *S. frugiperda* feeds, but it could also be related to underreporting from forested areas because few people have looked for *S. frugiperda* outside of areas of extensive agriculture. The importance of MinTemp supports the existence of a hard poleward geographical boundary, caused by one or more months where temperature drops below a threshold. Indeed, only 5% populations in the current range are found in grid cells with MinTemp of 10.9°C or less, and none in grid cells with MinTemp below 3.8°C (Figure 17).
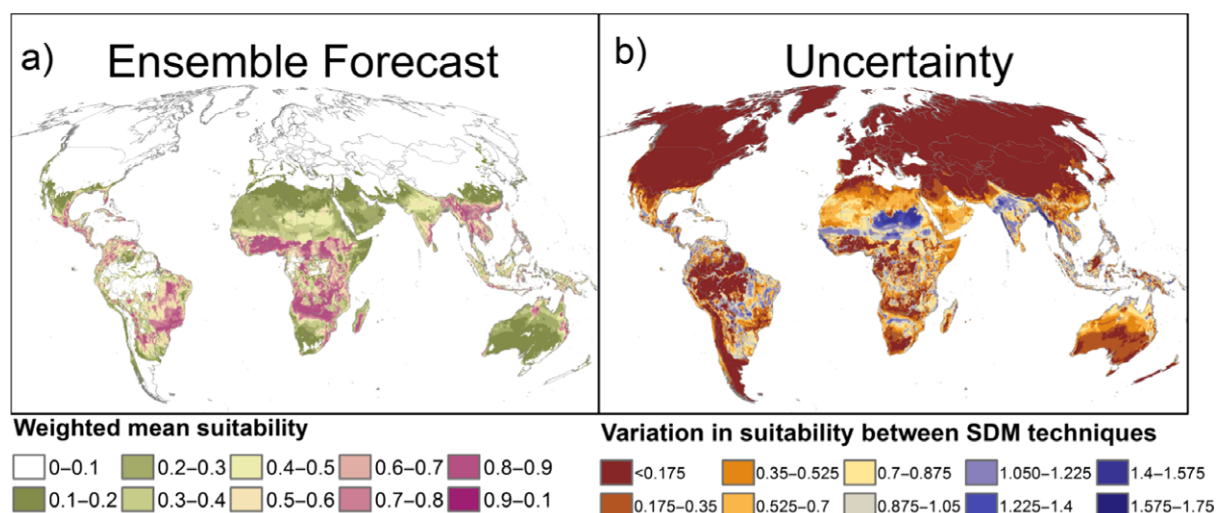
Figure 17: (a) Potential global distribution of *S. frugiperda*, as predicted by an ensemble of SDMs constructed using all distribution data and with four pseudo-absence data sets. SDMs were permitted into the ensemble if the TSS evaluated against 30% randomly selected validation data points was ≥ 0.4. The ensemble was calculated as the mean of all projections, weighted by the TSS of the model. (b) Uncertainty in projections, as calculated by the variation between all SDM projections included in the SDM

3.2.1.3. CLIMEX modelling generating maps at point sources

Using the parameters in du Plessis et al. (2018) and with the CLIMEX irrigation scenario in place, the climate at meteorological stations in southern Spain (Andalucia), southern Italy (including Sicily) and Greece have a positive ecoclimatic index (EI) suggesting climatic conditions support the establishment of *S. frugiperda* (indicated by blue dots in Figure 18). The larger the blue dot the more suitable the climate. Crosses mark the location of meteorological stations where climate is not suitable for establishment. Stations along the North African coast also appear suitable.

In interpreting CLIMEX maps, it should be recognised that maps generated using empirical weather data from meteorological stations can reveal pockets where climate is suitable for establishment whilst maps using interpolated data over the same area might not indicate establishment is possible, particularly where EI is relatively low. The set of underlying meteorological observation data and methods of interpolation can sometimes lead to differences in climatic variables (Kriticos pers comm).

In relation to *S. frugiperda* and the du Plessis et al. (2018) parameters, applied to the Euro-Mediterranean area and north African coast, a study of interannual variation reveals that in some years locations have positive EIs (Kriticos, pers comm.)

Figure 18: Climate suitability for *S. frugiperda* in Africa and Europe modelled using CLIMEX. Parameters from du Plessis et al. (2018) with irrigation scenario

3.2.1.4. Distribution of favoured hosts in NUTS 2 regions supporting establishment

S. frugiperda is a polyphagous pest, but maize, rice and sorghum are among the favoured hosts. These crops, to some extent, are present in all the NUTS 2 regions shown by the ensemble model to be suitable for establishment, with the exception of Ionia Nisia and Cyprus (Table 7). However, *S. frugiperda* can feed on many other Poaceae, including wild species that are commonly distributed in all the suitable areas.

Areas of the main host crops of *S. frugiperda*, within the NUTS 2 regions where establishment may be possible (suitability index higher than 0.45). NUTS2 indicated with asterisks regions contain patches where suitability index is higher than 0.67.

Table 7: Areas of the main host crops of *S. frugiperda*, within the NUTS 2 regions where establishment may be possible (suitability index higher than 0.45). NUTS2 indicated with asterisks regions contain patches where suitability index is higher than 0.67.

Nuts 2	Grain maize (ha)	Green maize (ha)	Sorghum (ha)	Rice (ha)
EL41 – Voreio Aigaio	0	1,000	0	0
EL42 – Notio Aigaio*	0	7,000	0	0
EL43 – Kriti*	0	1,000	0	0
EL 54 – Iperios*	6,000	5,000	–	–
EL62 – Ionia Nisia*	0	0	0	0
EL63 – Dytiki Ellada*	17,000	11,000	0	1,000
EL65 – Peloponnisos	1,000	2,000	0	0
ES13 – Cantabria	0	1,000	0	0
ES11 – Galicia*	19,000	69,000	0	0
ES61 – Andalucía*	31,000	1,000	4,000	40,000
ITF3 – Campania	14,000	20,000	47,000	0
ITF6 – Calabria*	4,000	1,000	131,000	0
ITG1 – Sicilia	47,000	133,000	81,000	0
CY0 – Kypros	0	0	0	0
PT11 – Norte	30,000	40,000	0	0
PT15 – Algarve	0	0	0	0
PT16 – Centro	33,000	23,000	0	6,000
PT17 – Lisboa	2,000	1,000	0	4,000
PT18 – Alentejo	34,000	6,000	0	17,000

The area and intensity of green maize and rice grown in the EU is illustrated in Figure 19 (green maize) and Figure 20 (rice).
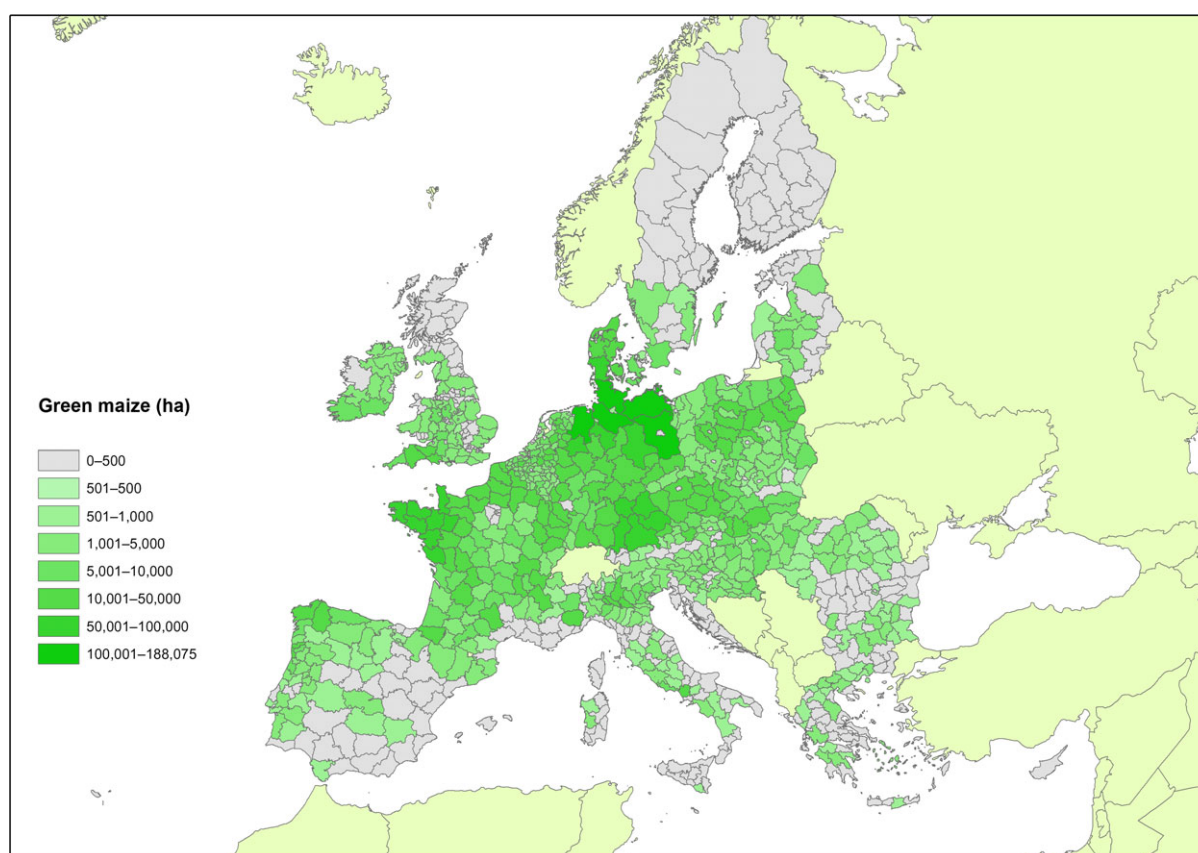
Figure 19: Distribution of a preferred host, maize: *Zea mays*

In northern Europe, maize is mostly cultivated as non-irrigated continuous silage maize or rotated with grass. In central Europe, non-irrigated grain maize is produced either in rotation or as a continuos crop. In southern Europe, continuous grain maize and grain or silage maize in rotation are irrigated (Vasileiadisa et al., 2011).
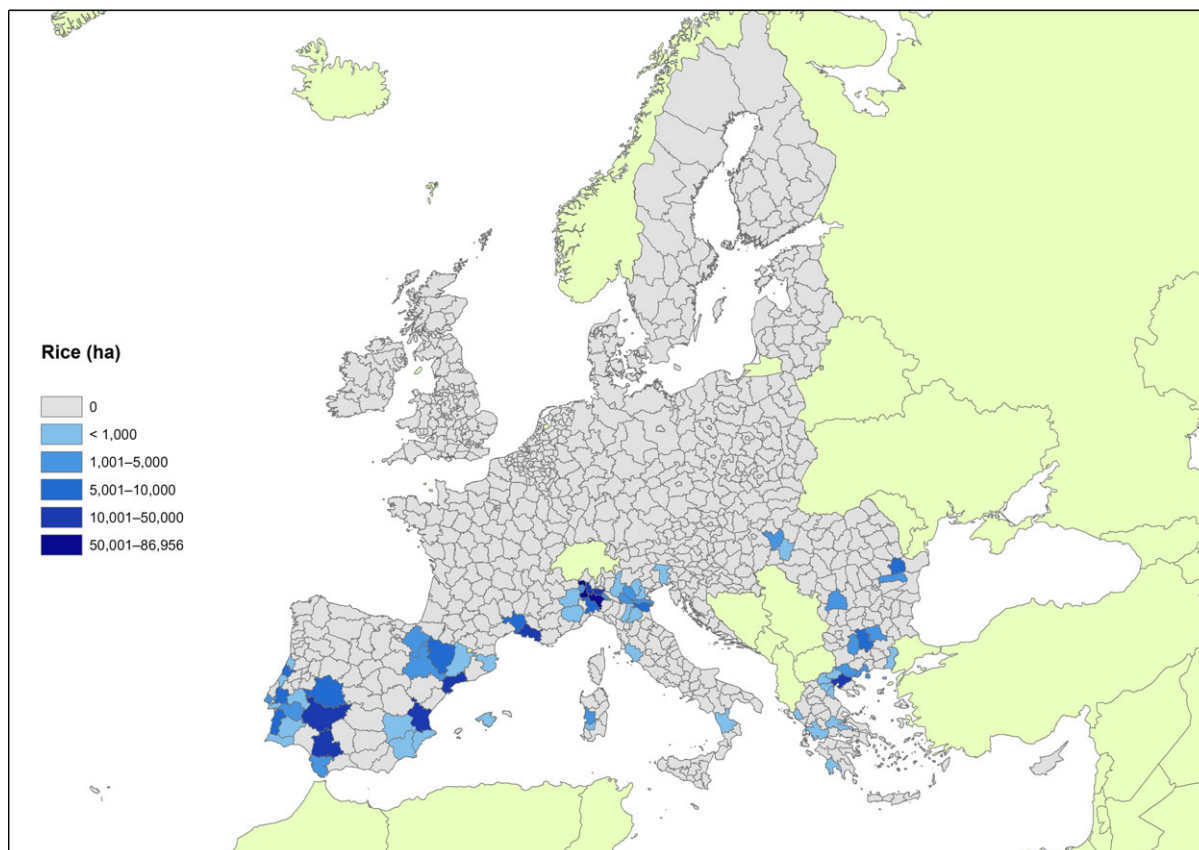
Figure 20: Distribution of a preferred host, rice: *Oryza sativa*

3.2.2. Uncertainties affecting the assessment of establishment

3.2.2.1. Ensemble modelling

Internal cross-validation indicated that the accuracy of SDMs were 'moderate' according to TSS (mean 0.55, standard deviation 0.07) and 'fair' according to AUC (mean 0.81, standard deviation 0.06). This is well within the acceptable accuracy range for SDMs, and indicates it is reasonable to make predictions of establishment potential in Europe with these models (Table 8).

Table 8: Comparison between percentage of *S. frugiperda* presences and pseudo-absences that are correctly predicted by four different thresholds. (See Section 2.2.1.3 for further explanation of 'sensitivity' and 'specificity')

Threshold number	Rationale	Threshold	% of known *S. frugiperda* presences predicted to be suitable, i.e. sensitivity ($\pm$SD)	% of *S. frugiperda* pseudo-absences predicted to be unsuitable, i.e. specificity ($\pm$SD)	No. of EU 10 arc-minute grid cells predicted to be suitable for establishment
1	Predicts all but 5% of *S. frugiperda* presences to be suitable	0.452	95%	67% ($\pm$0.02)	291
2	Predicts all but 10% of *S. frugiperda* pseudo-absences to be suitable	0.572	90%	76% ($\pm$0.02)	171

Threshold number	Rationale	Threshold	% of known *S. frugiperda* presences predicted to be suitable, i.e. sensitivity (±SD)	% of *S. frugiperda* pseudo-absences predicted to be unsuitable, i.e. specificity (±SD)	No. of EU 10 arc-minute grid cells predicted to be suitable for establishment
3	Maximises the sum of sensitivity and specificity	0.674	88% (±0.02)	80% (±0.02)	67
4	Minimises the difference between sensitivity and specificity.	0.625	83% (±0.02)	83% (±0.01)	

Each of the four different thresholds that the panel applied resulted in limited areas in Europe being suitable for *S. frugiperda* establishment. Thresholds 1 and 2 result in grid cells being suitable in Portugal as well as in Spain, Italy and Greece. Thresholds 3 and 4 are supported by research as making the most 'accurate' predictions (Liu et al., 2005; Jiménez-Valverde and Lobo, 2007). Therefore, it is possible that thresholds 1 and 2 overestimate the extent of *S. frugiperda* establishment. However, 'accuracy' is a result of predicting both suitable and unsuitable locations accurately. There are two reasons this might not be appropriate. First, the pseudo-absences used to indicate unsuitable locations are not real observations but are instead randomly generated. The presences used to indicate suitable locations are real observations. As the real observations are more accurate it can be argued that they should be weighted more highly, and so a threshold that results in more presences being correctly predicted could be preferable (i.e. thresholds 1 or 2). Second, the consequences of decision-making based on an overestimate of threat may not be equal to the consequences of decision-making based on an underestimate.

In order to inform the most appropriate threshold, it is instructive to compare results with predictions for Texas and Florida, the parts of the native range where temperatures are most similar to Europe and where the species distribution is fairly well known. All thresholds result in the environment being classed as suitable for establishment at the sites of Florida populations. Only threshold 1 classifies the environment as suitable for establishment at the sites of Texas populations. However, this threshold also classifies a strip of land along the gulf coast as suitable, and there is anecdotal evidence that *S. frugiperda* can overwinter in some of these locations.

The lower suitability threshold predicts a large portion of the Sahara desert to be suitable, whereas expert opinion firmly agrees that climate there is too dry for *S. frugiperda* to establish year round. This erroneous prediction appears to be because *S. frugiperda* occupies some areas that are climatically hot and dry in Peru, but these sites are irrigated using rivers flowing from the Andes. These sites are in the Sechura desert north of Lima. As the SDMs were not supplied with irrigation data, the models interpreted hot, dry sites as having a low, but non-trivial, level of suitability. This does not suggest concern for the predictions in EU as precipitation levels in EU are much higher, similar to precipitation in several parts of the American and African distribution, and the EU distribution is instead limited by cold temperatures.

The agreement among results generated by eight SDM techniques and 20 data sets that contributed to the ensemble prediction, i.e. the variation between predictions from multiple SDM techniques and data sets) is shown in Figure 15b). This figure can be thought of as illustrating the uncertainty that the ensemble accurately represents environmental favourability for *S. frugiperda* population growth, given the results from different data sets and models. In Europe, all the grid cells classed as suitable using the lower threshold of 0.452 are in the 40th–90th percentile of uncertainty values, i.e. they are among the 40–90% most uncertain in the world. All the grid cells classed as suitable using the higher threshold of 0.572 are in the 40–70th percentiles of uncertainty values, i.e. they are among the 40–70% most uncertain in the world. So it should be remembered that the level of suitability in the grid cells identified as suitable for establishment could reasonably be expected to be higher or lower than predicted (See also Appendix O).

3.2.2.2. Comparisons among different modelling approaches for establishment, including CLIMEX with station weather data and interpolated weather data

CLIMEX with gridded weather data did not predict establishment in Europe or North Africa (du Plessis et al., 2018). Elsewhere in the world, the predictions were very similar to the SDM ensemble forecast. This suggests that models based purely on distribution data (SDMs), and models that integrate distribution data with some expert estimates on physiological parameters (CLIMEX) capture similar effects of the environment on *S. frugiperda* distribution. However, there are some key differences between the SDM ensemble and the CLIMEX approach.

First, CLIMEX can be considered a single modelling technique using a single data set, akin to one of the many models that is included in the SDM ensemble. The CLIMEX map should not then be compared directly to the ensemble map, but instead it should be asked whether CLIMEX is within the range of estimates produced by the many SDM techniques. Visual comparison of the two maps suggests this is the case.

Second, CLIMEX uses physiological parameters drawn from literature or suggested by expert opinion, and then moderates the parameters so that the map visually matches the known distribution (no formal assessment of accuracy is done, so a table like Table 8 cannot be made). CLIMEX' forecast of the European range is limited by the cold stress temperature threshold, which was set to 12°C for *S. frugiperda*. There is a broader range of measurements of minimum temperature for *S. frugiperda* development reported in literature: 8.7°C, 13.8°C, 9.5–10.9°C and 10°C (Vickery, 1929; Wood et al., 1979; Hogg et al., 1982b; Barfield and Ashley, 1987; Busato et al., 2005; Valdez-Torres et al., 2012). The true cold stress threshold may then be lower than 12°C (or indeed higher), in which case CLIMEX may well classify European areas as suitable for establishment.

Third, the CLIMEX results did not use populations in Texas to moderate parameter values, and only predicted a very small area in Texas to be suitable although large populations of *S. frugiperda* are present in a wider area of Texas (and possibly along the Gulf coast). Additionally, known populations in Argentina are not predicted to be suitable by CLIMEX. Argentina and Texas are at the margins for cold tolerance of *S. frugiperda*, and are the parts of the current range that have temperatures most similar to Europe. As these points are excluded from the CLIMEX model and predictions, it is possible that CLIMEX underestimates *S. frugiperda* cold tolerance, which would underestimate the potential for establishment in Europe.

Along the North African coast, empirical weather data from meteorological stations reveal pockets where climate is suitable for establishment (Figure 18) although when interpolated, the subsequent gridded data results in model results that indicate that establishment is not possible (see du Plessis et al., 2018). Where EI is relatively low, different climatologies may indicate differences in patterns of establishment potential due to idiosyncrasies in the manner in which they were generated. The set of underlying meteorological observation data and methods of interpolation can sometimes lead to differences in climatic variables (D. Kriticos, pers comm.). A study of interannual variation of gridded data used in du Plessis et al. (2018) reveals that in some years locations along the North African coast have positive EIs (Kriticos pers comm.) However, this does not indicate establishment is possible but it shows where, and under what conditions, transient populations could occur.
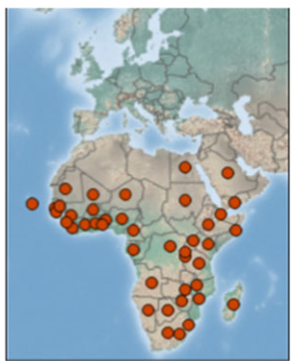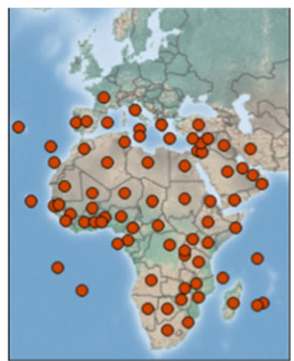
The ensemble SDM shown in Figure 17 and the point station CLIMEX model shown in Figure 18 used monthly 1961–1990 climatic data whereas du Plessis et al. (2018) used 1950–2000 data (CliMond 1975H historical climate data set, Kriticos et al. 2012). Ensemble SDM and du Plessis et al. (2018) interpolated the data to provide gridded maps. Using a more recent data set such as 1975–2017 (JRC – Agri4Cast Data) could allow an improved assessment of establishment and provide greater confidence in identifying current areas where climatic conditions would and would not support the establishment of *S. frugiperda* in the EU.

While acknowledging the uncertainties, the predictions from the SDM model ensemble and two CLIMEX models do indicate that Europe is at the margin of potential *S. frugiperda* distribution based on its cold tolerance. It is certainly more difficult for *S. frugiperda* to establish in Europe than in sub-Saharan Africa, but pockets of the Mediterranean have climatic conditions where it is reasonable to expect establishment is possible.

3.2.2.3. Comparison with other *Spodoptera* species

When seeking to reduce uncertainty, risk assessors can inform their judgements by drawing on relevant information from related species (ISPM 11). Table 9 provides summary information allowing comparisons to be made between *S. frugiperda* and two other *Spodoptera* species regarding aspects of their biology and occurrence in Africa.

Table 9: Comparing threshold temperatures for development, distribution and hosts between *Spodoptera* species

<table>
<tr>
<td rowspan="2">Distribution in Africa, Near East and Europe (Source: CABI Invasive Species Compendium)</td>
<td>Spodoptera frugiperda</td>
<td>Spodoptera exempta</td>
<td>Spodoptera littoralis</td>
</tr>
<tr>
<td colspan="3"></td>
</tr>
<tr>
<td>Common name:</td>
<td>Fall armyworm</td>
<td>Black armyworm</td>
<td>Cotton leaf worm</td>
</tr>
<tr>
<td>Development threshold:</td>
<td>9.5°C–10.9°C (Busato et al., 2005); Complete life cycle: 10.9°C (Ramirez Garcia et al., 1987); 10°C (Wood et al., 1979) 13.8°C (Hogg et al., 1982)</td>
<td>Eggs: 10–12°C
Larva & pupa: 13–14°C (CABI, Invasive Species Compendium, 2017)</td>
<td>Eggs and pupae: 13°C (Baker and Miller, 1974)</td>
</tr>
<tr>
<td>Comment on distribution:</td>
<td>Northern limit of distribution in USA corresponds to areas where winter frosts are infrequent. The species has no diapause (similar to S. littoralis)</td>
<td>Widespread in Africa south of the Sahara; most prevalent in the east, also the Arabian Peninsula, SE Asia and Oceania (CABI Invasive Species Compendium, 2017)</td>
<td>Northern limit of distribution in Europe corresponds to areas where winter frosts are infrequent. The species has no diapause (Miller, 1976; Sidibe and Lauge, 1977)</td>
</tr>
<tr>
<td>Hosts:</td>
<td>Prefers Poaceae, but highly polyphagous</td>
<td>Preferred hosts are grasses (Poaceae) although during high-density outbreaks, non-host plants are eaten (CABI Invasive Species Compendium, 2017)</td>
<td>Highly polyphagous with hosts in 40 families; 87 host species are of economic importance (CABI, Invasive Species Compendium, 2018)</td>
</tr>
</table>

Note that *S. littoralis* has been measured to have a development threshold of 13°C, and has established in southern Europe. This threshold is higher than many values reported for *S. frugiperda*, suggesting that *S. frugiperda* would not be limited in the EU by the lower temperature threshold for its development.

3.2.3. Conclusions on establishment

S. frugiperda is native to tropical and subtropical regions of the Americas where it is established in regions where temperatures rarely fall below 10°C (Sparks, 1979; Ashley et al., 1989; Nagoshi and Meagher, 2008), i.e. the regions remain free from frosts. Its northern limit of distribution in the USA corresponds to areas where winter frosts are infrequent. The results from an ensemble of SDM indicate that a key factor affecting establishment is the lowest temperatures in the coldest months are therefore consistent with what is reported in nature. The other key factor is area of forest, indicating the absence of host (assuming *S. frugiperda* field crop hosts do not occur in forested areas). Depending on the sensitivity threshold selected, pockets of habitat a few NUTS 2 regions in Spain, Italy and Greece, and possibly Portugal, have climatic conditions where it is reasonable to expect *S. frugiperda* can establish year-round populations. The NUTS regions in which such areas occur are highlighted in Figure 21, which also indicates the median number of infested commodity units traded into the NUTS regions.

CLIMEX modelling also indicates that cold stress (low temperatures) limit the distribution of *S. frugiperda* in Europe.
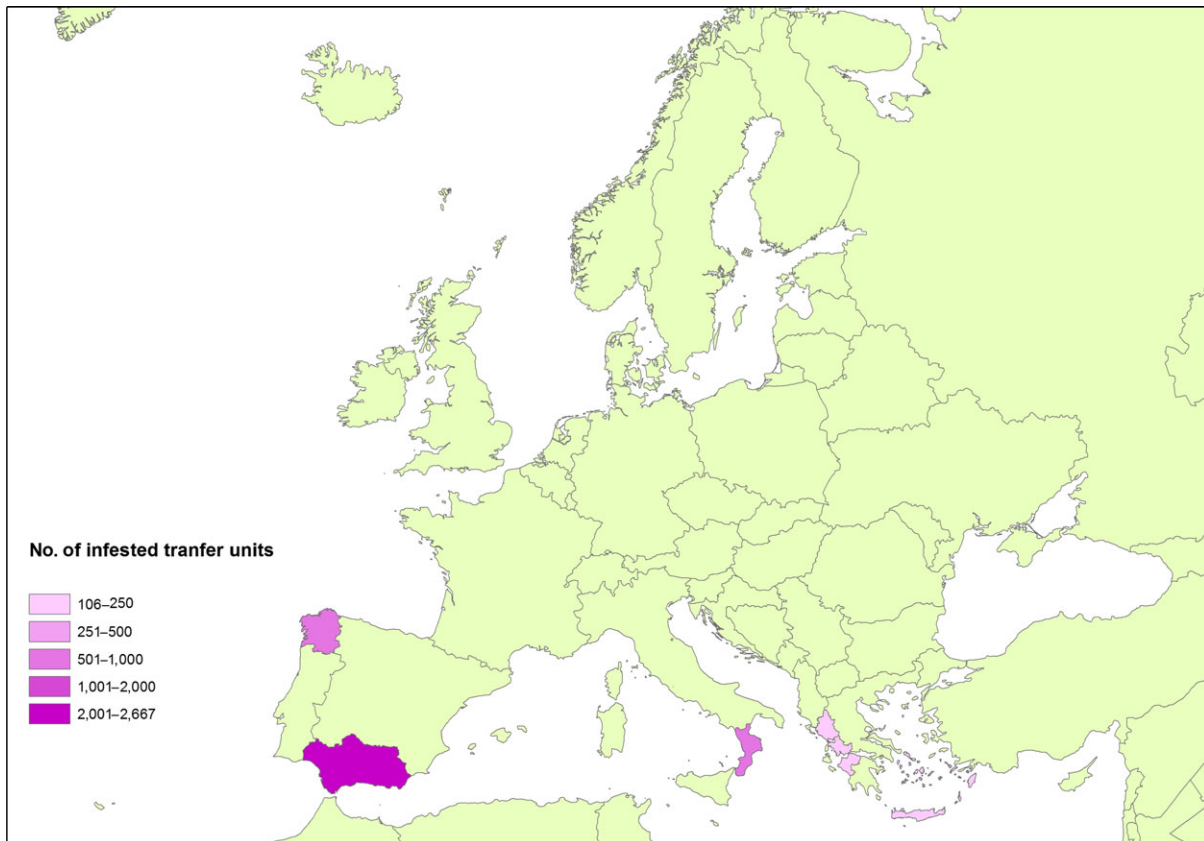
Figure 21: Amount of infested commodities entering NUTS2 regions containing patches where climatic conditions support establishment (Threshold 0.67 suitability index)

3.2.4. Number of potential transient generations

As noted in Section 1.2 (interpretation of ToR), pest spread within the risk assessment area (EU) was outside the scope for this partial assessment; nevertheless, the PLHP thought it would be informative to indicate where transient populations could occur within the EU.

S. frugiperda is well known as a seasonal migrant, able to disperse hundreds of km (Johnson, 1987). Adult migrations lead to it expanding gradually northwards from its area of core occurrence in Central America and southern USA generally spreading up to approximately 300 miles before settling to reproduce the next generation. Prevailing winds and host availability influence the rate and direction of migrations (Hogg et al., 1982; Johnson, 1987). Triggers for migration are not well understood (Abrahams et al., 2017). If *S. frugiperda* does establish in the Mediterranean region of the EU, there is potential for it to undertake spring and summer migrations, similar to those reported in the USA, so that there could be seasonal spread to more temperate areas of the EU. Based on accumulated temperature (threshold 10.9°C), Figure 22 shows the number of transient generations potentially possible across the EU. However, the map must be interpreted with great caution; whether there will be sufficient factors causing migration of large numbers of moths, such as large areas infested, high population pest densities or deterioration of the host, resulting in pressure for *S. frugiperda* to disperse widely over the EU is unknown. The map in Figure 22 does not integrate *S. frugiperda* phenology and potential migration with temperature sum for each grid cell hence the map is liable to overestimate the number of generations possible. An assessment of impact was outside the scope of this assessment; nevertheless, large migrations reaching into less mature crops would result in higher impacts than migrations into crops that were further advanced.
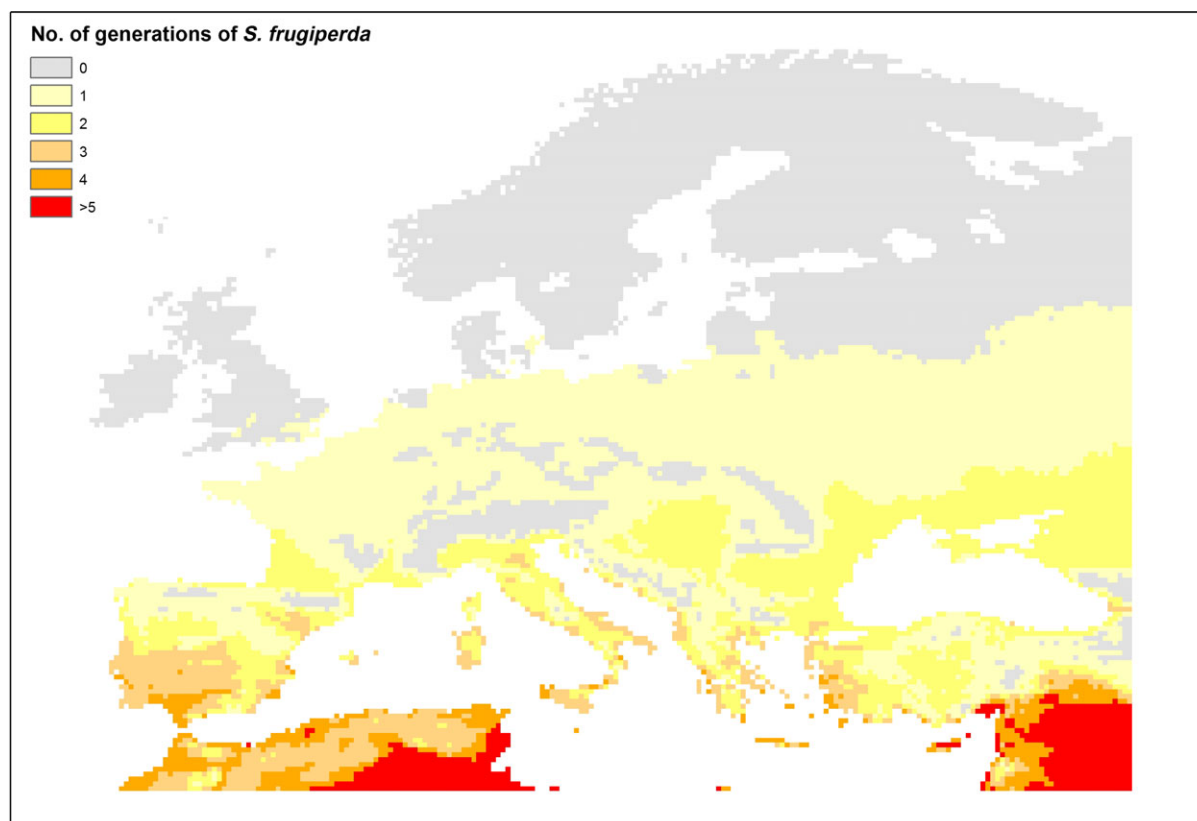
Figure 22: Number of potential transient generations of *S. frugiperda* across the EU per year (note caveats within text)

4. Pest control methods

As requested in the ToR, methods for the control of *S. frugiperda* that could be used if the pest established in the EU, are to be assessed.

There are two genetically distinct strains of *S. frugiperda,* the corn strain and the rice strain (Cano-Calle et al., 2015; Dumas et al., 2015; Hanninger et al., 2017). Although the strains are reported to have host preferences, laboratory experiments have not shown consistent host performance or preference differences between the strains and there are high rates of hybridisation (Juárez et al., 2012; Juárez et al., 2014). Both strains occur in Africa (Nagoshi et al., 2018) with severe impacts being reported on maize (Abrahams et al., 2017).

4.1. Arthropod pests of maize in Europe

Maize is one of the most important crops in Europe, covering a production area of approximately 17.7 million hectares in 2016 (FAOSTAT, 2018). In northern EU maize growing regions, maize is mostly cultivated as non-irrigated continuous silage maize or rotated with grass. In central Europe, non-irrigated continuous grain maize, or grain maize grown in rotation e.g. with winter wheat and oilseed rape, are dominant maize systems. In southern Europe, continuous and irrigated grain maize, as well as irrigated grain and silage maize/winter wheat rotations, are prevalent (Vasileiadisa et al., 2011). Crop protection is mainly pesticide-based with different levels of IPM implementation within Europe (Meissle et al., 2010). Naturally occurring predators and parasitoids contribute to biological control of maize pests in Europe and can be harmed by broad spectrum insecticides. However, natural enemies can be promoted on farmland through landscape manipulation, e.g. by providing overwintering habitat and managing field margins to encourage floral resources (Landis et al., 2000; MacLeod et al., 2004). Biological control with pathogens is not currently economically important within European maize production (Meissle et al., 2010).

The most important arthropod pest of maize in Europe is the European corn borer, *Ostrinia nubilalis* (Figure 23a)*.* In the infested areas, *O. nubilalis* occurs in a large proportion of fields ranging from 20%

in Hungary to 60% in Spain and estimated yield losses between 5% and 30% are typical without control measures. In France and Spain, the Mediterranean corn borer *Sesamia nonagrioides* causes additional economic damage (Figure 23b). Other species causing damage to corn are *S. cretica* in southern Europe (CABI, 2017a,b) and *D. virgifera* in eastern Europe (Figure 23c). Between two and four million ha of maize in Europe suffer from economic damage due to these corn pests (Brookes, 2009). In several European countries, corn borers remain untreated in spite of economic losses.

Figure 23: Distribution of the three main maize pests in Europe. (a): European corn borer (*Ostrinia nubilalis*); (b): Mediterranean corn borer (*Sesamia nonagrioides*) (c): western corn rootworm (*Diabrotica virgifera virgifera*). From https://www.cabi.org/cpc/

In European maize production, the European corn borer and other arthropod pests are often controlled with broad-spectrum insecticides including pyrethroids and organophosphates. Spraying is effective only when timed shortly after the eggs hatch and before the larvae bore into the maize stem. This requires frequent scouting and often several treatments.

4.2.   Control methods applicable to *S. frugiperda*

In general, chemical insecticides are economical and growers are equipped and experienced in using them. Foliar application of insecticides on high maize stands, however, requires special and expensive spray equipment. The spectrum of activity is usually broad, which allows the control of several arthropod pests simultaneously. This, however, is also the major drawback, as deleterious effects on valued non-target organisms are frequent. These include species that fulfil important ecosystem services, such as predators, parasitic wasps, pollinators and decomposers.

Lepidoptera pests in maize are also controlled with the biological control agent *Trichogramma* sp., a wasp that parasitises eggs of *O. nubilalis*. In Europe, the small wasps are released on about 150,000 ha per year, with the largest area in France (Meissle et al., 2010). Under optimal conditions, efficacy can be comparable with chemical insecticides. Appropriate scouting, forecast systems and efficient logistics ensure optimal timing, which is crucial for success.

Spodoptera frugiperda eggs and larvae can be parasitised (e.g. Dequech et al., 2013). Sisay et al. (2018) report five species of parasitoids recovered from *S. frugiperda* eggs and larvae in Ethiopia, Kenya and Tanzania. The dominant parasitoid species varied between countries as did the rates of parasitism. Natural enemies in Europe may be able to adapt and exploit *S. frugiperda*, thereby contributing to its control.

The use of virus-based insecticides for Lepidoptera control is advancing rapidly in the Americas and Australia and could soon be an important option in Europe.

O. nubilalis and *S. nonagrioides* are controlled with Bt maize in Spain. In certain areas, it is economically viable and adopted. Bt maize is not authorised for use in most European countries.

The same control practices used for *O. nubilalis* and *S. nonagrioides* largely function for the control of *S. frugiperda*. If this pest were to arrive and become a pest of maize in Europe, it is likely that the existing available tools could be used to control it effectively. Some additional applications might be necessary to control *S. frugiperda* in addition to pests that are already managed, such as *O. nubilalis*, *S. nonagrioides* and *S. cretica*, and additional scouting may be needed. These increased costs may jeopardise the economic viability of maize production in certain areas for certain uses. The presence of *S. frugiperda* in European maize production would likely motivate the registration of innovative products, such as biopesticides and spur discussions about policies regarding the authorisation of GM maize.

5.   Conclusions

Following the first report of *S. frugiperda* in Africa by Goergen et al. (2016), the pest has now been reported in all sub-Saharan countries. A first phase assessment (pest categorisation) for the EU concluded that the organism could establish in a small area of the southern EU although there were uncertainties (EFSA PLH Panel, 2017). As requested, this second phase partial risk assessment has focused on the main pathways for entry and used SDMs to identify factors affecting establishment.

This risk assessment considers two scenarios. The first scenario (A0) is a baseline scenario representing the regulatory conditions applied to each of the studied pathways when this assessment was initiated in January 2018. At that time, *Capsicum, S. melongena* and *Rosa* cut flowers were regulated, although not specifically with respect to *S. frugiperda*. Sweetcorn and asparagus were not regulated and consignments were allowed to enter without phytosanitary checks. In the second scenario assessed (A1), regulated commodities must be certified free from *S. frugiperda* following pre-export inspection.

Of five trade pathways studied in some detail, peppers contribute most to the numbers of *S. frugiperda* likely to be transported into the EU over the next 5 years in both scenarios. Peppers are already regulated and are inspected on entry to the EU. As peppers are chill sensitive, cold treatments to disinfest the commodity are not appropriate. Further regulation (inspection) is anticipated to have a marginal affect except in the most extreme circumstances of levels of infestation. Bringing sweetcorn into phytosanitary regulation will substantially reduce the likelihood of pest entry on *Z. mays*.

Accurately determining the boundaries of a species climatic envelope is one of the most challenging aspects of SDM and further data regarding the presence and especially the absence of the organism in the Americas and Africa would help refine all forecasts. Furthermore, inclusion of irrigation data in SDM could improve predictions, but data were lacking at the time of this assessment. Depending on the sensitivity threshold selected, an ensemble model identifies pockets of habitat totalling around 94,000 ha, across a few NUTS 2 regions in Spain, Italy and Greece that have climatic conditions that would support establishment. Independently, CLIMEX modelling identifies points in the same regions where establishment may be possible. Low temperature is a key factor that limits the area of establishment.

Entry by extant populations migrating directly from sub-Saharan Africa into the EU is judged not feasible. However, if *S. frugiperda* continues to spread within Africa and establishes north of the Sahara, then in the range of tens to hundreds of thousands of adults could seasonally migrate from North Africa into southern EU, particularly Andalucia and Sicily. The likelihood that substantial numbers of *S. frugiperda* enter by migrating into NUTS 2 regions where small pockets are climatically suitable for establishment is therefore much greater than via commercial trade but is contingent on the establishment of *S. frugiperda* in North Africa. The most promising option for mitigating the risk of entry of the pest via natural dispersal from Africa is via control of the pest in Africa. There are no possibilities for preventing entry via natural dispersal through phytosanitary measures in the EU.

Spatially combining the results of entry and establishment allows comparisons to be made between entry of *S. frugiperda* via trade and natural migration from North Africa (Table 10). The 50% probability interval (25th–75th percentile) of the mean annual number of infested commodity units entering Andalucia and Sicily where establishment of *S. frugiperda* may be possible is two orders of magnitude lower than the mean annual number of adult *S. frugiperda* migrating into southern EU (mainly Andalucia and Sicily) were *S. frugiperda* to establish in Morocco and Tunisia. Given the cannibalistic nature of *S. frugiperda* larvae, each infested transfer unit is assumed to sustain one individual immature larvae.

Table 10:   Numbers of immature *S. frugiperda* entering into Andalucia and Sicily on infested commodities vs numbers of adults migrating into southern EU (mainly Andalucia and Sicily) from North Africa were *S. frugiperda* to establish in Morocco and Tunisia

Percentile[a]	75th	Median (50th)	25th	50% prob int[b]
Andalucia	1,200	2,600	6,400	5,200
Sicily	700	1,600	3,800	3,100
Migration into EU	4,000	32,000	200,000	196,000

(a): Descending cumulative probability.
(b): 50% probability interval between 75th and 25th percentile.

If *S. frugiperda* were to arrive and become a pest of maize in Europe broad spectrum insecticides currently used against existing pests could be used to control it.

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Abbreviations

ADVANCE	USAID Agricultural Development and Value Chain Enhancement
AGL	above ground level (in reference to altitude)
ANN	artificial neural networks
ARL	Air Resources Laboratory
AUC	Area Under Receiver Operating Curve
CN	Combined nomenclature (8-digit code building on HS codes to provide greater resolution)
CRU	climatic research unit
CTA	classification tree analysis
EI	ecoclimatic index (an index of climatic suitability used by CLIMEX)
EPPO	European and Mediterranean Plant Protection Organization
FAO	Food and Agriculture Organization of the United Nations

FAW	Fall armyworm (*Spodoptera frugiperda*)
FDA	flexible discriminant analysis
GAM	generalised additive models
GLM	generalised linear models
HS	Harmonized System (6-digit World Customs Organization system to categorize goods)
IPM	Integrated Pest Management
IPPC	International Plant Protection Convention
MARS	multivariate adaptive regression splines
MS	Member state (of the EU)
NOAA	National Oceanic and Atmospheric Administration
NCEP	National Centers for Environmental Prediction
PFA	pest free area
PFPP	pest free place of production
PFPS	pest free production site
PLHP	EFSA Panel on Plant Health
RF	random forest
RRO	risk reduction option
SDM	species distribution model/modelling
SRE	surface range envelope
ToR	Terms of Reference
TSS	True Skill Statistic

Appendix A – Model formulation and formalisation

Here the conceptual models for entry are elaborated as formal models.

A.1.   Formal model for entry via trade

Pathway model for entry of *Spodoptera frugiperda* into the EU

$$E_i = u \times a_i \times \sum_j \left(\frac{T_j \times 100}{w_j} \times e_j^1 \times \left(1 - m_j^1\right) \times \left(1 - m_j^2\right) \times \left(1 - m_j^3\right) \times \left(1 - m_j^4\right) \right)$$

E_i Entry into NUTS2 region i. Entry is expressed in number of units of product (transfer units) infested with one or more individuals of *S. frugiperda* entering into a NUTS region. The end point of the pathway model is pre-market, pre-consumer.

u Multiplier expressing the contribution of other pathways, resulting in a u times greater entry than calculated from the five pathways that were quantified and modelled.

a_i Proportion of the population of EU living in NUTS region i. The trade flow is apportioned to NUTS regions in proportion to the number of people (consumers) living in them.

$\sum_j$ Summation symbol indicating that entry is the sum of all entry over different pathways j.

j Index representing the pathway (j = 1: sweetcorn, j = 2: peppers, j = 3: asparagus, j = 4: eggplants, j = 5: cut roses).

T_j Total trade in commodity j into EU from core America and sub-Saharan Africa. Units: 100 kg (consistent with EUROSTAT).

w_j Weight of a single transfer unit (kg).

e_j^1 Proportion of transfer units that are infested with *S. frugiperda* following harvest of the product in the field.

m_j^1 Proportion of infested transfer units that is removed in the region of origin during sorting and grading of the harvested product (efficacy of sorting and grading for pathway j).

m_j^2 Effectiveness of treatments carried out in the region of origin before the product is shipped to the EU (includes export inspections).

m_j^3 Effectiveness of import inspection; proportion of transfer units infested with the pest that are removed from the trade at import.

m_j^4 Effectiveness of treatments carried out in the receiving EU country after import inspection and before the product is marketed to consumers.

Ten years of EU import data, 2007–2016, for sweetcorn (CN code: 0709 9960 and 0709 9060 for years prior to 2012), peppers (CN code: 0709 6010 for sweet peppers (*Capsicum annum*) and 0709 6099 for other peppers (fruits of other *Capsicum* or *Pimenta*)), eggplant (CN code: 0709 3000), asparagus (CN code: 0709 2000) and fresh cut roses (CN code: 0603 1100) were retrieved from EUROSTAT, and an estimate of future trade for 2019–2023 was made using regression. Parameter w_j for the weight of a unit of product destined for consumer was retrieved from EFSA sources (EFSA unpublished). Parameters e_j^1, m_j^1, m_j^2, m_j^3, and m_j^4 were elicited by experts independently for each pathway, both for a baseline scenario A_0 of the current situation, and also for a scenario A_1 with specific measures for *S. frugiperda*. A single parameter u was elicited to account for the contribution of pathways that were not quantified. Elicitations were made on the basis of evidence dossiers, following EFSA's guidance on expert knowledge elicitation. The experts used a shortened approach based on the Sheffield method (EFSA 2014). Information supporting the estimations are found in Appendices E–I. The pathway model is illustrated in Figure 2 and was implemented in @Risk for Excel.

Entry was mapped on the European territory in two ways: (1) distributing goods across the EU in accordance to population density (NUTS 2) not taking into account suitability of establishment within a NUTS 2 regions, and (2) showing entry only for those regions where establishment is potentially possible.

A.2.   Formal model for migration from North Africa

The model for entry via migration has five substeps, and uses five elicited parameters. It starts with statistical information on maize area in Morocco and wheat area in Tunisia, both are suitable hosts although maize is preferred. These countries were chosen because the mapping of potential for establishment showed pockets of area that were potentially suitable for establishment (including winter survival) in those countries. The first parameter (p1) represents the proportion of the crop area (maize

in Morocco and wheat in Tunisia) in which *S. frugiperda* produces new generations, either because it can overwinter in the local area, or it can migrate to these areas from areas within the country suitable for overwintering. The second parameter (p2) represents the density of the insect in host crops. The third parameter (p3) is the proportion of adults engaging in long-distance flight. The fourth parameter (p4) is related to the weather systems that can transport the moth from northern Africa to Europe and is based on simulations with the HYSPLIT model (Stein et al., 2015), the probability of aerial trajectories starting in source locations reaching Europe within the maximum flight duration of the moth (not more than 12 h as it is a night flier). The last substep (p5) is the proportion of moths surviving flight.

The resulting model is formalised in the following equation:

$$E_{by\ flight} = A_{host\ crops} \times 10,000 \times p_1 \times p_2 \times p_3 \times p_4 \times p_5$$

where

$E_{by\ flight}$ is the total number of moths arriving in the European territory each year from selected host crops (maize and wheat) in the selected northern African countries (maize in Morocco, wheat in Tunisia) as a result of migration by flight.

$A_{host\ crops}$ is the area of host crops (maize and wheat) in the selected northern African countries (maize in Morocco, wheat in Tunisia) (ha).

10,000 is a conversion factor from ha to m^2.

p_1 is the proportion of the areas of maize (Morocco) or wheat (Tunisia) acting as a source for migrating adults.

p_2 is the density of *S. frugiperda* in the maize or wheat area acting as a source for migrating adults ($\#/m^2$).

p_3 is the proportion of *S. frugiperda* adults that engage in long-distance flight.

p_4 is the proportion of trajectories that originate in the selected source areas in northern Africa that connect to sinks in southern Europe.

p_5 is the proportion survival during flight.

The pathway model is visualized in the flow chart as Figure 3.

Appendix B – Parameter estimates for the formal model

B.1. Entry

B.1.1. Assessment of entry via trade for the different scenarios

Estimates for the values of model parameters are shown below for each entry substep, pathway and scenario. Scenario A0 is the baseline (i.e. the situation when the assessment began) and does not account for the emergency measures that were published in April 2018 (European Commission, 2018a,b). Scenario A1 is a scenario with additional phytosanitary measures in place. Estimates were based on the information reviewed and discussed during expert knowledge elicitation and summarized in the evidence dossiers in Appendices E–I.

	Substep	Pathway	Scenario	Percentile				
				1	25	50	75	99
1	Infestation at origin. Average <u>percentage</u> of infested product in export production fields in the area of origin e^1	1: Sweetcorn	A0	0.01	0.1	0.3	1.0	10.0
			A1	0.01	0.1	0.3	1.0	3.0
		2: Peppers	A0	0.005	0.05	0.15	0.5	5.0
			A1	0.005	0.05	0.15	0.5	2.0
		3: Asparagus	A0	0.001	0.01	0.03	0.1	1.0
			A1	0.001	0.01	0.03	0.1	0.4
		4: Eggplant	A0	0.005	0.05	0.15	0.5	5.0
			A1	0.005	0.05	0.15	0.5	2.0
		5: Roses	A0	0.0001	0.0005	0.001	0.002	0.01
			A1	0.0001	0.0005	0.001	0.002	0.01
2	Effectiveness of post-harvest sorting. Average <u>percentage</u> of infested material removed. m^1	1: Sweetcorn	A0	80.0	90.0	95.0	97.0	99
			A1	95	97.5	99	99.5	99.9
		2: Peppers	A0	15	30	40	55	80
			A1	15	30	40	55	80
		3: Asparagus	A0	90	93	95	97	99
			A1	90	93	95	97	99
		4: Eggplant	A0	15	30	40	55	80
			A1	15	30	40	55	80
		5: Roses	A0	70	85	90	91.5	95
			A1	75	85	90	91.5	95
3	Effectiveness of post-harvest treatments (includes storage and shipping). Average <u>percentage</u> of infested material removed. m^2	1: Sweetcorn	A0	30	43	50	57	70
			A1	50	63	70	77	90
		2: Peppers	A0	0	0	0	0	0
			A1	0	0	0	0	0
		3: Asparagus	A0	75	88	95	97	99
			A1	75	88	95	97	99
		4: Eggplant	A0	0	0	0	0	0
			A1	0	0	0	0	0
		5: Roses	A0	75	88	95	98	99
			A1	75	88	95	98	99
4	Effectiveness of import inspections (peppers, eggplant and roses already inspected in A0, sweetcorn and asparagus are not). Percentage infested removed. m^3	1: Sweetcorn	A0	0	0	0	0	0
			A1	1	6	10	15	25
		2: Peppers	A0	1	6	10	15	25
			A1	1	6	10	15	25
		3: Asparagus	A0	0	0	0	0	0
			A1					
		4: Eggplant	A0	1	6	10	15	25
			A1	1	6	10	15	25
		5: Roses	A0	0	0	0	0	0
			A1	0	0	0	0	0

	Substep	Pathway	Scenario	Percentile				
				1	25	50	75	99
5	Processing in EU Average percentage of infested material removed m^4	1: Sweetcorn	A0	0.1	0.3	1	2	5
			A1	0.1	0.3	1	2	5
		2: Peppers	A0	0	0	0	0	0
			A1	0	0	0	0	0
		3: Asparagus	A0	0	0	0	0	0
			A1	0	0	0	0	0
		4: Eggplant	A0	0	0	0	0	0
			A1	0	0	0	0	0
		5: Roses	A0	0	0	0	0	0
			A1	0	0	0	0	0
6	Multiplier *u* expressing the contribution of other pathways, resulting in a u times greater entry than calculated from the five pathways that were quantified and modelled		A0	1.5	1.7	2	2.5	3
			A1	1.5	1.7	2	2.5	3

Future trade volumes (2018–2022) were projected using a linear regression of log transformed trade on year, using EUROSTAT data for the years 2007–2016. The projections were generated taking into account both uncertainty about the regression line parameters and the residuals around the line, i.e. in statistical terminology they are predictions for future years with associated prediction intervals (https://en.wikipedia.org/wiki/Prediction_interval; Upton and Cook, 2008). Calculations in @Risk were initiated with the average projected future trade over the years 2018–2022.

B.1.2. Assessment of entry via migration from North Africa

Estimates for the values of model parameters are shown below for each migration substep.

	Substep	Percentile				
		1st	25th	Median (50th)	75th	99th
1	Area of host crop	Fixed/constant (FAO stat)				
2	Proportion of crop acting as a source for migrating adults	0.10	0.55	1.00	1.00	1.00
3	*S. frugiperda* density in source crops	0.1	0.4	1.0	2.5	10.0
4	Proportion of adults engaging in migration	0.1	0.35	0.5	0.65	0.9
5	Proportion of trajectories that connect source populations to the EU	0.0001	0.0003	0.001	0.003	0.01
6	Proportion of adults surviving migration to reach EU	0.001	0.01	0.1	0.3	0.9

Appendix N provides the information reviewed and discussed during expert knowledge elicitation that informed the estimates above.

Appendix C – *Spodoptera frugiperda* hosts

Source: CABI *Spodoptera frugiperda* datasheet (2017)

Preferred hosts

Family	Binomial	Common name
Poaceae	*Zea mays*	Maize
Poaceae	*Zea mays* subsp. *mays*	Sweetcorn
Poaceae	*Zea mays* subsp. *mexicana*	Teosinte
Poaceae	*Oryza sativa*	Rice
Poaceae	*Sorghum bicolor*	Sorghum
Poaceae	*Panicum miliaceum*	Millet

Other hosts

Family	Binomial	Common name
Poaceae	*Agrostis*	Bentgrasses
Poaceae	*Agrostis gigantea*	Black bent
Poaceae	*Andropogon virginicus*	Broomsedge
Poaceae	*Avena sativa*	Oats
Poaceae	*Cenchrus incertus*	Spiny burrgrass
Poaceae	*Chloris gayana*	Rhodes grass
Poaceae	*Echinochloa colona*	Junglerice
Poaceae	*Hordeum vulgare*	Barley
Poaceae	*Pennisetum clandestinum*	Kikuyu grass
Poaceae	*Pennisetum glaucum*	Pearl millet
Poaceae	*Phleum pratense*	Timothy grass
Poaceae	*Poa annua*	Annual meadowgrass
Poaceae	*Poa pratensis*	Smooth meadowgrass
Poaceae	*Saccharum officinarum*	Sugarcane
Poaceae	*Secale cereale*	Rye
Poaceae	*Setaria italica*	Foxtail millet
Poaceae	*Setaria viridis*	Green foxtail
Poaceae	*Sorghum caffrorum*	
Poaceae	*Sorghum halepense*	Johnson grass
Poaceae	*Sorghum sudanense*	Sudan grass
Poaceae	*Triticum aestivum*	Wheat
Poaceae	Turfgrasses	
Poaceae	*Urochloa*	
Amaranthaceae	*Amaranthus*	Amaranth
Apiaceae	*Eryngium foetidum*	
Apocynaceae	*Plumeria*	Frangipani
Asteraceae	*Chrysanthemum morifolium*	Chrysanthemum (florists')
Asteraceae	*Chrysanthemum*	Daisy
Asteraceae	*Dahlia pinnata*	Garden dahlia
Asteraceae	*Lactuca sativa*	Lettuce
Asteraceae	*Xanthium strumarium*	Common cocklebur
Brassicaceae	*Brassica oleracea*	Cabbages, cauliflowers
Brassicaceae	*Brassica rapa* subsp. *rapa*	Turnip
Brassicaceae		Cruciferous crops
Brassicaceae	*Brassica oleracea* var. *capitata*	Cabbage
Brassicaceae	*Brassica oleracea* var. *viridis*	Collards
Brassicaceae	*Brassica rapa* subsp. *oleifera*	Turnip rape
Caryophyllaceae	*Dianthus caryophyllus*	Carnation
Chenopodiaceae	*Beta vulgaris* var. *saccharifera*	Sugarbeet

Chenopodiaceae	*Spinacia oleracea*	Spinach
Chenopodiaceae	*Beta*	
Chenopodiaceae	*Beta vulgaris*	Beetroot
Chenopodiaceae	*Chenopodium quinoa*	Quinoa
Chenopodiaceae	*Chenopodium album*	Fat hen
Convolvulaceae	*Ipomoea batatas*	Sweet potato
Convolvulaceae	*Convolvulus*	Morning glory
Convolvulaceae	*Ipomoea purpurea*	Tall morning glory
Cucurbitaceae	*Cucumis sativus*	Cucumber
Cucurbitaceae	*Cucurbitaceae*	Cucurbits
Cucurbitaceae	*Citrullus lanatus*	Watermelon
Cyperaceae	*Cyperus rotundus*	Purple nutsedge
Cyperaceae	*Carex*	Sedges
Ericaceae	*Vaccinium corymbosum*	Blueberry
Euphorbiaceae	*Codiaeum variegatum*	Croton
Euphorbiaceae	*Hevea brasiliensis*	Rubber
Fabaceae	*Arachis hypogaea*	Groundnut
Fabaceae	*Glycine max*	Soya bean
Fabaceae	*Medicago sativa*	Lucerne
Fabaceae	*Phaseolus*	Beans
Fabaceae	*Phaseolus vulgaris*	Common bean
Fabaceae	*Trifolium*	Clovers
Fabaceae	*Cicer arietinum*	Chickpea
Fabaceae	*Mucuna pruriens*	Velvet bean
Fabaceae	*Pisum sativum*	Pea
Fabaceae	*Trifolium pratense*	Purple clover
Fabaceae	*Trifolium repens*	White clover
Geraniaceae	*Pelargonium*	Pelargoniums
Iridaceae	Gladiolus hybrids	Sword lily
Juglandaceae	*Carya*	Hickories
Juglandaceae	*Carya illinoinensis*	Pecan
Liliaceae	*Allium*	
Liliaceae	*Allium cepa*	Onion
Liliaceae	*Asparagus officinalis*	Asparagus
Malvaceae	*Gossypium*	Cotton
Malvaceae	*Alcea rosea*	Hollyhock
Malvaceae	*Gossypium herbaceum*	Short staple cotton
Malvaceae	*Hibiscus cannabinus*	Kenaf
Musaceae	*Musa*	Banana
Platanaceae	*Platanus occidentalis*	Sycamore
Polygonaceae	*Fagopyrum esculentum*	Buckwheat
Portulacaceae	*Portulaca oleracea*	Purslane
Rosaceae	*Fragaria ananassa*	Strawberry
Rosaceae	*Fragaria chiloensis*	Chilean strawberry
Rosaceae	*Malus domestica*	Apple
Rosaceae	*Prunus persica*	Peach
Rutaceae	*Citrus aurantium*	Sour orange
Rutaceae	*Citrus limon*	Lemon
Rutaceae	*Citrus reticulata*	Mandarin
Rutaceae	*Citrus sinensis*	Navel orange
Solanaceae	*Capsicum annuum*	Bell pepper

Solanaceae	*Nicotiana tabacum*	Tobacco
Solanaceae	*Solanum lycopersicum*	Tomato
Solanaceae	*Solanum melongena*	Aubergine
Solanaceae	*Solanum tuberosum*	Potato
Solanaceae	*Capsicum*	Peppers
Solanaceae	*Atropa belladonna*	Deadly nightshade
Solanaceae	*Solanum*	Nightshade
Violaceae	*Viola*	Violet
Vitaceae	*Vitis*	Grape
Vitaceae	*Vitis vinifera*	Grapevine
Zingiberaceae	*Zingiber officinale*	Ginger

Appendix D − Evidence of entry provided by interceptions

S. frugiperda has been intercepted in the EU on a range of produce and cut flowers from the Americas (EUROPHYT, 2017), and since late 2017 has also been intercepted on plant products from Africa. For the period January 1995 to May 2018, there are 76 records of interceptions of *S. frugiperda.* Fifty per cent of all interceptions are on *Capsicum* and *Solanum melongena*.

Table D.1: Hosts and country of origin for EU interceptions notified on EUROPHYT to May 2018. Hosts examined in a specific pathway analysis are marked with an asterisk

Plant name	Brazil	Dominican Republic	Ecuador	Guatemala	Kenya	Mali	Mexico	Peru	Suriname	Tanzania	Uganda	Zambia	Zimbabwe
Capsicum sp.*		5					2		19		1		
Solanum melongena*									11				
Asparagus sp.*								4					
Rosa*	1			2								1	
Abelmoschus esculentus									1				
Coriandrum sativum					1								
Eryngium sp.			2										
Eustoma grandiflorum										1			
Imperata cylindrica				1									
Momordica charantia									5				
Momordica sp.							1		3				
Pisum sp.													2
Solanum aculeatissimum									1				
Solanum aethiopicum						1							
Solanum macrocarpon									8				
Solanum sp.									1				
Tillandsia sp.			1										
Vigna unguiculata													
Xanthosoma sagittifolium									1				
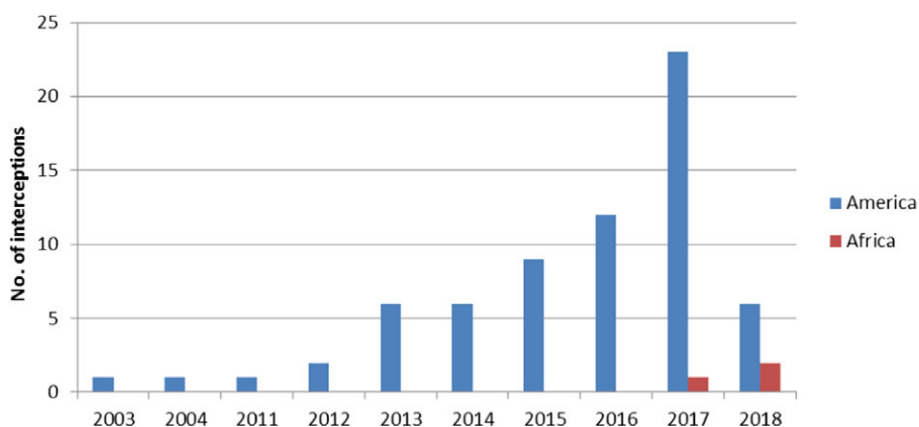
Figure D.1: Interceptions through time. Note the emergence of Africa as a source beginning in 2017

Appendix E – Evidence dossier: Trade pathway – sweetcorn (*Zea mays*)

E.1. Mean trade volume of sweetcorn into the EU from countries where *Spodoptera frugiperda* occurs over the next 5 years

EUROSTAT data was extracted to determine the amount of imports and EU intracommunity trade for sweetcorn over the most recent 7 years (2010–2016) (CN 0709 9060 in 2010 and 2011, then CN 0709 9960 from 2012 to 2016). Because of the widespread occurrence of *S. frugiperda* in the Americas and in Africa, import data were grouped into five regions (Map 1).

Table E.1: EU imports of sweetcorn (CN 0709 9060 and CN 0709 9960) from Third countries and intra-EU trade 2010–1016 (Source: EUROSTAT)

	2010	2011	2012	2013	2014	2015	2016	Mean
Intra-EU	306,651	411,705	361,459	275,847	349,313	325,281	342,524	338,969
Core America	313	79	207	100	171	106	161	162
Sub-Saharan Africa	85,102	120,186	92,581	33,742	46,142	146,119	213,049	105,274
North Africa	74,295	64,548	51,591	74,383	69,374	128,140	126,043	84,053
Middle East	151	0	11	0	15	0	12	27
other	66,501	60,449	59,086	66,296	80,228	73,741	74,356	68,665
Sum Third country	226,362	245,262	203,476	174,521	195,930	348,106	413,621	258,183
Intra EU + Third country	533,013	656,967	564,935	450,368	545,243	673,387	756,145	597,151

EU third country imports of sweetcorn (CN 0709 9060 then 0709 9960) from regions in relation to distribution of *S. frugiperda* (Hundreds kg)
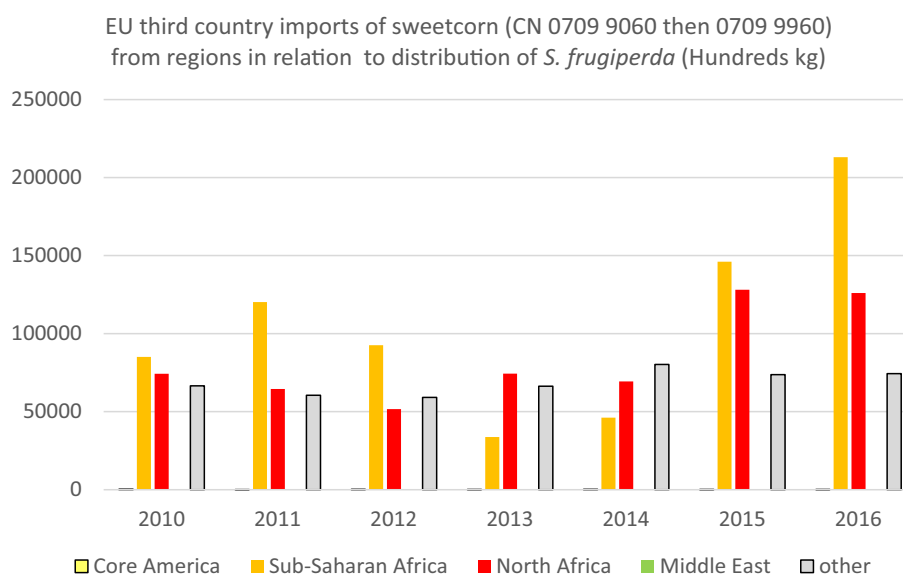
Table E.2: Sweetcorn annual imports from third country regions expressed as a %

	2010	2011	2012	2013	2014	2015	2016
Core America	0.1	0.0	0.1	0.1	0.1	0.0	0.0
Sub-Saharan Africa	37.6	49.0	45.5	19.3	23.6	42.0	51.5
North Africa	32.8	26.3	25.4	42.6	35.4	36.8	30.5
Middle East	0.1	0.0	0.0	0.0	0.0	0.0	0.0
other	29.4	24.6	29.0	38.0	40.9	21.2	18.0
Sum	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Other considerations to take into account:

1) No extensive literature search was performed for this parameter.
2) Only EUROSTAT data were collected and assessed.
3) No trade body/industry information was obtained to verify EUROSTAT.
4) The data indicates that imports and intra-EU trade have fluctuated over the past 7 years.
5) The region from which the EU sources most fresh sweetcorn most often is sub-Saharan Africa.
6) Demand for sweetcorn in Europe has grown in recent years (Freshplaza, June 2018[1]) (imports may rise in the future).
7) *S. frugiperda* is affecting yield and destroying maize crops in sub-Saharan Africa (Abrahams et al., 2017) (imports may decline in future).
8) Well organised NPPOs in Africa supporting significant exports to the EU may be able to cope with *S. frugiperda*. Conversely, weaker NPPOs, or those with smaller exports where the export horticulture sector is less developed could find it problematic (Abrahams et al., 2017).
9) For scenario A1, phytosanitary measures will add costs and may reduce volume of trade.

Other factors discussed and input from external experts:

- Only a very small fraction (< 0.1%) of sweetcorn is imported from core America.
- The majority of sweetcorn from sub-Saharan Africa comes from Senegal (87%). Kenya, Mozambique and Ghana are the other main exporters (Europhyt data).
- Operators in Senegal appear well organised and operate quality control systems. Additional measures are not anticipated to impact exports.
- To maintain high value export markets, producers are expected to apply additional pesticides.
- Additional measures are not anticipated to significantly alter the amount of exports to EU over the next 5 years.

Following discussion, it was agreed that past import data best informed likely future imports and a regression was performed to estimate mean annual future imports over the next 5 years, i.e. until the time horizon of the opinion.

Table E.3: Estimated range of mean sweetcorn imports into the EU from the regions sub-Saharan Africa and core America over the next 5 years (time horizon for assessment) based on regression of previous import (hundreds of kg)

Quantile (Percentile)	Lower (1%)	Q1 (25%)	Median (50%)	Q3 (75%)	Upper (99%)
Scenario **A0** (baseline)	106,682	193,663	248,556	322,165	657,877
Scenario **A1** (with measures)	106,682	193,663	248,556	322,165	657,877

No difference in imports was anticipated in a scenario A1.

E.2. Weight of a transfer unit (sweetcorn cob)

A standard conversion factor for an individual sweetcorn cob (0.215 kg, EFSA unpublished data) was used to convert mass of imports into an estimate of the number of pieces of sweetcorn. This standard conversion factor was used to estimate the number of transfer units imported on the pathway.

Other uncertainties and factors to take into account:

1) No extensive literature search was performed for this parameter.
2) Only a small number of UK supermarkets were sampled.
3) The sampled sweetcorn may not have originated in sub-Saharan Africa.
4) At some times of year, sweetcorn is available with and without husks; cobs with husks would be heavier.

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[1] http://www.freshplaza.com/article/190353/Greek-producer-sees-increased-European-demand-for-sweet-corn

5) Husks can be partially or completely removed at prepacking, and the cob trimmed reducing weight by up to 35%, hence reducing transport costs (cited in Showalter, 1964).
6) Some trimming and packing may take place in Africa, some may take place in the EU at packing houses.
7) Importers and customer preferences for the size of sweetcorn may change over the next five years leading to heavier, or lighter sweetcorn cobs.

E.3. Proportion of export production fields infested; effectiveness of post-harvest sorting and post-harvest treatments

Factors to take into account:

1) *Zea mays* is a favoured host of *S. frugiperda* and larvae can cause serious damage to maize foliage, stems and ears.
2) *S. frugiperda* is spreading and damaging maize in sub-Saharan Africa.
3) Eggs masses are usually laid on the underside of leaves so will not normally be associated with harvested sweetcorn.
4) Young larvae on maize tend to feed on the foliage and will also generally not be associated with harvested sweetcorn.
5) If attacked early in the growing season, maize plants may fail to produce cobs and hence there will be a lack of harvested product to export.
6) Late instar larvae that attack more developed maize can chew through the protective leaf bracts into the side of the cob where they feed on the developing kernels (Abrahams et al., 2017) and could potentially be shipped with harvested cobs for export.
7) Sweetcorn is harvested for fresh market consumption when the pollination silks are dried and the kernels are still immature making the ear firm and turgid (Szymanek et al., 2006).
8) A short video showing production and processing of sweetcorn in Senegal is available at https://www.youtube.com/watch?v=-xURItme4Uo
9) The quality of fresh market sweetcorn is judged by its fresh, uniform appearance, uniform and well filled rows, plumpness of kernels, milky kernel contents, and freedom from damage and defects such as discoloration, harvest injury, pest damage, the presence of live insects, decaying silks or kernels (CargoHandbook.com, 2012a).
10) Smallholders growing sweetcorn are less likely to be able to manage *S. frugiperda* than larger growers.
11) Smallholder farmers' access to European export markets is often impeded by their having to meet strict food safety standards, industry quality standards and sometimes phytosanitary standards (Hellin et al., 2011).
12) Between 2010 and 2016, 99.2% of sweetcorn exported into the EU from sub-Saharan Africa came from Senegal (87.1%), Mozambique (4.3%), Kenya (3.1%), Ghana (2.0%), Zambia (1.5%) and South Africa (1.2%). As of March 2018, *S. frugiperda* was not confirmed as being present in Senegal although it was suspected to be there.
13) *S. frugiperda* occurs year round in sub-Saharan Africa with overlapping generations.
14) Exports from sub-Saharan Africa occur year round although most exports occur during the European winter, spring and early summer months.
15) There are no records of *S. frugiperda* interceptions on *Zea mays* in the Europhyt interceptions database.
16) Takahashi et al. (2003) reported *S. frugiperda* being intercepted on *Z. mays* at Narita Airport in Japan (most likely cobs although only the host name was listed).
17) Noctuid quarantine pests have previously been intercepted on sweetcorn entering the EU from Africa (see table below; Source Europhyt, extracted 10 April 2018).

Year	Source	EU MS	Pest intercepted	Date of interception
1998	Morocco	Spain	*Helicoverpa zea*	12/08/1998
2006	Senegal	United Kingdom	*Helicoverpa armigera*	3/2/2006
2006	Senegal	United Kingdom	*Helicoverpa armigera*	12/5/2006
2006	Morocco	Spain	*Helicoverpa* sp.	16/6/2006
2008	Uganda	United Kingdom	*Helicoverpa armigera*	19/6/2008
2011	Uganda	United Kingdom	*Helicoverpa armigera*	21/6/2011

Mean monthly imports (2015–2016) of fresh sweetcorn from four main supply countries in sub-Saharan Africa (hundreds of kg)
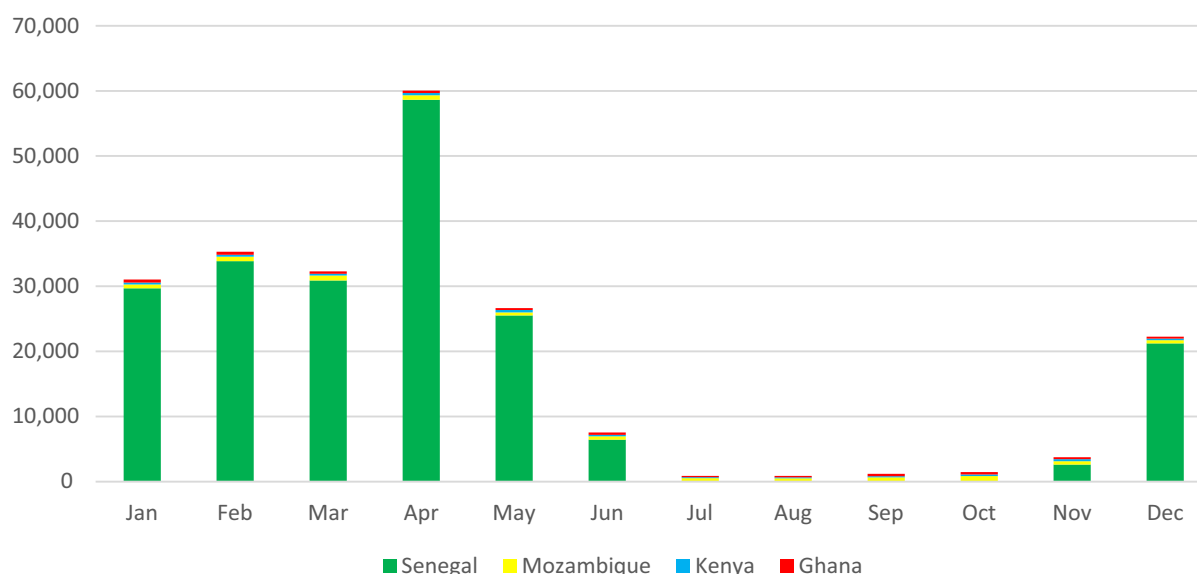
18) To maintain quality, harvested sweetcorn is cooled shortly after harvest, for example being submerged into cold water ($1°C$) for an hour (Barfoot, 2018).
19) Sweetcorn is not chill sensitive and is stored as cold as possible without freezing. To avoid quality loss, sweetcorn varieties are seldom stored for more than a few days.
20) Fresh sweetcorn in husks are graded by hand prior to export.
21) Larval damage to corn cobs can reveal infested ears; frass can be seen at the tip of a cob by the silks and holes at the base of the cob, near the bract where larger larvae enter also indicate infested ears that can be graded out (removed from export).
22) Fresh sweetcorn for consumption is not regulated by the Plant Health Directive 2000/29 EC.
23) Although not covered by specific EU horticultural marketing standards, sweetcorn marketed in the EU must still meet general marketing standards including being clean and practically free from pests and practically free from damage caused by pests (Anon, 2017b).

Other factors discussed and input from external experts:

- Finding larvae of *S. frugiperda* in the ears of corn is much more common in Africa than in the Americas. Consequently, direct feeding damage by *S. frugiperda* in Africa is very destructive.
- To save transport costs cobs are de-husked/shucked. A mature larva would very likely be seen and the cob rejected at this stage.
- Density of maize in Africa is much lower than in Europe or the Americas (perhaps 5 m^{-2})
- Within a crop of maize, *S. frugiperda* will be clumped (not evenly distributed) within a field.
- In Africa, early instar larva penetrate to eat the tassels, post-harvest treatment submerging cobs in cold water for an hour will be effective at removing such larvae.
- In high value export crops, additional pest management measures (more chemical sprays) will be applied to ensure quality control, and maintain market access.

For scenario A1 (with phytosanitary measures in place)

In a scenario where phytosanitary measures are in place against *S. frugiperda*, additional factors need to be taken into account when estimating the mean annual proportion of transfer units infested with *S. frugiperda* on sweetcorn exports.

A variety of phytosanitary measures are available to lower the likelihood that *S. frugiperda* enters the EU on hosts traded internationally. For example, hosts, such as sweetcorn, could be sourced from a pest free area, or pest free place of production, or prior to their export have been officially inspected and found free from *S. frugiperda* or subjected to treatment to ensure freedom from the pest.

In order to guarantee pest freedom within a crop, place of production, place of production and buffer zone, or area, it is necessary to fulfil the requirements outlined in ISPM No. 4 (FAO, 2017) and ISPM No. 10 (FAO, 2016). This would be very challenging for a pest such as *S. frugiperda* that is highly mobile and highly polyphagous. Ultimately, sweet corn would need to be inspected prior to export and found free of *S. frugiperda* so that a phytosanitary certificate could be issued. The question to consider then is how likely is an infested sweetcorn to escape detection taking into account existing crop protection practices, processing measures and quality control efforts.

Factors to take into account:

1) There is no survey information measuring the performance of export inspections.
2) ISPM 31 provides guidance for minimum sample sizes that provides either 95% or 99% confidence according to lot size and level of detection.
3) It is unknown how many inspections follow ISPM 31.
4) During an audit carried to evaluate the system of official controls for the export of plants and plant products to the EU in Ghana by DG Sante, EU officials found that sampling for export inspections was inconsistent and in some cases inadequate, and that there was not always enough time available to carry out effective inspections (European Commission DG Sante, 2016).
5) During a similar audit in Kenya in 2013, EU officials found a significant weakness in the system of official export checks, with insufficient time available for effective inspections although the risk arising from this was mitigated by the biosecurity and pest prevention measures applied by producers (European Commission DG Sante, 2013a).

Other factors discussed and input from external experts:

6) Major exporting countries, such as Senegal, have such good practices any infestation is at such a low level that visual inspection is not going to make a material difference on the level of infestation.

Estimation: Taking the above information into account, the following estimates were made:

- Mean percentage of infested product in export production fields in the area of origin over the next 5 years;
- Mean percentage of infested material removed by post-harvest sorting;
- Mean percentage of infested material removed by post-harvest treatments.

Sweetcorn pathway	Scenario	Percentile[a]				
		1	25	50	75	99
1. Infestation at origin: Average percentage of infested product in export production fields in the area of origin	A0	0.1%	0.3%	0.5%	0.7%	1%
	A1	0.01%	0.03%	0.05%	0.07%	0.1%
2. Effectiveness of post-harvest sorting Average percentage of infested material removed.	A0	1%	3%	5%	10%	20%
	A1	20%	35%	45%	50%	60%
3. Effectiveness of post-harvest treatments (includes storage and shipping)	A0	30%	43%	50%	57%	70%
	A1	50%	63%	70%	77%	90%

(a): Judgement was used to estimate five quantiles of the reduction factor expressing effectiveness.

In scenario A0 (baseline, without phytosanitary measures) infested sweetcorn arriving at the EU border are assumed to remain infested.

E.4. Proportion of infested units detected at EU border

As of February 2018, fresh sweetcorn for consumption is not regulated by the Plant Health Directive 2000/29 EC and does not need to be inspected for plant health purposes on arrival in the EU.

Infested corn ears are assumed to remain infested. However, in a scenario where sweetcorn becomes regulated, consignments would be subject to official inspection on arrival in the EU.

Factors to take into account:

1) There is little published evidence reporting the efficiency of effectiveness of plant health import inspections.
2) Analysing data relating to plants for planting, Liebhold et al. (2012) estimated about 72% of infested plant shipments passed through US ports undetected**.**
3) ISPM 31 provides guidance for minimum sample sizes that provides either 95% or 99% confidence according to lot size and level of detection
4) It is unknown how many inspections follow ISPM 31
5) The analysis by Liebhold et al. (2012) considered plants infested by any pest taxa, including pathogens. Detecting relatively large *S. frugiperda* larvae could be easier so the 28% success rate estimated by Liebhold et al. (2012) could be higher.
6) Work et al. (2005) estimated that inspectors detected 19–28% of pests in non-refrigerated maritime cargo and 30–50% of pests in cargo crossing the US–Mexico border.

Other factors discussed and input from external experts:

- Rejection of infested sweetcorn cobs when de-husked at origin leads to such low levels of infested cobs when exported that inspection of such material on arrival is not going to make a difference to the overall average level of infested sweetcorn that arrive.

Estimation: Taking the above information into account, the following estimates were made:

- Estimated range of mean annual proportion of infested sweetcorn cobs (transfer units) detected during phytosanitary inspections of sweetcorn from core America or sub-Saharan Africa at the EU border over the next 5 years (time horizon for assessment).

Sweetcorn pathwayEffectiveness of import inspections	Scenario	Percentile[a]				
		1	25	50	75	99
In Scenario A0, this substep has no effect as sweetcorn is not inspected in this scenario.	A0	0%	0%	0%	0%	0%
Percentage infested material removed at import	A1	1%	6%	10%	15%	25%

(a): Expert judgement was used to estimate five quantiles of the reduction factor expressing effectiveness.
EU supermarkets require suppliers to be accredited and to maintain rigorous quality standards.

E.5. Proportion of infested units rejected during post entry handling or processing

Sweetcorn that arrives in EU with husks are unloaded and de-husked, cut to size and packaged at packing plants. Any larvae arriving with sweetcorn are not likely to survive the processing procedures. Processing waste is shredded and can be used to feed anaerobic digesters to provide energy (Lancaster University, 2018). A proportion of imported sweetcorn may be sold with the husk on. This could provide an opportunity for any larvae infesting such cobs to remain protected until the consumer prepared the sweetcorn for consumption.

- Estimated range of mean annual proportion of infested sweetcorn rejected during postharvest handling or processing over the next 5 years (time horizon for assessment)

Sweetcorn pathway	Scenario	Percentile[a]				
		1	25	50	75	99
Average proportion of infested material remaining (i.e. this percentages represent the survival of larvae on/in infested sweetcorn).	A0	0.1%	0.3%	1%	2%	5%
	A1	0.1%	0.3%	1%	2%	5%

(a): Expert judgement was used to estimate five quantiles of the reduction factor expressing effectiveness.

Appendix F – Evidence dossier: Trade pathway – peppers (*Capsicum* spp.)

F.1.   Mean trade volume of peppers into the EU from countries where *Spodoptera frugiperda* occurs over the next 5 years

EUROSTAT data was extracted to determine the amount of imports and EU intracommunity trade for *Capsicum* and other peppers over the most recent 7 years (2010–2016) (CN 07096010). Because of the widespread occurrence of *S. frugiperda* in the Americas and in Africa, import data were grouped into five regions (Map 1).

Table F.1:   Example import data for EU imports of *Capsicum* (CN 07096010) from Third countries and intra-EU trade 2010–1016 (Source: EUROSTAT) (hundreds kg)

Year Source	2010	2011	2012	2013	2014	2015	2016	Mean
Intra-EU	9,971,766	10,785,776	11,055,552	11,357,621	11,997,279	12,278,468	12,348,644	11,399,301
Core America	13,275	15,752	16,055	17,806	19,152	15,322	10,257	15,374
Sub-Saharan Africa	66,645	60,742	49,546	50,202	58,506	40,152	43,210	52,715
North Africa	625,456	619,887	637,285	776,644	893,046	916,190	1,025,708	784,888
Middle East	1,092,659	1,132,258	1,142,945	859,524	590,800	478,835	247,183	792,029
Other	749,825	784,350	715,956	676,799	790,612	884,680	1,002,285	800,644
Sum	2,547,860	2,612,989	2,561,787	2,380,975	2,352,116	2,335,179	2,328,643	2,445,650
Intra-EU + TC	12,519,626	13,398,765	13,617,339	13,738,596	14,349,395	14,613,647	14,677,287	13,844,951

% of EU Third country imports of *Capsicum* (CN 0709 60) from regions in relation to distribution of *S. frugiperda*
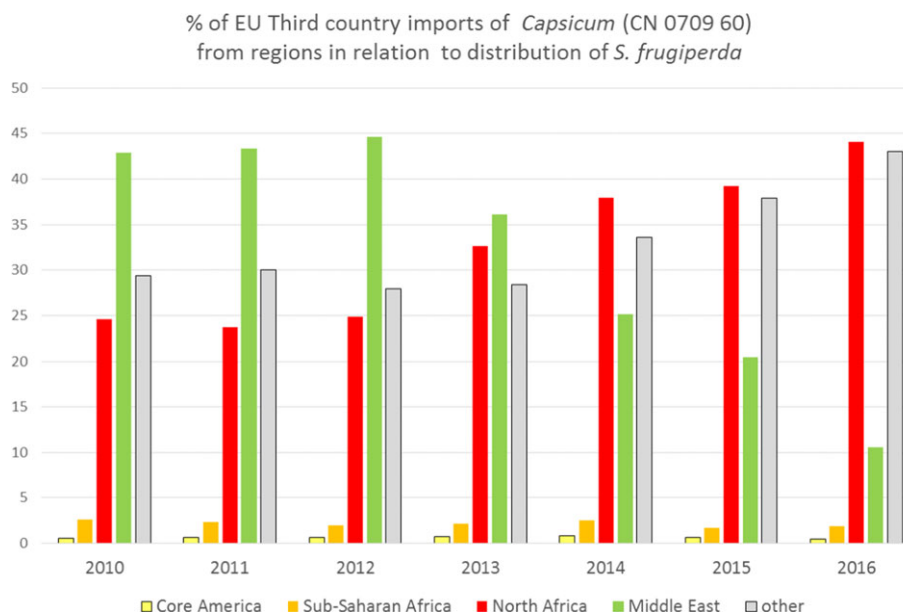
Table F.2: *Capsicum* annual imports from third country regions expressed as a %

Source	2010	2011	2012	2013	2014	2015	2016
Core America	0.5	0.6	0.6	0.7	0.8	0.7	0.4
Sub-Saharan Africa	2.6	2.3	1.9	2.1	2.5	1.7	1.9
North Africa	24.5	23.7	24.9	32.6	38.0	39.2	44.0
Middle East	42.9	43.3	44.6	36.1	25.1	20.5	10.6
other	29.4	30.0	27.9	28.4	33.6	37.9	43.0
Sum	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Other factors to take into account:

1) No extensive literature search was performed for this parameter.
2) Only EUROSTAT data were collected and assessed.
3) No trade body/industry information was obtained to verify EUROSTAT.
4) The data indicates that imports and intra-EU trade have fluctuated over the past 7 years.
5) The region from which the EU sources most *Capsicum* fruit most often are the Middle East, North Africa and Other regions. Since 2012, there has been a trend showing a decrease of imports from the Middle East and an increase from North Africa and Other. All these areas are at the moment, not affected by *S. frugiperda*.
6) Total third country imports of *Capsicum* into the EU between 2012 and 2016 has been stable just below approximately 250 million kg per year.
7) Although not a preferred host, *S. frugiperda* may affect yield or quality of *Capsicum* in sub-Saharan Africa and imports may decline in future.
8) Well-organised NPPOs in Africa supporting significant exports to the EU may be able to cope with *S. frugiperda*. Conversely, weaker NPPOs, or those with smaller exports where the export horticulture sector is less developed could find it problematic (Abrahams et al., 2017).
9) For scenario A1, phytosanitary measures will add costs and may reduce volume of trade.
10) Repeated EU interceptions of Lepidopteran pests (not *S. frugiperda*) on *Capsicum* from Uganda led to Uganda imposing a self-ban on exporting *Capsicum* to the EU in 2017. (Around 30% of EU imports of *Capsicum* from sub-Saharan Africa 2010–2016 was sourced from Uganda).

Following discussion, it was agreed that past import data best informed likely future imports and a regression was performed to estimate mean annual future imports over the next 5 years, i.e. until the time horizon of the opinion.

Table F.3: Estimated range of mean pepper imports into the EU from the region 'core Americas' and sub-Saharan Africa over the next 5 years (time horizon for assessment) based on regression of previous import (hundreds of kg)

Quantile (Percentile)	Lower (1%)	Q1 (25%)	Median (50%)	Q3 (75%)	Upper (99%)
Scenario **A0** (baseline)	39,813	53,821	63,960	79,434	195,489
Scenario **A1** (with measures)	39,813	53,821	63,960	79,434	195,489

No difference in imports was anticipated in a scenario A1.

F.2. Weight of a transfer unit (pepper fruit)

A standard conversion factor for an individual pepper fruit (0.160 kg, EFSA unpublished data) was used to convert mass of imports into an estimate of the number of peppers imported on the pathway. The conversion factor is used to represent sweet and hot (chilli) peppers.

Estimation: Taking the import data and other factors noted above into account, the Panel estimated the range in the annual mean volume (mass) of *Capsicum* imported into the EU from Core America and sub-Saharan Africa over the next 5 years. Estimates are shown in Tables x and x + 1.

F.3.   Proportion of export production fields infested; effectiveness of post-harvest sorting and post-harvest treatments

Factors to take into account:

1) *Capsicum annum* is indicated as host of *S. frugiperda* and larvae can cause serious damages to the fruit (Barlow and Kuhar, 2005).
2) Larval densities is usually reduced to one or two per plants, due to cannibalistic behaviour (Barlow and Kuhar, 2005).
3) *S. frugiperda* is spreading and damaging several crops in sub-Saharan Africa.
4) In sub-Saharan Africa *Capsicum* is grown in open fields although recent pressure from *Thaumatotibia leucotreta* (false codling moth) is putting pressure on growers to grow within protection.
5) In core America. *Capsicum* is grown outdoors and under protection.
6) *Capsicum* (*C. annuum*) is subject to EC marketing standards (EC Regulation 543/2011; Annex 1, Part B 8: Anon, 2017b) which requires sweet peppers to be clean and practically free from pests; free from damage caused by pests affecting the flesh; free from damage caused by low temperature or frost. Light traps, capturing males and females, and pheromone traps, capturing only males, can be used to detect adults in the field and in production-, storage- and handling facilities (EPPO, 2015).
7) Harvested peppers will be graded by hand prior to export, larval damage to fruit might can be detected and can be graded out (removed from export) (unknown detection effectiveness).
8) To maintain quality, harvested sweet pepper are stored and transported at temperature ranging from 7 to 10°C.
9) *S. frugiperda* has been intercepted in the EU many times on *Capsicum* from the region 'Core America' (Table x). Some other intercepted pests include other Lepidoptera and a weevil species (*Anthonomus eugenii*) that burrows into *Capsicum* fruit.
10) Lepidopteran pests that burrow into *Capsicum* fruit have been intercepted from sub-Saharan Africa (e.g. Table Y).
11) Smallholders growing *Capsicum* are less likely to be able to manage *S. frugiperda* than larger growers.
12) After harvest, fresh market peppers should be rapidly cooled to no lower than 7°C and kept at 90–95% RH to reduce water loss and subsequent shrivel which would lower quality. Peppers are subject to chilling injury when stored below 7°C. Chilling sensitivity varies by cultivar and some are sensitive at 7°C, so a good storage temperature is 7–13°C. Ripe (coloured) peppers are less chill sensitive than green peppers. Above 13°C, peppers are subject to accelerated ripening and bacterial soft rot (CargoHandbook.com, 2017b).
13) Smallholder farmers' access to European export markets is often impeded by their having to meet strict food safety standards, industry quality standards and sometimes phytosanitary standards (Hellin et al., 2011).

Table F.4:   EU Interceptions of Lepidoptera and Coleoptera pests on *Capsicum* from Dominican Republic, Mexico, Peru and Suriname (countries in core America that export the most *Capsicum* from that region to the EU) 2011–2017 Source: Europhyt

Type	Pest Year	2011	2013	2014	2015	2016	2017	Sum
Coleoptera	*Anthonomus eugenii*		29	21	19	4	16	89
Lepidoptera		3	6	12	19	13	17	70
Lepidoptera by Genus								
	Spodoptera frugiperda		**6**	**10**	**10**	**8**	**14**	**48**
	Spodoptera eridania				6			6
	Helicoverpa zea				3	2		5
	Heliothis sp.	3						3
	Spodoptera latifascia					3		3
	Other Noctuidae						3	3
	Helicoverpa armigera			2				2

Table F.5: EU Interceptions of Lepidoptera pests on *Capsicum* from Gambia, Ghana, Kenya, Senegal and Uganda (countries in sub-Saharan Africa that export the most *Capsicum* from that region to the EU) 2010–2017 Source: Europhyt

Pest Year	2010	2013	2014	2015	2016	2017	Sum
Thaumatotibia leucotreta			289	595	271	232	1387
Tortricidae	6		14	5	5	3	33
Helicoverpa armigera				14	8		22
Cryptophlebia leucotreta		17					17
Other Lepidoptera				4	8		12
Leucinodes orbonalis				1			1

Other factors discussed and input from external experts:

- *S. frugiperda* occurrence is likely to be patchy within a field.
- NL kindly provided the inspection data of fruit and vegetables in 2015. A summary of the numbers of lots of *Capsicum* inspected from core American countries is shown.

Table F.6: NL inspection data of *Capsicum* lots from core America 2015

Source in core America	No. lots	kg	Mean lot size (kg)	*S. frugiperda* finds	% of import
Peru	63	145,000	2302	0	70.4
Dominican Republic	19	22,000	1158	0	10.7
Mexico	7	7,000	1000	1	3.4
Cuba	11	10,000	909	0	4.9
Brazil	4	500	125	0	0.2
Suriname	285	21,500	75	15	10.4

- Note that the majority of finds were from Suriname that exports small lots (mean size of a lot was 75 kg) compared with lot sizes of approximately 1000 kg or more from Peru, Dominican Republic, Mexico and Cuba. Chi-square test 2.57, df = 1, p = 0.11 NSD. However, small sample size and experts think that with more samples, a difference would be detected.
- Larvae enter fruit under the bract, making detection difficult. The larvae mature within the fruit and symptoms are nor easily detected.
- In South America, production of peppers is relatively diffuse with many small and medium growers. Export companies buy from them and ship to export markets. However, in Africa, production is more sophisticated and centrally controlled.

For scenario A1 (with phytosanitary measures in place)

In a scenario where phytosanitary measures are in place against *S. frugiperda*, additional factors need to be taken into account when estimating the mean annual proportion of transfer units infested with *S. frugiperda* on pepper exports.

A range of phytosanitary measures are available to lower the likelihood that *S. frugiperda* enters the EU on hosts traded internationally. For example, hosts, such as pepper, could be sourced from a pest free area, or pest free place of production, or prior to their export have been officially inspected and found free from *S. frugiperda* or subjected to treatment to ensure freedom from the pest.

In order to guarantee pest freedom within a crop, place of production, place of production and buffer zone, or area, it is necessary to fulfil the requirements outlined in ISPM No. 4 (FAO, 2017) and ISPM No. 10 (FAO, 2016). This would be very challenging for a pest such as *S. frugiperda* that is highly mobile and highly polyphagous. Ultimately pepper would need to be inspected prior to export and found free of *S. frugiperda* so that a phytosanitary certificate could be issued. The question to consider then is how likely is an infested pepper to escape detection taking into account existing crop protection practices, processing measures and quality control efforts.

Factors to take into account:

1) There is no survey information measuring the performance of export inspections.
2) ISPM 31 provides guidance for minimum sample sizes that provides either 95% or 99% confidence according to lot size and level of detection.

3) It is unknown how many inspections follow ISPM 31.
4) During an audit carried to evaluate the system of official controls for the export of plants and plant products to the EU in Ghana by DG Sante, EU officials found that sampling for export inspections was inconsistent and in some cases inadequate, and that there was not always enough time available to carry out effective inspections (European Commission DG Sante, 2016).
5) During a similar audit in Kenya in 2013, EU officials found a significant weakness in the system of official export checks, with insufficient time available for effective inspections although the risk arising from this was mitigated by the biosecurity and pest prevention measures applied by producers (European Commission DG Sante, 2013).

Other factors discussed and input from external experts:

- With additional measures, growers likely to apply more rigorous pest management practices as detection post-harvest, during packing and sorting is expensive (more time and labour required).
- With measures, exports would apply measures in field, such as growing under netting, better monitoring and targeting of chemical measures, improved crop management, leading to a ten-fold reduction in infestation, both in core America and sub-Saharan Africa.
- Examples of the effectiveness of phytosanitary measures are rare within the literature. However, when measures were applied to orchids from Asia, the level of pests detected in the EU dropped by about half in the 3 years after additional phytosanitary measures were in place (MacLeod Thrips palmi example); Also, when Solidago and Gypsophila cut flowers became regulated due to presence of Leaf miner pest interceptions fell from around 7% to 3.5% in the 6 months after regulation (MacLeod and Baker, 1998).
- There is more scope for improving conditions in pepper production (to reduce infestation)

Estimation: Taking the above information into account, the following estimates were made:

- Mean percentage of infested product in export production fields in the area of origin over the next 5 years.
- Mean percentage of infested material removed by post-harvest sorting.
- Mean percentage of infested material removed by post-harvest treatments.

Peppers pathway	Scenario	Percentile[a]				
		1	25	50	75	99
1. Infestation at origin: Average percentage of infested product in export production fields in the area of origin	A0	0.005	0.05	0.15	0.5	5.0
	A1	0.005	0.005	0.15	0.5	2.0
2. Effectiveness of post-harvest sorting Average percentage of infested material removed.	A0	15	30	40	55	80
	A1	15	30	40	55	80
3. Effectiveness of post-harvest treatments (includes storage and shipping)	A0	0	0	0	0	0
	A1	0	0	0	0	0

(a): Expert judgement was used to estimate five quantiles of the reduction factor expressing effectiveness.

F.4. Proportion of infested units detected at EU border

Fruits of *Capsicum* originating in the African continent are regulated by Commission implementing directive 2017/1279 which amends Annexes I to V of 2000/29/EC. Such fruits should come from a country, area or place of production free from *Thaumatotibia leucotreta*, or have been subject to a cold treatment to ensure freedom from *T. leucotreta*. Peppers from Africa are therefore subject to official inspection on arrival in the EU.

Factors to take into account:

1) There is little published evidence reporting the efficiency of effectiveness of plant health import inspections.

2) Analysing data relating to plants for planting, Liebhold et al. (2012) estimated about 72% of infested plant shipments passed through US ports undetected**.**
3) ISPM 31 provides guidance for minimum sample sizes that provides either 95% or 99% confidence according to lot size and level of detection.
4) It is unknown how many inspections follow ISPM 31.
5) The analysis by Liebhold et al. (2012) considered plants infested by any pest taxa, including pathogens. Detecting relatively large *S. frugiperda* larvae could be easier so the 28% success rate estimated by Liebhold et al. (2012) could be higher.
6) Work et al. (2005) estimated that inspectors detected 19–28% of pests in non-refrigerated maritime cargo and 30–50% of pests in cargo crossing the US–Mexico border.
7) Although sometimes inspected, *Capsicum* from South America are not regulated officially.

Other factors discussed and input from external experts:

Estimation: Taking the above information into account, the following estimates were made:

- Estimated range of mean annual proportion of infested peppers detected during phytosanitary inspections from core America or sub-Saharan Africa at the EU border over the next 5 years (time horizon for assessment).

Pepper pathway	Scenario	Percentile[a]				
		1	25	50	75	99
Effectiveness of import inspections Percentage infested material removed at import	A0	1	6	10	15	25
	A1	1	6	10	15	25

(a): Expert judgement was used to estimate five quantiles of the reduction factor expressing effectiveness.

F.5. Proportion of infested units rejected during post entry handling or processing

Peppers from Africa arrive loose in cardboard boxes for wholesale markets, others came pre-packaged ready for supermarkets. Nevertheless, there would be no further processing, simply some storage and transport for wholesale or retail.

- Estimated range of mean annual proportion of infested peppers rejected during postharvest handling or processing over the next 5 years (time horizon for assessment).

Pepper pathway	Scenario	Percentile[a]				
		1	25	50	75	99
Effectiveness of post-entry handling/processing Percentage infested material removed after import	A0	0	0	0	0	0
	A1	0	0	0	0	0

(a): Expert judgement was used to estimate five quantiles of the reduction factor expressing effectiveness.

Appendix G – Evidence dossier: Trade pathway – asparagus (*Asparagus officinalis*)

G.1. Mean trade volume of asparagus into the EU from countries where *Spodoptera frugiperda* occurs over the next 5 years

EUROSTAT data was extracted to determine the amount of imports and EU intracommunity trade for asparagus (CN 0709 20) over the seven year period 2010–2016. Because of the widespread occurrence of *S. frugiperda* in the Americas and in Africa, import data were grouped into five regions (Figure 1).

Table G.1: EU imports of asparagus (CN 0709 20) from Third countries and intra EU trade 2010–1016 (Source: EUROSTAT)

	2010	2011	2012	2013	2014	2015	2016	mean
Intra-EU	576,118	566,125	587,483	595,244	626,372	611,904	632,492	599,391
Core America	338,239	347,328	358,409	343,388	363,150	336,903	346,955	347,767
Sub-Saharan Africa	1,213	1,922	2,233	3,186	4,725	358	417	2,008
North Africa	19,909	16,920	12,637	7,304	3,231	2,870	1,243	9,159
Middle East	0	4	12	7	0	0	0	3
other	11,610	9,075	6,169	3,958	5,720	8,496	16,428	8,779
Sum Third country	370,971	375,249	379,460	357,843	376,826	348,627	365,043	367,717
Intra-EU + Third Country	947,089	941,374	966,943	953,087	1,003,198	960,531	997,535	967,108

EU third country imports of asparagus (CN 0709 20) from regions in relation to distribution of *S. frugiperda* (Hundreds kg)
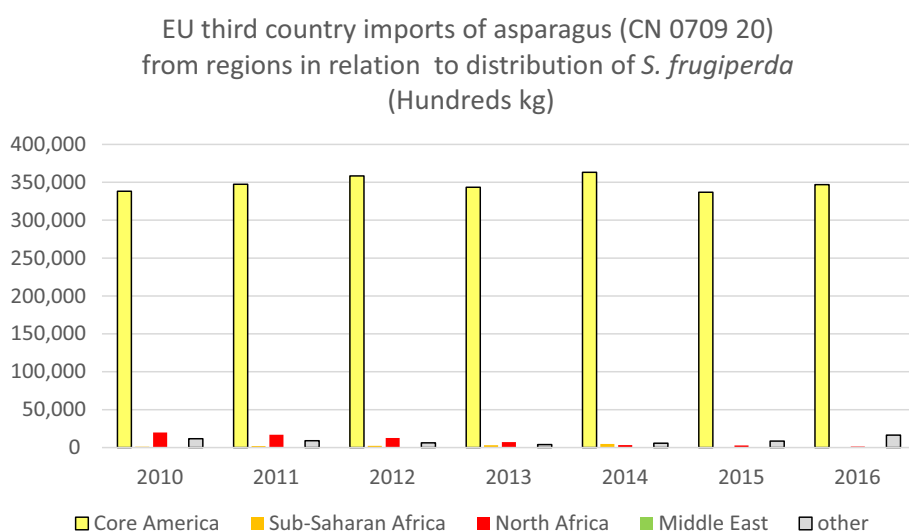
Table G.2: Asparagus annual imports from third country regions expressed as a %

	2010	2011	2012	2013	2014	2015	2016
Core America	91.2	92.6	94.5	96.0	96.4	96.6	95.0
Sub-Saharan Africa	0.3	0.5	0.6	0.9	1.2	0.1	0.1
North Africa	5.4	4.5	3.3	2.0	0.9	0.8	0.3
Middle East	0.0	0.0	0.0	0.0	0.0	0.0	0.0
other	3.1	2.4	1.6	1.1	1.5	2.4	4.5
Sum	100.0	100.0	100.0	100.0	100.0	100.0	100.0

The great majority of fresh asparagus imported by the EU from third countries comes from countries in Central and South America, the area of 'core distribution' of *S. frugiperda*.

Other considerations to take into account:

1) No extensive literature search was performed for this parameter.
2) Only EUROSTAT data were collected and assessed.
3) No trade body/industry information was obtained to verify EUROSTAT.
4) The data indicates that imports and intra-EU trade have fluctuated over the past 7 years.
5) Fresh asparagus is growing in popularity, a global market analysis estimated demand grew by 2% in 2017. Demand is expected to grow year on year and could be 3.1% higher by 2027. Most demand is from the USA and Europe (Future market insights, 2017).
6) There are severe limits to the area in Europe suitable for asparagus production (Freshplaza, 2018) so there is a relatively large amount of import from third countries.
7) USDA FAS GAIN (2017) report increasing demand for asparagus in US and Europe with Peru (and Mexico) being major exporters to these markets.
8) For scenario A1, phytosanitary measures will add costs and may reduce volume of trade.

Following discussion, it was agreed that past import data best informed likely future imports and a regression was performed to estimate mean annual future imports over the next 5 years, i.e. until the time horizon of the opinion.

Table G.3: Estimated range of mean asparagus imports into the EU from the region 'core Americas' and sub-Saharan Africa over the next 5 years (time horizon for assessment) based on regression of previous import (hundreds of kg)

Quantile (Percentile)	Lower (1%)	Q1 (25%)	Median (50%)	Q3 (75%)	Upper (99%)
Scenario **A0** (baseline)	381,898	425,417	442,233	464,025	519,826
Scenario **A1** (with measures)	381,898	425,417	442,233	464,025	519,826

No difference in imports was anticipated in a scenario A1.

G.2. Weight of a transfer unit (pack of asparagus spears)

A standard conversion factor for asparagus (0.033 kg, EFSA unpublished data) was used to convert mass of imports into an estimate of the number of pieces (spears) of asparagus imported. It was assumed that on average 10 spears would constitute the size of a pack of asparagus or transfer unit, hence a standard conversion factor of 0.33 kg was used to estimate the number of transfer units imported on the pathway. This seems reasonable given that European supermarkets sell asparagus spears in bunches and packs of various sizes from 150 to 500 g (MacLeod, unpublished).

G.3. Proportion of export production fields infested; effectiveness of post-harvest sorting and post-harvest treatments

Factors to take into account:

1) Although a host, CABI Crop Protection Compendium (2017a, 2017b) does not regard *Asparagus* as a main host for *S. frugiperda.*
2) Asparagus is a perennial crop and plants are productive for 15–20 years (USDA FAS GAIN, 2017).
3) Asparagus is imported from countries in core America into the EU every month of the year.
4) Within core America Peru is the major asparagus producer.
5) In Peru, asparagus is grown outdoors in the coastal region (mild temperatures, low rainfall) and is irrigated, providing year round high quality asparagus (USDA FAS GAIN, 2017). (Hence ongoing exposure to *S. frugiperda*.)
6) Asparagus spears are harvested only a few days after emergence and so each spear is not exposed much to a gravid *S. frugiperda* seeking a site for oviposition. This likely limits the rate of filed infestation.
7) Asparagus has a high metabolic rate after harvest and is among the most perishable crops. Harvested spears are cooled immediately to between 0° and 2°C during a process of washing, grading and packing. After packing *Asparagus* is cooled to near 0°C. Freezing injury

occurs at temperatures below −0.5°C. Maintaining a low storage temperature is critical to delay senescence, tissue toughening and flavour loss (CargoHandbook.com, 2017a; CABI 2018b).

8) Fresh asparagus for consumption is not regulated by the Plant Health Directive 2000/29 EC. However, Commission Implementing Directive (EU) 2017/1279 updated 2000/29 EC and added *Asparagus officinalis* plants for planting, other than seed, to Annex V of 2000/29 EC. Nevertheless, fresh asparagus for consumption remains unregulated for plant health purposes.

9) Although no longer covered by specific EU horticultural marketing standards (Anon, 2017b), *Asparagus* marketed in the EU must still meet general marketing standards or a specific UNECE standard which includes being clean and practically free from pests and practically free from damage caused by pests (UNECE, 2010; Schuster and Maertens, 2013).

10) *S. frugiperda* egg masses and first instar larvae have been intercepted on *Asparagus* arriving in the EU (NL) from core America (Peru) (4 interceptions) (1 in 2012; 2 in 2013, 1 in 2017).

11) The amount of *Asparagus* imported from Peru into NL in the months when an interception was found does not reveal any relationship between amount of *Asparagus* imported in a month and the likelihood of *S. frugiperda* being intercepted.

12) NL kindly provided inspection data for fruit and vegetables from around the world for 1 year (2015) which indicated that between 1 January and 31 December, there were 3,396 lots of asparagus from Peru that were inspected, either for horticultural marketing or plant health purposes. (It is possible that multiple lots from a single consignment were inspected). Lots were inspected every month of the year. The number of lots ranged from 115 in May to 325 in July. The vast majority of lots weighed less than 10,000 kg. Of those under 10,000 kg, the median lot weighed approximately 2,170 kg (95% confidence approximately 500 kg to 5,000 kg). No *S. frugiperda* were found on inspected lots during 2015.

13) High level production and processing standards required by EU supermarkets dis-favour sourcing asparagus and other horticultural products from (small-scale) producers (Schuster and Maertens, 2013).

14) Lichtenberg and Olson (2018) model plant pest entry into the USA on fruit and vegetable imports. Based on trade volume, country of origin, season, port of entry and tariff status, they estimate that importing 10 shipments of asparagus per year from Peru into USA would give between 0.24 and 0.26 probability that at least one 'actionable pest' would be enter. Of course, the 'actionable pest' may not be *S. frugiperda*.

15) Lichtenberg and Olson (2018) also provide an estimate for *Asparagus* from Ecuador (0.15–0.17)

16) In a scenario where phytosanitary measures are in place against *S. frugiperda*, additional factors need to be taken into account when estimating values for model inputs.

17) A range of phytosanitary measures are available to lower the likelihood that *S. frugiperda* enters the EU on hosts traded internationally. For example, hosts, such as *Asparagus*, could be sourced from a pest free area, or pest free place of production, or prior to their export have been officially inspected and found free from *S. frugiperda* or subjected to treatment to ensure freedom from the pest.

18) In order to guarantee pest freedom within a crop, place of production, place of production and buffer zone, or area, it is necessary to fulfil the requirements outlined in ISPM No. 4 (FAO, 2017) and ISPM No. 10 (FAO, 2016). This would be very challenging for a pest such as *S. frugiperda* that is highly mobile and highly polyphagous. Ultimately *Asparagus* would need to be inspected prior to export and found free of *S. frugiperda* so that a phytosanitary certificate could be issued. The question to consider then is how likely is an infested bunch of *Asparagus* to escape detection taking into account existing crop protection practices, processing measures and quality control efforts.

19) There is no survey information measuring the performance of export inspections.

20) ISPM 31 provides guidance for minimum sample sizes that provides either 95% or 99% confidence according to lot size and level of detection.

21) It is unknown how many inspections follow ISPM 31.

22) During an audit carried to evaluate the system of official controls for the export of plants and plant products to the European Union from the Dominican Republic, EU officials found

that there was a lack of detailed guidelines and written instructions for export inspectors; this could undermine the effectiveness of pre-export controls (European Commission DG Sante, 2015). Such an issue may also occur in other countries within the region 'core America'.

23) FVO audits in Africa found that inspectors had insufficient time for export checks (European Commission DG Sante, 2013). This may also be the case in countries within 'core America'.

Estimation: Taking the above information into account, the following estimates were made:

- Mean percentage of infested product in export production fields in the area of origin over the next 5 years;
- Mean percentage of infested material removed by post-harvest sorting;
- Mean percentage of infested material removed by post-harvest treatments.

Asparagus pathway	Scenario	Percentile[a]				
		1	25	50	75	99
1. Infestation at origin: Average percentage of infested product in export production fields in the area of origin	A0	0.001	0.01	0.03	0.1	1.0
	A1	0.001	0.01	0.03	0.1	0.4
2. Effectiveness of post-harvest sorting Average percentage of infested material removed.	A0	90	93	95	97	99
	A1	90	93	95	97	99
3. Effectiveness of post-harvest treatments (includes storage and shipping)	A0	75	88	95	97	99
	A1	75	88	95	97	99

(a): Expert judgement was used to estimate five quantiles of the reduction factor expressing effectiveness.

G.4.   Proportion of infested units (*Asparagus* bunches) detected at EU border

Fresh *Asparagus* for consumption is not currently regulated under EU plant health legislation. However, in a scenario where it had to arrive in the EU free from *S. frugiperda*, imports would be sampled and subject to official inspection on arrival in the EU.

Factors to take into account:

8) There is little published evidence reporting the efficiency of effectiveness of plant health import inspections.

9) Analysing data relating to plants for planting, Liebhold et al. (2012) estimated about 72% of infested plant shipments passed through US ports undetected.

10) ISPM 31 provides guidance for minimum sample sizes that provides either 95% or 99% confidence according to lot size and level of detection.

11) It is unknown how many inspections follow ISPM 31.

12) The analysis by Liebhold et al. (2012) considered plants infested by any pest taxa, including pathogens. Detecting relatively large *S. frugiperda* larvae could be easier so the 28% success rate estimated by Liebhold et al. (2012) could be higher.

13) EU interceptions on *Asparagus* have been egg masses and early instar larvae.

14) Work et al. (2005) estimated that inspectors detected 19–28% of pests in non-refrigerated maritime cargo and 30–50% of pests in cargo crossing the US–Mexico border.

Other factors discussed and input from external experts:

15) Small consignments from countries where exporters are not Global GAP accredited are assumed to have higher infestation rates than large consignments from accredited exporters where producers are catering to large supermarket chains in the EU that exercise rigorous quality standards. We may consider an efficacy of import inspection in reducing the level of infestation in the incoming trade in those cases where the total population of incoming infested product is concentrated in few consignments with high rates of infestation that may be identified upon import.

16) Infestation rate is so low that prohibitively large sample sizes are required to confidently detect infested consignments.

Estimation: Taking the above information into account, the following estimates were made:

- Estimated range of mean annual proportion of infested asparagus bunches (transfer units) detected during phytosanitary inspections of asparagus from core America or sub-Saharan Africa at the EU border over the next 5 years (time horizon for assessment)

Asparagus pathway	Scenario	Percentile[a]				
		1	25	50	75	99
Effectiveness of import inspections Percentage infested material removed at import	A0	0	0	0	0	0
	A1	0	0	0	0	0

(a): Expert judgement was used to estimate five quantiles of the reduction factor expressing effectiveness.

G.5. Proportion of infested units rejected during post entry handling or processing

Asparagus arrives in EU prepackaged as a tray with cling-film. Hence there would be no further processing, simply some storage and transport for retail.

- Estimated range of mean annual proportion of infested asparagus rejected during postharvest handling or processing over the next 5 years (time horizon for assessment)

Asparagus pathway	Scenario	Percentile[a]				
		1	25	50	75	99
Effectiveness of post-entry handling/processing Percentage infested material removed after import	A0	0	0	0	0	0
	A1	0	0	0	0	0

(a): Expert judgement was used to estimate five quantiles of the reduction factor expressing effectiveness.

Appendix H – Evidence dossier: Trade pathway – eggplant (*Solanum melongena*)

H.1. Mean trade volume of eggplant imported into the EU from countries where *Spodoptera frugiperda* occurs over the next 5 years

EUROSTAT data was extracted to determine the amount of imports and EU intracommunity trade for eggplant (CN 0709 6030) over the 7 year period 2010–2016. Because of the widespread occurrence of *S. frugiperda* in the Americas and in Africa, import data were grouped into five regions (Map 1).

Table H.1: EU imports of eggplant (CN 0709 6030) from Third countries and intra-EU trade 2010–1016 (Source EUROSTAT)

Source	2010	2011	2012	2013	2014	2015	2016	Mean
Intra-EU	1,693,603	1,706,386	1,844,193	1,884,293	2,016,872	2,113,577	2,152,724	1,693,603
Core America	11,973	14,638	14,194	17,517	17,410	14,216	11,629	14,511
Sub-Saharan Africa	18,561	15,805	18,355	16,373	19,150	27,071	27,517	20,405
North Africa	6,540	8,402	3,495	1,519	2,877	2,429	5,325	4,370
Middle East	2,146	1,753	1,073	1,506	1,156	1,414	2,988	1,719
Other	50,182	50,232	53,736	60,199	67,883	61,325	72,752	59,473
Sum Third Countries	89,402	90,830	90,853	97,114	108,476	106,455	120,211	100,477
Intra EU + TC	1,872,407	1,888,046	2,025,899	2,078,521	2,233,824	2,326,487	2,393,146	1,894,559

% of EU Third country imports of eggplants (CN 0709 30) from regions in relation to distribution of *S. frugiperda*
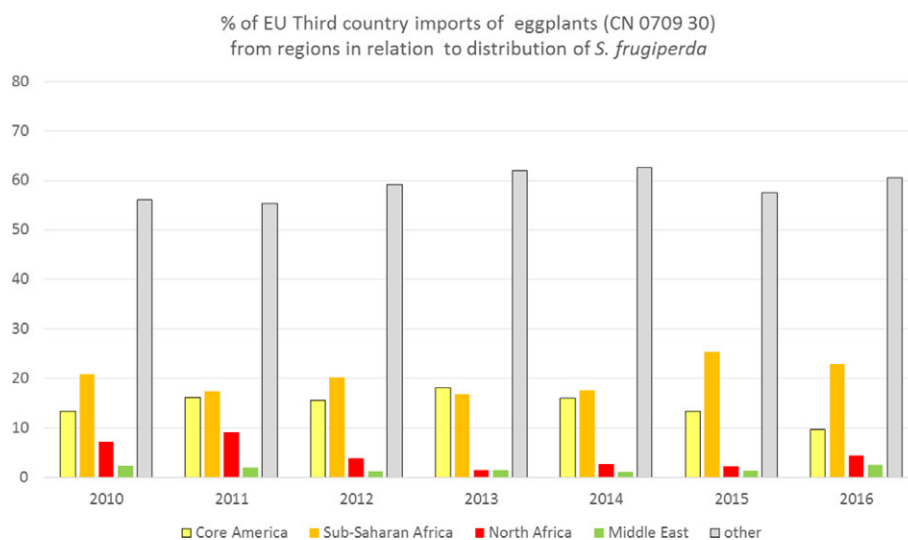
Table H.2: Eggplant annual imports from third country regions expressed as a %

	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Core America	13.4	16.1	15.6	18.0	16.0	13.4	9.7
Sub-Saharan Africa	20.8	17.4	20.2	16.9	17.7	25.4	22.9
North Africa	7.3	9.3	3.8	1.6	2.7	2.3	4.4
Middle East	2.4	1.9	1.2	1.6	1.1	1.3	2.5
other	56.1	55.3	59.1	62.0	62.6	57.6	60.5
Sum	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Other considerations to take into account:

– No extensive literature search was performed for this parameter.
– Only EUROSTAT data were collected and assessed.
– No trade body/industry information was obtained to verify EUROSTAT.
– The data indicates that imports and intra-EU trade have fluctuated over the past 7 years.
– The region from which the EU sources most eggplant fruit most often are Other regions, Sub-Saharan Africa and Core America.
– Import of eggplant in Europe is stable.
– For the global import of eggplant, the *S. frugiperda* affected areas represents approximately 1/3 of the total import.

Following discussion, it was agreed that past import data best informs likely future imports and a regression was performed to estimate mean annual future imports over the next 5 years, i.e. until the time horizon of the opinion.

Table H.3: Estimated range of mean eggplant imports into the EU from the region 'core Americas' and sub-Saharan Africa over the next 5 years (time horizon for assessment) based on regression of previous import (hundreds of kg)

Quantile (Percentile)	Lower (1%)	Q1 (25%)	Median (50%)	Q3 (75%)	Upper (99%)
Scenario **A0** (baseline)	41,698	49,686	53,405	57,485	68,936
Scenario **A1** (with measures)	41,698	49,686	53,405	57,485	68,936

No difference in imports was anticipated in a scenario A1.

H.2. Weight of a transfer unit (single individual eggplant fruit)

A standard conversion factor for an individual eggplant fruit (0.271 kg, EFSA unpublished data) was used to convert mass of imports into an estimate of the number of pieces of eggplant fruit. This standard conversion factor was used to estimate the number of transfer units imported on the pathway.

H.3. Proportion of export production fields infested; effectiveness of post-harvest sorting and post-harvest treatments

Factors to take into account:

1) *S. frugiperda* is native to the tropical regions of the western hemisphere from the United States to Brazil and Argentina (Sarmento et al., 2002; Ferreira et al., 2010).
2) Although Poaceae are preferred, *S. melongena* is a host of *S. frugiperda* and larvae can cause damage to the fruit consisting of 3–6 mm wide holes (Brust, 2013).
3) Larvae of *S. frugiperda* are cannibalistic. Barlow and Kuhar (2005) suggests larval density is reduced to one or two per plant; Chapman et al. (1999) suggests one to three fully grown larvae may remain on host plants. However, the authors were not referencing larvae on eggplants specifically.

4) The Dominican Republic is the major EU source of eggplant from core America. Between 2010 and 2016 from almost 70–92% of eggplants from core America were sourced from the Dominican Republic (EUROSTAT data). *S. frugiperda* occurs in the Dominican Republic (Nagoshi et al., 2017a,b).

Table H.4: EU imports of eggplant from Suriname, Dominican Republic and other countries in 'core America' 2010- 2016 (Hundreds of kg, Source: EUROSTAT)

	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Dom. Republic	8,326	11,201	12,234	16,124	15,492	12,172	9,277
Suriname	1,561	1,488	1,838	1,313	898	1,006	1,044
Others	2,086	1,949	122	80	1,020	1,038	1,308
Sum	11,973	14,638	14,194	17,517	17,410	14,216	11,629

Table H.5: % of EU imports of eggplant from Suriname, Dominican Republic and other countries in 'core America' 2010–2016

Dom. Republic	**69.5**	**76.5**	**86.2**	**92.0**	**89.0**	**85.6**	**79.8**
Suriname	13.0	10.2	12.9	7.5	5.2	7.1	9.0
Others	17.4	13.3	0.9	0.5	5.9	7.3	11.2
	100.0	100.0	100.0	100.0	100.0	100.0	100.0

5) In the Dominican Republic, *S. melongena* is grown outdoors and in glasshouses (Despradel, 2013).
6) Rapid (pre-)cooling of eggplant fruit to 10°C immediately after harvest is necessary to retard discolouration, weight loss, drying of calyx, and decay (CargoHandbook.com, 2012b).
7) *S. frugiperda* has been intercepted from the Dominican Republic in the EU before, but only on *Capsicum* (twice in 2013; three times in 2014, Europhyt data).
8) *S. frugiperda* has not been intercepted on *S. melongena* from Dominican Republic.
9) All interceptions of *S. frugiperda* on *S. melongena* or *S. macrocarpon* recorded in Europhyt originate from Suriname. Examining agricultural production in Suriname could explain why this is.
10) A marketing survey examining fruit and vegetable products in Suriname during 2008 and 2009 revealed that Suriname had relatively small scale fruit and vegetable production and a lack of cold storage and chilled transport facilities to maintain a cold supply chain to maintain product quality (Anon. 2013). Production was largely undertaken by small and part-time farmers using very labour-intensive and rudimentary methods. Customers, especially supermarket chains in Europe, generally require producers to be certified according to farm assurance systems such as GLOBALGAP (Global good agricultural practice, Henson et al., 2011) and HACCP, with exporters certified according to International Food Safety standards, British Retail Consortium standards or ISO 22000 (Filipović et al., 2008). Most of the Surinamese fruit and vegetable producers did not meet the requirements for such assurance systems. The need for greater farmer education, improved product packaging and handling and the creation of efficient cold store chains was identified (Fresh plaza 2012; Anon, 2013). Given a lack of GLOBAL GAP accreditation, *S. melongena* from Suriname are probably not destined EU supermarkets and distribution across the EU but rather more limited distribution to specific communities.
11) In contrast with Suriname, export facilities in the Dominican Republic are more developed. A FVO audit carried out in the Dominican Republic to evaluate the system of official controls for the export of plants and plant products to the EU (European Commission DG Sante, 2015) found that in response to EU interceptions of *Thrips palmi* on *S. melongena*, a national action plan (NAP) to reduce pests on exported *S. melongena* has been in place since 2014. The NAP applies to production sites, pack houses and points of exit (e.g. airport).
12) All exporting pack houses are required to be registered; registered pack houses must have post-harvest treatment facilities including initial pressure water washing and hot water treatment (50– 53° C, for four minutes, followed by cold water bath (4–11° C) for 4 minutes at least. The post-harvest treatment and pre-export inspections in pack houses

resulted in a significant decrease in the number of EU pest interceptions in 2015 (European Commission DG Sante, 2015).

13) Fresh eggplant for consumption is regulated in Annex IV, B of the Plant Health Directive 2000/29/EC. This means that imports are subject to a plant health inspection before being permitted to enter the EU

From sub-Saharan Africa

14) *S. frugiperda* is spreading and damaging several crops in sub-Saharan Africa.

15) *Solanum melongena* is a host of *S. frugiperda* and larvae can cause damage to the fruit consisting of 1/8 to 1/4 inch wide holes (Brust, 2013)

16) Larvae of *S. frugiperda* are cannibalistic. Barlow and Kuhar (2005) suggests larval density is reduced to one or two per plant; Chapman et al. (1999) suggests one to three fully grown larvae may remain on host plants. However, the authors were not referencing larvae on eggplants specifically.

17) The majority of eggplants from sub-Saharan Africa imported into the EU come from Kenya (approximately 60–75% of eggplants from sub-Saharan Africa 2010–2016). The next biggest exporter in recent years has been Uganda. Imports rose from less than 4% of sub-Saharan eggplants in 2010 to almost 20% in 2016. Imports from Burkino Faso have also risen. In contrast imports from Ghana have fallen (Europhyt data).

Table H.6: EU imports of eggplant from sub-Saharan Africa, 2010–2016 (hundreds of kg, Source: EUROSTAT)

Source	2010	2011	2012	2013	2014	2015	2016
Kenya	11,674	11,838	12,974	12,067	12,757	17,067	16,577
Uganda	707	661	991	2,171	3,280	4,325	5,336
Ghana	4,936	2,050	229	180	274	437	64
Burkina Faso	254	234	597	554	1,318	2,997	2,130
others	990	1,022	3,564	1,401	1,521	2,245	3,410
Sum	18,561	15,805	18,355	16,373	19,150	27,071	27,517

18) In Kenya, eggplant production is conducted throughout the year and the bulk of the crop is exported. Eggplant has a cropping period of 4–7 months. In Kenya they are normally planted from beginning of June to end of December to correspond with the export season from October to May (Infonet biovision, 2018). Eggplant is mainly grown outdoors but some is grown under glass.

Table H.7: % of EU imports of eggplant from sub-Saharan Africa, 2010–2016 (Source: EUROSTAT)

Source	2010	2011	2012	2013	2014	2015	2016
Kenya	62.9	74.9	70.7	73.7	66.6	63.0	60.2
Uganda	3.8	4.2	5.4	13.3	17.1	16.0	19.4
Ghana	26.6	13.0	1.2	1.1	1.4	1.6	0.2
Burkina Faso	1.4	1.5	3.3	3.4	6.9	11.1	7.7
others	5.3	6.5	19.4	8.6	7.9	8.3	12.4
Sum	100.0	100.0	100.0	100.0	100.0	100.0	100.0

19) Fresh eggplant for consumption is regulated in Annex IV, B of the Plant Health Directive 2000/29/EC (European Commission, 2002). This means that imports are subject to a plant health inspection before being permitted to enter the community.

20) Between 2004 and 2015, there were 57 interceptions of pests on eggplant from sub-Saharan Africa (Tables below). Some were EU listed quarantine pests.

Table H.8: Pests recorded on Europhyt interceptions on *S. melongena* from sub-Saharan Africa 2004–2015

Pests	Kenya	Uganda	Burkina Faso	Sum
Lepidoptera, e.g. *Helicoveroa armigera, Diaphania indica, Leucinodes orbonalis*	8	22[a]		30
Thysanoptera, e.g. *Thrips palmi, Scirtothrips dorsalis*	11		5	16
Diptera/Tephritidae, e.g. non-European	5	2		7
Tetranychus	3			3
Bemisia tabaci	1			1
Sum	28	24	5	57

(a): All Lepidoptera from Uganda were *Leucinodes orbonalis*.

21) Lepidoptera were last intercepted on eggplant from Kenya in 2009 (*Diaphania indica*). Prior to this *Helicoverpa armigera* were intercepted in 2008 and 2006 (Europhyt data).

22) During 2014, 2015 and 2016, UK, NL, FR and BE collectively imported between 83% and 95% of all EU 28 imports of *S. melongena* from Kenya (EUROSTAT). The number of consignments imported and the number inspected are shown below. Note that consignment and inspection data does not come from all EU MS.

Table H.9: Consignments of *S. melongena* from Kenya 2014–2016; consignments inspected and number of consignments contaminated with quarantine pests

Source	Year	Number of consignments	Number inspected	Number of interceptions of listed pests	% inspected	Propn of inspected which contaminated	expected total consignments contaminated
Kenya	2014	4,334	1,673	0	38.6	0.0000	0
Kenya	2015	3,800	683	2[a]	18.0	0.0029	11
Kenya	2016	3,325	404	0	12.2	0.0000	0

(a): the quarantine pests found on *S. melongena* from Kenya in 2015 were *Scirtothrips dorsalis* and *Bemisia tabaci* (non-European).

1) As a regulated commodity, all consignments of *S. melongena* imported into the EU are subject to inspection. However, a reduced frequency of checks can be applied where justified. Justification is based on criteria for assessing eligibility for reduced checks. The criteria are that (i) an average of 200 or more consignments have been imported into the EU each year over the last 3 years, (ii) a minimum of 600 inspections have been carried out during the last 3 years, and (iii) less than 1% of consignments imported were found to be infested.

2) *S. melongena* from Kenya have been subject to a reduced inspection level of 10% given good compliance in recent years (European Commission, 2018a,b).

Figure: Europhyt notifications of pests from Kenya on eggplant
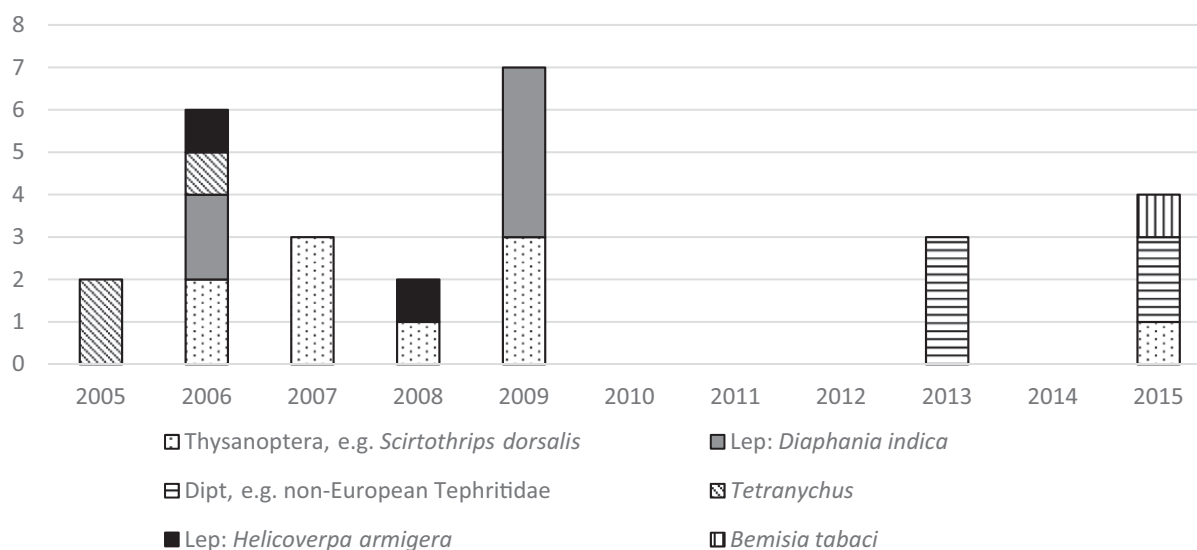
Note: The two 2015 findings of Diptera were not identified to species or family so could not be confirmed as non-European Tephritidae.

25) Horticulture for export is well supported by Kenyan government. For example, the Government established a Pest Control Products Board which licenses and registers pest control products imported and used in Kenya; Government and industry stakeholders train farmers on the safe use of pesticides. A National Code of Practice has been established partly to address phytosanitary issues and the post-harvest handling process. The Fresh Produce Exporters Association promote specific Codes of Practice for their members (Export Promotion Council, 2018).

26) Supermarket chains in Europe generally require producers to be certified according to farm assurance systems such as GLOBALGAP (Global good agricultural practice, Henson et al., 2011) and HACCP, with exporters certified according to International Food Safety standards, British Retail Consortium standards or ISO 22000 (Filipović et al., 2008).

Other factors discussed and input from external experts:

27) Cropping practices for exports are more haphazard in core Americas than sub-Saharan Africa. *S. frugiperda* is currently a high profile pest in Africa, this is not the case in Core America

28) There is scope to improve crop husbandry practices, e.g. grow under netting, improved scouting for pest Lepidoptera such as *S. frugiperda*, better targeting of pesticides. This could improve conditions for the worst affected producers hence we applied a reduction in the range at 99th percentile for Scenario A1.

29) There are no further treatments for eggplants. Eggplants are stored at 7 to 13°C, this is assumed not to cause mortality to *S. frugiperda* infesting the fruit.

Estimation: Taking the above information into account, the following estimates were made:

- Mean percentage of infested product in export production fields in the area of origin over the next 5 years;
- Mean percentage of infested material removed by post-harvest sorting;
- Mean percentage of infested material removed by post-harvest treatments.

Eggplant pathway	Scenario	Percentile[a]				
		1	**25**	**50**	**75**	**99**
1. Infestation at origin: Average percentage of infested product in export production fields in the area of origin	A0	0.005	0.05	0.15	0.5	5.0
	A1	0.005	0.05	0.15	0.5	2.0
2. Effectiveness of post-harvest sorting Average percentage of infested material removed	A0	15	30	40	55	80
	A1	15	30	40	55	80
3. Effectiveness of post-harvest treatments (includes storage and shipping)	A0	0	0	0	0	0
	A1	0	0	0	0	0

(a): Judgement was used to estimate five quantiles of the reduction factor expressing effectiveness.

Infested eggplants arriving at the EU border are assumed to remain infested unless detected during import inspections.

H.4. Proportion of eggplant fruit detected at EU border

For scenario A1 (with phytosanitary measures in place)

In a scenario where phytosanitary measures are in place against *S. frugiperda*, additional factors need to be taken into account when estimating the mean annual proportion of transfer units infested with *S. frugiperda* on eggplant exports.

A range of phytosanitary measures are available to lower the likelihood that *S. frugiperda* enters the EU on hosts traded internationally. For example, hosts, such as eggplants could in principle be sourced from a pest free area, or pest free place of production, or prior to their export have been officially inspected and found free from *S. frugiperda* or subjected to treatment to ensure freedom from the pest.

In order to guarantee pest freedom within a crop, place of production, place of production and buffer zone, or area, it is necessary to fulfil the requirements outlined in ISPM No. 4 (FAO, 2017) and ISPM No. 10 (FAO, 2016). This would be very challenging for a pest such as *S. frugiperda* that is highly mobile and highly polyphagous. Ultimately eggplant fruit would need to be inspected prior to export and found free of *S. frugiperda* so that a phytosanitary certificate could be issued. The question to consider then is how likely is an infested eggplant to escape detection taking into account additional crop protection practices, processing measures and quality control efforts.

EXPORT INSPECTIONS

FAs well as the factors considered in scenario A0, the following factors are also taken into account:

1) There is no survey information measuring the performance of export inspections.
2) ISPM 31 provides guidance for minimum sample sizes that provides either 95% or 99% confidence according to lot size and level of detection.
3) It is unknown how many inspections follow ISPM 31.
4) A FVO audit carried out in the Dominican Republic to evaluate the system of official controls for the export of plants and plant products to the EU (European Commission DG Sante, 2015) found that post-harvest treatment and pre-export inspections in pack houses resulted in a significant decrease in the number of EU pest interceptions in 2015 (European Commission DG Sante, 2015).
5) During an audit carried to evaluate the system of official controls for the export of plants and plant products to the EU in Ghana by DG Sante, EU officials found that sampling for export inspections was inconsistent and in some cases inadequate, and that there was not always enough time available to carry out effective inspections (European Commission DG Sante, 2016).
6) During a similar audit in Kenya in 2013, EU officials found a significant weakness in the system of official export checks, with insufficient time available for effective inspections although the risk arising from this was mitigated by the biosecurity and pest prevention measures applied by producers (European Commission DG Sante, 2013).

7) *S. melongena* fruit are stored at 10–12°C with 90–95% RH. Fruit are sensitive to chilling below 10°C. At 5°C, chilling injury will occur in 6–8 days. Storage of eggplant is generally less than 14 days as quality rapidly deteriorates (CargoHandbook.com, 2012b).

IMPORT INSPECTIONS

8) Exports arriving in EU are assumed to generally be transported by air to reduce storage time and maintain quality.

9) Many countries that keep records of pest interceptions do not register the total number of inspections, which makes a precise assessment of the proportion of infested shipments impossible (Eschen et al., 2015). The USA quarantine agency has sufficient resources to inspect 2% of incoming shipments (National Research Council, 2002) whilst in New Zealand no more than 18% of shipping containers can be inspected (Everett, 2000).

10) Infested eggplants departing core America or sub-Saharan Africa are assumed to remain infested as they arrive in the EU. As a regulated commodity *S. melongena* should already be inspected on arrival in the EU.

11) In a scenario where additional measures were put in place and *S. melongena* were to be inspected for *S. frugiperda*, the reduced inspection regime may be lifted (removed) and all consignments would be subject to official inspection on arrival in the EU.

12) There is little published evidence reporting the efficiency of effectiveness of plant health import inspections.

13) An EU inspectorate with DG Sante (previously known as the Food and Veterinary Office (FVO)), assists the European Commission in the application of phytosanitary regulations and audits the plant inspection systems in each Member State. Their study tours revealed differences and shortcomings in the inspection practices in audited countries (e.g. FVO 2011a,b, 2012a,b), such as a lack of guidelines for visual inspections, different levels of inspection of the same commodities depending on the points of entry, non-random sampling (e.g. examining just the easily accessible boxes).

14) Analysing data relating to plants for planting, Liebhold et al. (2012) estimated about 72% of infested plant shipments passed through US ports undetected**.**

15) ISPM 31 provides guidance for minimum sample sizes that provides either 95% or 99% confidence according to lot size and level of detection

16) It is unknown how many inspections follow ISPM 31

17) The analysis by Liebhold et al. (2012) considered plants infested by any pest taxa, including pathogens. Detecting relatively large *S. frugiperda* larvae could be easier so the 28% success rate estimated by Liebhold et al. (2012) could be higher.

18) Work et al. (2005) estimated that inspectors detected 19–28% of pests in non-refrigerated maritime cargo and 30–50% of pests in cargo crossing the US–Mexico border.

Other factors discussed and input from external experts:

1) Estimation: Taking the above information into account, the Panel estimated the mean annual proportion of infested transfer units detected at the EU border.

2) Table x: Estimated range of mean annual proportion of infested transfer units detected during phytosanitary inspections at the EU border over the next 5 years (time horizon for assessment)

Estimation: Taking the above information into account, the following estimates were made:

- Estimated range of mean annual proportion of infested eggplant fruit (transfer units) detected during phytosanitary inspections from core America or sub-Saharan Africa at the EU border over the next 5 years (time horizon for assessment)

Eggplant pathway	Scenario	Percentile[a]				
		1	25	50	75	99
Effectiveness of import inspections Percentage infested material removed at import	A0	1	6	10	15	25
	A1	1	6	10	15	25

(a): Expert judgement was used to estimate five quantiles of the reduction factor expressing effectiveness.

H.5. Proportion of infested units rejected during post entry handling or processing

Most of the eggplants arrive loose in cardboard boxes ready for the markets (as for peppers). Hence there would be no further processing, simply some storage and transport for wholesale or retail.

- Estimated range of mean annual proportion of infested eggplants rejected during postharvest handling or processing over the next 5 years (time horizon for assessment)

Eggplant pathway	Scenario	Percentile[a]				
		1	25	50	75	99
Effectiveness of post-entry handling/processing Percentage infested material removed after import	A0	0	0	0	0	0
	A1	0	0	0	0	0

(a): Expert judgement was used to estimate five quantiles of the reduction factor expressing effectiveness.

Appendix I − Evidence dossier: Trade pathway − rose cut flowers (*Rosa* sp.)

I.1. Mean trade volume of *Rosa* cut flowers into the EU from countries where *Spodoptera frugiperda* occurs over the next 5 years

EUROSTAT data was extracted to determine the amount of imports and EU intracommunity trade for rose cut flowers over the most recent 7 years (2010−2016) (CN 0603 11). Because of the widespread occurrence of *S. frugiperda* in the Americas and in Africa, import data were grouped into five regions (Figure 1).

Table I.1: EU imports of rose cut flowers (CN 0603 11) from Third countries and intra-EU trade 2010-1016 (Source EUROSTAT) (Hundreds of kg)

	2010	2011	2012	2013	2014	2015	2016	mean
Intra-EU	1,210,251	1,213,653	1,387,407	1,455,738	1,470,640	1,930,906	1,977,894	1,520,927
Core America	205,964	212,071	211,936	200,404	216,020	217,548	226,859	212,972
Sub-Saharan Africa	1,175,722	1,256,129	1,229,309	1,910,560	2,010,784	2,394,573	2,412,557	1,769,948
North Africa	141	75	55	57	39	1	35	58
Middle East	321	138	23	12	10	15	10	76
Other	8,327	4,994	4,565	5,680	7,800	9,400	11,950	7,531
Sum Third C	1,390,475	1,473,407	1,445,888	2,116,713	2,234,653	2,621,537	2,651,411	1,990,583
Intra-EU + TC	2,600,726	2,687,060	2,833,295	3,572,451	3,705,293	4,552,443	4,629,305	3,511,510

Table I.2: Rose cut flowers annual imports from third country regions expressed as a %

	2010	2011	2012	2013	2014	2015	2016	Mean
Core America	14.81	14.39	14.66	9.47	9.67	8.30	8.56	11.4
Sub-Saharan Africa	84.56	85.25	85.02	90.26	89.98	91.34	90.99	88.2
North Africa	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.0
Middle East	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.0
Other	0.60	0.34	0.32	0.27	0.35	0.36	0.45	0.4
Sum	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Other considerations to take into account:

1) No extensive literature search was performed for this parameter.
2) Only EUROSTAT data were collected and assessed.
3) No trade body/industry information was obtained to verify EUROSTAT.
4) The data indicates that imports and intra-EU trade have fluctuated over the past 7 years.
5) The region from which the EU sources most fresh cut roses is sub-Saharan Africa.
6) The majority of rose cut flowers from sub-Saharan Africa comes from Kenya (60%) and Ethiopia (30%). Uganda, Zambia and Zimbabwe are the other main exporters (Europhyt data).
7) Well-organised NPPOs in Africa supporting significant exports to the EU may be able to cope with *S. frugiperda*. Conversely, weaker NPPOs, or those with smaller exports where the export horticulture sector is less developed could find it problematic (Abrahams et al., 2017).
8) For scenario A1, phytosanitary measures will add costs and may reduce volume of trade.
9) Additional measures are not anticipated to significantly alter the amount of exports to EU over the next 5 years.

Following discussion, it was agreed that past import data best informs likely future imports and a regression was performed to estimate mean annual future imports over the next 5 years, i.e. until the time horizon of the opinion.

Table: Estimated range of mean rose cut flower imports into the EU from the region 'core Americas' and sub-Saharan Africa over the next 5 years (time horizon for assessment) based on regression of previous import (hundreds of kg)

Quantile (Percentile)	Lower (1%)	Q1 (25%)	Median (50%)	Q3 (75%)	Upper (99%)
Scenario **A0** (baseline)	3,373,522	3,796,871	3,989,603	4,198,252	4,755,635
Scenario **A1** (with measures)	3,373,522	3,796,871	3,989,603	4,198,252	4,755,635

No difference in imports was anticipated in a scenario A1.

I.2. Weight of a transfer unit (single individual cut rose stem)

A standard conversion factor for an individual stem of a rose (0.051 kg, EFSA unpublished data) was used to convert mass of imports into an estimate of the number of transfer units (individual stems) imported on the pathway.

I.3. Proportion of export production fields infested; effectiveness of post-harvest sorting and post-harvest treatments

1) Roses are perennial so may be exposed to pests at all times of the year. However, in the major African producing countries roses are grown in protected plastic houses. There are approximately 3,000 ha of plastic houses in Kenya, 1,000 ha in Ethiopia and less than 100 ha in each of Tanzania and Uganda (H. Wainwright, RealIPM, Kenya, pers comm.)

2) In Kenya, the floriculture industry comprises of large-, medium- and small-scale producers who have attained high management standards and have invested heavily in value addition through adoption of modern technology in production, precision farming and marketing (Anon., 2017a). Farmers use drip irrigation, fertigation systems, greenhouse ventilation systems, net shading, pre-cooling, cold storage facilities, grading, bouqueting, fertiliser recycling systems to prevent wastage, wetlands for waste water treatment, artificial lighting to increase day length, grading/packaging sheds, and refrigerated trucks for distribution (Anon., 2018).

3) Half of Kenya's 127 flower farms are concentrated around Lake Naivasha, 90 km northwest of Nairobi. Searching on Google maps around Lake Naivasha, Kenya, one can identify greenhouses and horticultural sites of production. No signs of arable crops (e.g. maize fields) can be identified in the surrounding area.

Figure I.1: Horticultural production on the shore of Lake Naivasha, Kenya (Source: Googlemaps https://www.google.co.uk/maps/@-0.9080218,36.3501326,10867a,35y,37.82t/data=!3m1!1e3)

1) Roses are harvested at different levels of maturity, depending on marketing and cultivar. For long-distance transport or storage, roses are harvested with some of the sepals reflexed (CargoHandbook.com, 2013). Flowers are harvested by hand, providing an opportunity for pickers to spot pest infestations.

2) A short video showing production of cut roses in Kenya is available at https://www.youtube.com/watch?v=JsKnp8b66l8

3) Rose bunches are routinely sleeved in plastic, waxed paper, or soft corrugated card sleeves. When sold direct, e.g. to supermarkets, roses can be packed in sleeves labelled or made into bouquets at source, prior to export (http://www.kenyarep-jp.com/business/industry/f_index_e.html)

4) Kenya is the leading exporter of rose cut flowers to the European Union. Approximately 50% of roses are sold directly to retailers and 50% via Dutch auctions (Anon, 2018).

5) *S. frugiperda* occurs year round in sub-Saharan Africa with overlapping generations.

6) *S. frugiperda* is a minor pest of *Rosa* (CABI, 2018a). Nevertheless, *S. frugiperda* larvae have been found on rose cut flowers during import inspections (e.g. Zambia, 2018).

7) Within a crop, *S. frugiperda* will be clumped (not evenly distributed) within a field/glasshouse.

8) In high value export crops, additional pest management measures (more chemical sprays) will be applied to ensure quality control, and maintain market access.

9) Rose cut flowers are regulated within 2000/29 EC as plants which must be subject to a plant health inspection in the country of origin or the consignor country, if originating outside the community, before being permitted to enter the community (2000/29 EC, Annex V, B 2). Rose cut flowers imported into the EU must originate in a country free from non-European *Bemisia tabaci* (Annex IV A 1, 45.2). Phytosanitary inspections prior to export may prevent some infested consignments being shipped.

10) A short video illustrating export inspection of rose cut flowers in Tanzania is available at https://www.youtube.com/watch?v=qNRAeRyzaxg

11) Despite the required pre-export inspections, Noctuid quarantine pests have previously been intercepted on roses entering the EU from Africa (see table below; Source Europhyt, extracted 10 April 2018).

12) During an audit carried to evaluate the system of official controls for the export of plants and plant products to the EU from Kenya in 2013, EU officials found a significant weakness in the system of official export checks, with insufficient time available for effective inspections although the risk arising from this was mitigated by the biosecurity and pest prevention measures applied by producers (European Commission DG Sante, 2013a,b).

13) Quarantine Lepidoptera in the same family as *S. frugiperda* have been the most commonly recorded harmful organisms on cut roses from sub-Saharan Africa. Lepidoptera are found as larvae.

Table I.3: Europhyt interceptions of harmful organisms on rose cut flowers from sub-Saharan countries 2000-2017

	Zimbabwe	Kenya	Ethiopia	Zambia	Burundi	Malawi	Sum	% of sum
Spodoptera littoralis	436	43	9	31	4	4	527	53.0
Helicoverpa armigera	217	118	57	32	6	4	429	43.1
Helicoverpa sp.	2	1		2			5	0.5
Spodoptera frugiperda				2			2	0.2
Spodoptera sp.	1				1		2	0.2
Bemisia tabaci	5	2					7	0.7
Tetranychus	4						4	0.4
Thysanoptera	2	3					5	0.5
Bemisia sp.		3					3	0.3

	Zimbabwe	Kenya	Ethiopia	Zambia	Burundi	Malawi	Sum	% of sum
Liriomyza huidobrensis	2						2	0.2
Liriomyza trifolii			2				2	0.2
Acari		2					2	0.2
Sum	669	172	68	67	11	8	995	100.0
All Lepidoptera	656	162	66	67	11	8	970	97.0
As % Of All Lepidoptera	68.0	16.8	6.8	6.9	1.1	0.8	100.0	

The chart below shows the number of quarantine Lepidoptera intercepted on cut roses from sub-Saharan countries 2003–2017. Since the peak in 2008, there has been a decline in interceptions.
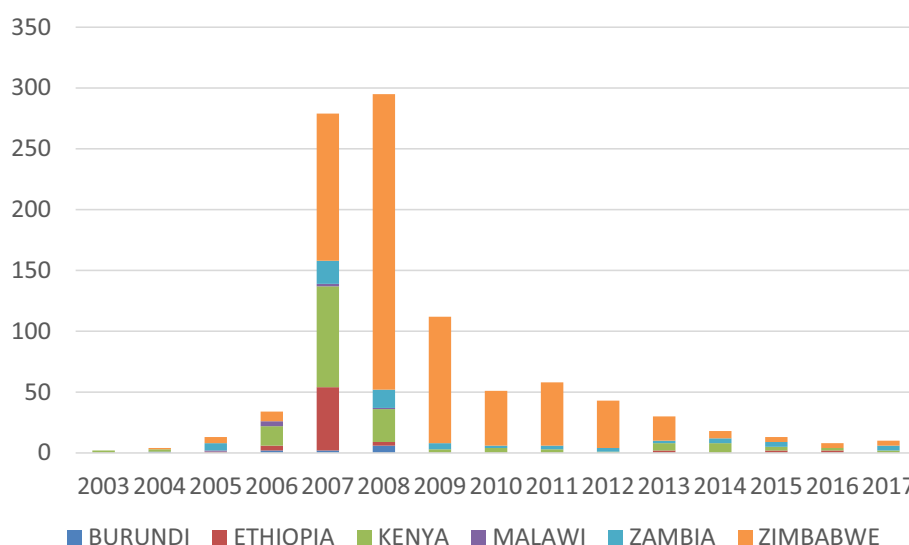

Figure I.2: Numbers of quarantine Lepidoptera intercepted in the EU on roses from six African nations 2003–2017 (Source: Europhyt)

1) As noted above, rose cut flowers are already regulated by the EU and such material must be inspected on arrival in the EU. However, a reduced frequency of checks can be applied where justified. Justification is based on criteria for assessing eligibility for reduced checks. The criteria are that (i) an average of 200 or more consignments have been imported into the EU each year over the last 3 years, (ii) a minimum of 600 inspections have been carried out during the last 3 years, and (iii) less than 1% of consignments imported were found to be infested.

2) Since January 2011, cut roses from Kenya have been subject to a reduced inspection level of 5% given good compliance in recent years. Cut roses from Ethiopia have been subject to 5% inspection since January 2016. Cut roses from Zambia have been subject to 10% inspection since January 2017 whilst cut roses from Tanzania have been subject to 15% level of inspection since January 2014 (European Commission, 2018a,b).

3) Of 73,362 consignments of rose cut flowers that entered the EU in 2014, 9,540 were inspected of which 3 resulted in pest interceptions. In 2015 of 74,605 consignments 10,404 were inspected with 1 pest interception. In 2016 of 75,219 consignments, 11,618 were inspected with 1 interception. (Data from BE, CY, DE, FR, NL, SE and UK). Table I.4 below shows this data and the equivalent data for Ethiopia, Tanzania and Zambia. Note that consignment and inspection data does not come from all EU MS. Nevertheless, the data from these 7 EU MS represents > 99% of all rose cut flowers entering the EU28 from Kenya, Ethiopia, Tanzania and Zambia during 2014, 2015 and 2016 (EUROSTAT data)

Table I.4:   Imports of rose cut flowers (CN 060311) into specific EU MS and all EU MS

Source	Year	Total imports to BE, CY, DE, FR, SE, NL, UK (hundreds kg)	Total EU 28 imports (hundreds kg)	BE, CY, DE, FR, SE, NL, UK as % of EU 28
Kenya	2014	1,248,434	1,250,186	99.9
Kenya	2015	1,305,183	1,307,231	99.8
Kenya	2016	1,344,148	1,346,577	99.8
Ethiopia	2014	486,910	487,541	99.9
Ethiopia	2015	849,045	850,129	99.9
Ethiopia	2016	834,387	835,420	99.9
Tanzania	2014	25,024	25,024	100.0
Tanzania	2015	15,569	15,569	100.0
Tanzania	2016	14,108	14,108	100.0
Zambia	2014	73,575	73,580	100.0
Zambia	2015	66,801	66,801	100.0
Zambia	2016	59,323	59,323	100.0

Table I.5:   Consignments of cut roses from sub-Saharan Africa 2014–2016; consignments inspected and number of consignments contaminated with quarantine pests

Source	Year	Number of consignments	Number inspected	Number of interceptions of listed pests	% inspected	Propn of inspected which contaminated	expected total consignments contaminated
Kenya	2014	73,362	9,540	3	13.0	0.0003	23
Kenya	2015	74,605	10,404	1	13.9	0.0001	7
Kenya	2016	75,219	11,618	1	15.4	0.0001	6
Ethiopia	2014	12,594	3,218	0	25.6	0.0000	-
Ethiopia	2015	9,915	2,050	1	20.7	0.0005	5
Ethiopia	2016	8,935	1,608	0	18.0	0.0000	-
Tanzania	2014	2,301	394	3	17.1	0.0076	18
Tanzania	2015	2,751	483	4	17.6	0.0083	23
Tanzania	2016	2,967	561	3	18.9	0.0053	16
Zambia	2014	2,192	1,007	2	45.9	0.0020	4
Zambia	2015	2,475	1,191	2	48.1	0.0017	4
Zambia	2016	2,352	1,265	0	53.8	0.0000	-

4) Plotting the number of Lepidoptera interceptions against the amount of rose cut flower imports indicates that for Kenya and Ethiopia (the biggest exporters) the highest number of interceptions occurred the year when exports were lowest.
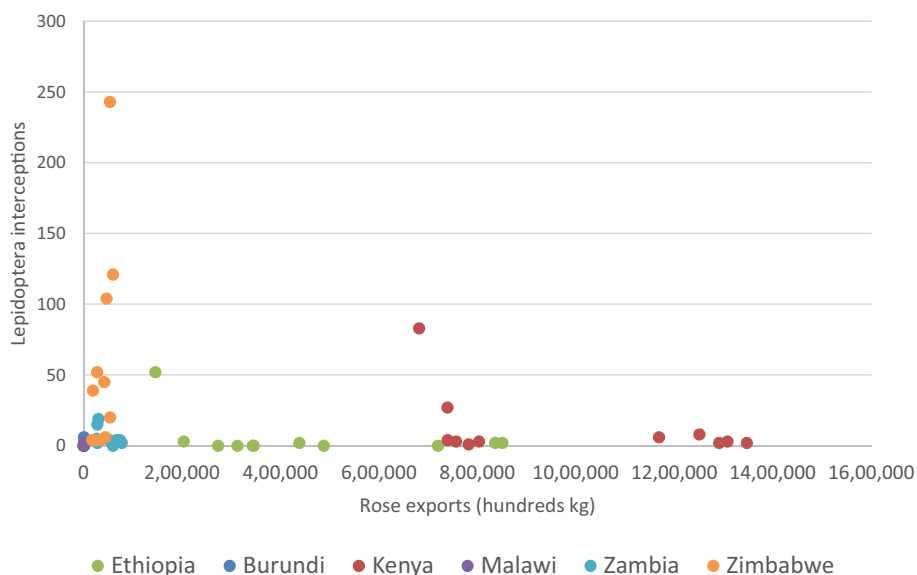
Figure I.3: Lepidoptera interceptions vs amount of cut rose imports

Other factors discussed and input from external experts:

For scenario A1 (with phytosanitary measures in place)

In a scenario where phytosanitary measures are in place against *S. frugiperda*, additional factors need to be taken into account when estimating the mean annual proportion of transfer units infested with *S. frugiperda* on rose cut flower exports.

A range of phytosanitary measures are available to lower the likelihood that *S. frugiperda* enters the EU on hosts traded internationally. For example, hosts, such as roses could be sourced from a pest free area, or pest free place of production, or prior to their export have been officially inspected and found free from *S. frugiperda* or subjected to treatment to ensure freedom from the pest.

In order to guarantee pest freedom within a crop, place of production, place of production and buffer zone, or area, it is necessary to fulfil the requirements outlined in ISPM No. 4 (FAO, 2017) and ISPM No. 10 (FAO, 2016). This would be very challenging for a pest such as *S. frugiperda* that is highly mobile and highly polyphagous. Ultimately, cut roses would need to be inspected prior to export and found free of *S. frugiperda* so that a phytosanitary certificate could be issued. The question to consider then is how likely is an infested rose to escape detection taking into account existing crop protection practices, processing measures and quality control efforts.

Factors to take into account:

7) There is no survey information measuring the performance of export inspections.
8) ISPM 31 provides guidance for minimum sample sizes that provides either 95% or 99% confidence according to lot size and level of detection.
9) It is unknown how many inspections follow ISPM 31.
10) During an audit carried to evaluate the system of official controls for the export of plants and plant products to the EU from Kenya in 2013, EU officials found a significant weakness in the system of official export checks, with insufficient time available for effective inspections although the risk arising from this was mitigated by the biosecurity and pest prevention measures applied by producers (European Commission DG Sante, 2013).
11) The number of quarantine Lepidoptera found on rose cut flowers from major exporting countries such as Kenya, Ethiopia and Zimbabwe have declined since a peak in 2008.
12) Since January 2011 cut roses from Kenya have been subject to a reduced inspection level of 5% given good compliance in recent years. Cut roses from Ethiopia have been subject to 5% inspection since January 2016. Cut roses from Zambia have been subject to 10% inspection since January 2017 while cut roses from Tanzania have been subject to 15% level of inspection since January 2014 (European Commission, 2018a,b).

Estimation: Taking the above information into account, the following estimates were made:

- Mean percentage of infested product in export production fields in the area of origin over the next 5 years;
- Mean percentage of infested material removed by post-harvest sorting;
- Mean percentage of infested material removed by post-harvest treatments.

Cut roses pathway	Scenario	Percentile[a]				
		1	**25**	**50**	**75**	**99**
1. Infestation at origin: Average percentage of infested product in export production fields in the area of origin	A0	0.0001	0.0005	0.001	0.002	0.01
	A1	0.0001	0.0005	0.001	0.002	0.01
2. Effectiveness of post-harvest sorting Average percentage of infested material removed.	A0	70	85	90	91.5	95
	A1	75	85	90	91.5	95
3. Effectiveness of post-harvest treatments (includes storage and shipping)	A0	75	88	95	98	99
	A1	75	88	95	98	99

(a): Expert judgement was used to estimate five quantiles of the infestation at origin and the reduction factor expressing effectiveness.

I.4. Proportion of infested units detected at EU border

1) Exports of roses from sub-Saharan Africa occur year round. Exports are highest during the spring. Cut roses are transported as air freight or by sea.
2) To preserve quality and vase life, cut roses should be transported at between 0.5 and 1.0°C (Harkema et al., 2017).
3) There are daily flights into the EU that carry rose cut flowers. Roses transported in refrigerated (reefer) shipping containers from Africa take 2–5 weeks to reach the EU (Harkema et al., 2017).
4) A typical supply chain could appear thus: roses are harvested, sorted, packed at the grower, transported to a consolidation centre, inspected prior to export, placed in a refrigerated (reefer) container, transported to the harbour, shipped to the EU, inspected on arrival in EU and transported to an auction/distribution centre and further transported to the shop targeted for the supermarket (based on Harkema et al., 2017).
5) Cut roses marketed at Dutch auctions must meet general quality standards applicable to all cut flowers and specific requirements for cut roses (CBI Market Intelligence, 2016).
6) As a regulated commodity, rose cut flowers are inspected on entry. Since January 2011, cut roses from Kenya have been subject to a reduced inspection level of 5% given good compliance in recent years. Cut roses from Ethiopia have been subject to 5% inspection since January 2016. Cut roses from Zambia have been subject to 10% inspection since January 2017 whilst cut roses from Tanzania have been subject to 15% level of inspection since January 2014 (European Commission, 2018a,b). Given that rose cut flowers provide a pathway into the EU, the reduced check regime may be revised and a higher proportion of rose consignments may be inspected in future. The following factors should be taken into account:
7) There is little published evidence reporting the efficiency of effectiveness of plant health import inspections.
8) ISPM 31 provides guidance for minimum sample sizes that provides either 95% or 99% confidence according to lot size and level of detection.
9) It is unknown how many inspections follow ISPM 31 (FAO, 2008),
10) Analysing data relating to plants for planting, Liebhold et al. (2012) estimated about 72% of infested plant shipments passed through US ports undetected.

11) The analysis by Liebhold et al. (2012) considered plants infested by any pest taxa, including pathogens. Detecting relatively large *S. frugiperda* larvae could be easier so the 28% success rate estimated by Liebhold et al. (2012) could be higher.

12) Work et al. (2005) estimated that inspectors detected 19–28% of pests in non-refrigerated maritime cargo and 30–50% of pests in cargo crossing the US–Mexico border.

13) A short video showing US border inspections of cut roses is available at https://www.youtube.com/watch?v=nJ8tF0_PpLE
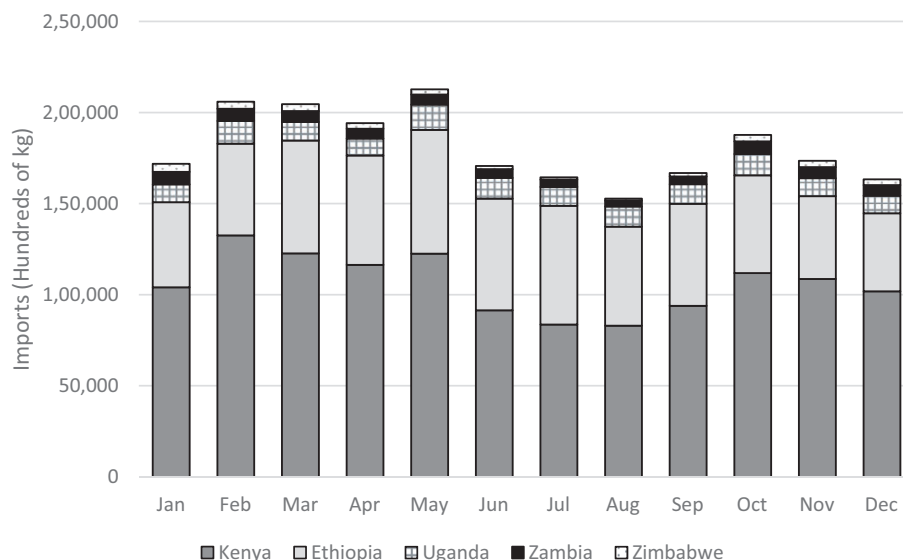

Figure I.4: Mean monthly EU imports (2013–2017) of rose cut flowers (CN 0603 11) from five main supply countries in sub-Saharan Africa (hundreds of kg)

Other factors discussed and input from external experts:

- Infestation is so low that it is not going to make a difference.
- Nevertheless interception may still occur.

Estimation: Taking the above information into account, the following estimates were made:

- Estimated range of mean annual proportion of infested rose cut flowers (transfer units) detected during phytosanitary inspections from core America or sub-Saharan Africa at the EU border over the next 5 years (time horizon for assessment)

Rose cut flowers pathway	Scenario	Percentile[a]				
		1	25	50	75	99
Effectiveness of import inspections Percentage infested material removed at import	A0	0	0	0	0	0
	A1	0	0	0	0	0

(a): Expert judgement was used to estimate five quantiles of the reduction factor expressing effectiveness.

Roses from core America

The vast majority of cut roses from core America come from Columbia and Ecuador

Table: Imports of rose cut flowers from countries in 'core America' (Hundreds of kg, EUROSTAT)

	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Ecuador	158,633	166,924	167,415	160,399	173,162	176,074	184,179
Colombia	46,390	44,294	44,245	38,818	42,809	41,426	42,614
Costa Rica	117	608	215	1090	0	1	0
Brazil	794	207	56	38	38	32	27
Peru	0	11	0	49	6	0	13
Guatemala	3	8	0	9	0	14	0
St Kitts and Nevis	26	0	0	0	0	0	0
Mexico	1	0	0	1	1	0	19
Dominican Republic	0	17	0	0	0	0	0
Suriname	0	1	1	0	4	1	6
Panama	0	1	3	0	0	0	0
Bolivia	0	0	0	0	0	0	1
El Salvador	0	0	1	0	0	0	0
Trinidad and Tobago	0	0	0	0	0	0	0
Uruguay	0	0	0	0	0	0	0
Sum core America	205,964	212,071	211,936	200,404	216,020	217,548	226,859
Table x.x: Imports from Equador, as a percentage							
Ecuador	77.0	78.7	79.0	80.0	80.2	80.9	81.2
Colombia	22.5	20.9	20.9	19.4	19.8	19.0	18.8
others	0.5	0.4	0.1	0.5	0.0	0.0	0.0
sum	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Colombia

1) Colombia grows 8,000 ha of flowers. Around 7,000 ha are cultivated under greenhouse conditions while 1,000 hectares are produced outdoors, under rain fed conditions (USDA Foreign Agricultural Service 2015).
2) The Colombian Association of Flowers Exporters representing 75% of Colombia's flower production, has invested in technology to improve and maintain quality (Bueno, 2005).
3) *S. frugiperda* is not regarded as a pest in protected cut flower production. Europhyt has no records of interceptions of *S. frugiperda* or any other pests on roses from Columbia.

Ecuador

4) Most of Ecuador's rose plantations are found in the province of Pichincha in the Andes at an altitude of between 2,800 and 3,000 metres (Conefrey, 2015).
5) Significant pests of roses in Ecuador include aphids, thrips and mites (Godoy Suárez, 2014; Bolanos-Carriel and Orellana, 2016).
6) In Ecuador, *S. frugiperda* is a problem on maize, cotton, tobacco, tomato, cucumber, rice, sugarcane, beans and soy beans (Andrews, 1988).
7) There are four records of Europhyt interceptions on roses from Ecuador (*Spodoptera* sp. x1 in 2011; *Helicoverpa* sp. x1 in 2014; *Helicoverpa zea* x 1 in 2014 and *Helicoverpa zea* x1 in 2017).
8) Cut flowers for export to the EU are subject to EURGAP and ISO quality accreditation
9) Noctuidae pests such as *Spodoptera litura* and *Chrysodeixis eriosoma* can be pests of cut flowers. The appropriate phytosanitary measure is to inspect the consignment to check that it is free from the pests (Mhlanga, 2014).

I.5.   Proportion of infested units rejected during post entry handling or processing

Roses are transported very heavily packaged, e.g. wrapped in cellophane with tape and with corrugated cardboard around the flower head to provide protection. Sometimes sachets of plant feed are also attached. Other than the removal of the cardboard and perhaps attaching sachets of flower food, there would be no further processing, simply some storage and transport for wholesale or retail.

- Estimated range of mean annual proportion of infested rose cut flowers rejected during postharvest handling or processing over the next 5 years (time horizon for assessment)

Rose cut flowers pathway	Scenario	Percentile[a]				
		1	25	50	75	99
Effectiveness of post-entry handling/processing Percentage infested material removed after import	A0	0	0	0	0	0
	A1	0	0	0	0	0

(a): Expert judgement was used to estimate five quantiles of the reduction factor expressing effectiveness.

Appendix J – @Risk generated results from pathway models

When the pathway model for entry via trade is implemented in @Risk, outputs are generated to a level of precision that is not warranted given the uncertain inputs. Results shown in the main body of the opinion are rounded appropriately. Nevertheless, for transparency the tables below provide the results as generated by @Risk.

Table J.1: @Risk outputs for pathway models for entry of *S. frugiperda* into the EU via the trade in peppers, sweetcorn, eggplants, cut roses and asparagus. Calculations with the pathway model were made assuming current regulations as at January 2018 (Scenario A0)

Percentile	5th	25th	Median (50th)	75th	95th	90% range	50% range
Peppers	1,755	9,534	30,520	98,350	525,903	524,148	88,816
Eggplant	805	4,248	13,478	43,036	222,133	221,328	38,788
Sweetcorn	137	885	2,482	6,012	17,566	17,429	5,127
Cut roses	30	159	453	1,179	4,450	4,420	1,020
Asparagus	4	31	126	485	3,218	3,214	454

Table J.2: @Risk outputs for pathway models for entry of *S. frugiperda* into the EU via the trade in peppers, sweetcorn, eggplants, cut roses and asparagus, Scenario A1

Percentile	5th	25th	Median (50th)	75th	95th	90% range	50% range
Peppers	2,014	9,962	29,669	90,767	442,085	440,071	80,805
Eggplant	906	4,457	13,346	39,339	188,146	187,240	28,882
Sweetcorn	4	26	78	190	583	579	164
Cut roses	29	160	448	1,180	4,506	4,477	1,020
Asparagus	4	32	124	451	2,754	2,750	419

Table J.3: @Risk outputs for pathway models for entry of *S. frugiperda* into the EU via the trade in other vegetable and cut flower hosts

Percentile	5th	25th	Median (50th)	75th	95th	90% range	50% range
Scenario A0	6,191	18,750	44,567	119,067	599,737	593,546	100,317
Scenario A1	4,204	14,297	37,533	104,008	496,076	491,872	89,711

Table J.4: @ Risk outputs – numbers of immature *S. frugiperda* entering into Andalucia and Sicily on infested commodities versus numbers of adults migrating into southern EU (mainly Andalucia and Sicily) from North Africa were *S. frugiperda* to establish in Morocco and Tunisia

Percentile[a]	25th	Median (50th)	75th	50% prob int[b]
Andalucia	651	1,479	3,885	2,234
Sicily	391	889	2,336	1,945
Migration into EU	3,876	31,725	203,399	16,523

Appendix K – Other commodity pathways

Depending on the level of detail at which a pathway is described, a risk assessment could potentially examine hundreds of pathways for a pest that occurs in many countries and feeds on many hosts (MacLeod and Baker, 2003). Recognising the polyphagous nature of *S. frugiperda*, it was not possible to examine all possible pathways, instead sweetcorn, a plant product from a major host, and vegetable hosts on which *S. frugiperda* had been intercepted and which have unique HS/CN codes, were assessed in some detail (Table A below). The volumes of other potential vegetable commodities (Table B) are taken into account within 'other uncertainties'.

Table K.1: (A) Commodity pathways assessed in detail: mean 5 year volumes imported into the EU from regions where *S. frugiperda* occurs (hundreds of kg) Source: EUROSTAT

Description	CN/HS code	core America	sub-Saharan Africa	Sum
Roses (cut flowers)[a]	06031100	328,250	1,878,283	2,206,532
Asparagus[a]	07092000	349,813	2,250	352,063
sweetcorn	07099960	149	106,327	106,476
Sweet peppers + other Capsicum[a]	07096010 + 07096099	31,487	31,177	62,664
Aubergines[a]	07093000	18,361	18,330	36,691
	Sum	728,060	2,036,366	2,764,426

(a): **=** commodity on which *S. frugiperda* has been intercepted.

Table K.2: (B) Other vegetable commodity pathways

Description	CN/HS code	core America	sub-Saharan Africa	Sum
Other cut flowers	06031970 + 06031980	214,564	512,551	727,115
Beans	07082000	31,511	369,142	400,653
Onions	07031019	217,810	32,786	250,596
Peas	07081000	112,708	113,608	226,316
Other veg. inc. *Momordica* *	07099990	100,383	105,865	206,247
Carnations (cut flowers)	06031200	120,825	56,992	177,816
Chrysanthemums (cut flrs)	06031400	42,772	18,345	61,117
Cauliflowers	07041000	914	28,585	29,499
Tomatoes	07020000	17,025	439	17,464
Garlic	07032000	15,074	351	15,425
Leeks	07039000	1,080	14,182	15,261
Other brassica	07049090	137	7,194	7,331
Other legumes	07089000	3,753	972	4,725
Rose cuttings	06024000	13	2,893	2,905
Brussels sprouts	07042000	58	2,309	2,366
Onion sets	07031011	1,207	403	1,610
Shallots	07031090	1,064	379	1,443
Cabbage	07049010	516	480	995
Gherkins	07070090	525	32	557
Cucumbers	07070005	254	23	277
Head lettuce	07051100	2	63	65
Other lettuce	07051900	0	53	53
	Sum	882,194	1,267,644	2,149,837

Ratio of assessed sum of commodity pathways: other vegetable commodity pathways = 1: 0.78.

Appendix L – Distributing commodities across NUTS 2 regions

L.1. Introduction to NUTS (Nomenclature Units for Territorial Statistics)

NUTS are an EU standard for identifying national and sub-national divisions within Members States of the EU. Four NUTS levels are used, NUTS 0 refers to a whole EU Member State; NUTS 1, 2 and 3 refer to increasingly smaller areas within a member state.

At present there are:

- 97 regions within NUTS 1,
- 270 regions at NUTS 2, and
- 1,294 regions at NUTS 3 level.
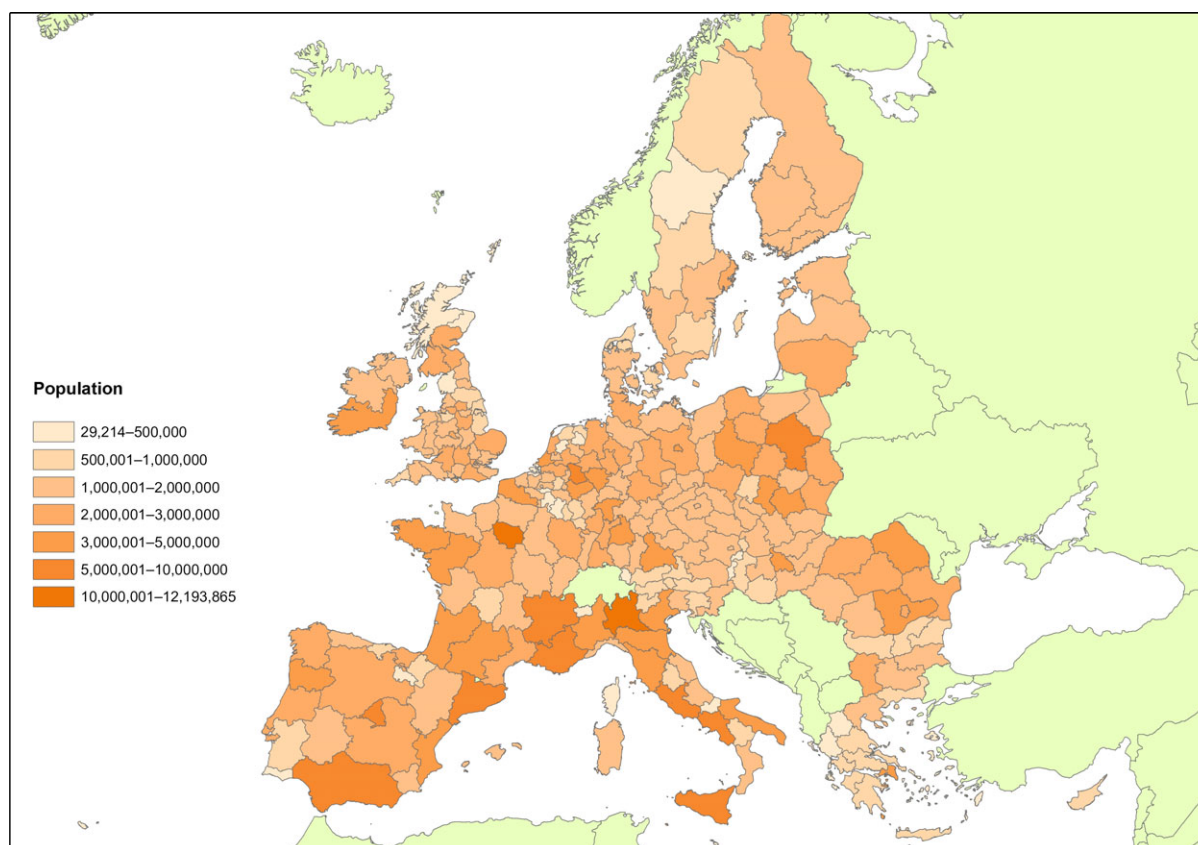
Figure L.1: Population of NUTS 2 regions

L.1.1. Regional consumption

For fresh produce, the majority of end-use consumption is expected to be dependent on the population of consumers across the EU. Thus it is assumed that the distribution of commodities across the EU is proportional to consumers in NUTS 2 regions. Whilst food consumption does vary regionally, Blandford (1984) found the differences in food consumption between OECD countries were decreasing, suggesting diets were converging and are become increasingly similar in the overall structure of their diet. When comparing diets within Europe, Elsner and Hartmann (1998), Mauracher and Valentini (2006), Schmidhuber and Traill (2006) and Polsel (2012) found European diets were also converging. Within the EU diets have become more homogeneous, there has been increased intakes in Mediterranean countries of saturated fats, cholesterol and sugar, while there has been reductions in saturated fat and sugar in Northern European countries (Schmidhuber and Traill, 2006).

Appendix M − Evidence dossier: Entry via migration directly from sub-Saharan Africa

M.1.   Natural spread of *Spodoptera frugiperda* in the Western Hemisphere

1) *S. frugiperda* is a migratory species with notable dispersal capacity (Johnson, 1987). Like most other noctuid moths they are nocturnal fliers, initiating flight short after sunset and generally terminating before dawn, an approximately 4−8 h flight duration (Westbrook, 2008). There is evidence that flights over successive nights can occur (Rose et al., 1975).

2) Adults fly downwind hence direction of movement depends largely on prevailing winds with host availability influencing the rate of spread (Luginbill, 1928; Hogg et al., 1982). Flight altitude is between 100 and 1,000 m above ground level (AGL) (corresponding approximately to 1,000 to 850 mb), a range also found for other migratory Noctuid moths including *Helicoverpa armigera* (Feng et al., 2005), *Autographa gamma* (Alerstam et al., 2011), *S. exigua* (Feng et al., 2003), and *S. exempta* (Riley, Reynolds, and Farmery, 1983).

3) Adult annual migrations occurring in the summer result in the pest expanding from its endemic area in the tropical and sub-tropical regions of the Americas to cover more than 2,000 km across the entire US up to Canada in the north and reaching Argentina and Chile in the south (Luginbill, 1928; Sparks, 1979; Pair et al., 1986).

4) In Central America, adults generally disperse about 500 km (approx. 310 miles) before oviposition, moving from seasonally dry habitats to wet habitats (Johnson, 1987).

5) Because *S. frugiperda* does not diapause, winter populations in the United States are limited to the southern regions of Texas and Florida with infestations in the rest of the continent due to annual migrations from these sites (Luginbill, 1928). Sparks (1979) and Johnson (1987) reproduce a map showing the typical annual northwards progression of *S. frugiperda* over the USA (Figure M.1a). Starting from southern Florida and Texas, the spring generation flies north, generally spreading several hundred km before settling to reproduce the next generation. The seasonal migration from Texas to Canada extends approximately 3,000 km. The northward migration coincides with progressively later corn plantings that makes the preferred host plant available throughout the migratory stages (Figure M.1b). Average wind vectors during the growing season strongly supports northerly flights at the altitude commonly used by *S. frugiperda* (Figure M.1c). These factors provide optimal conditions for long-distance migration.
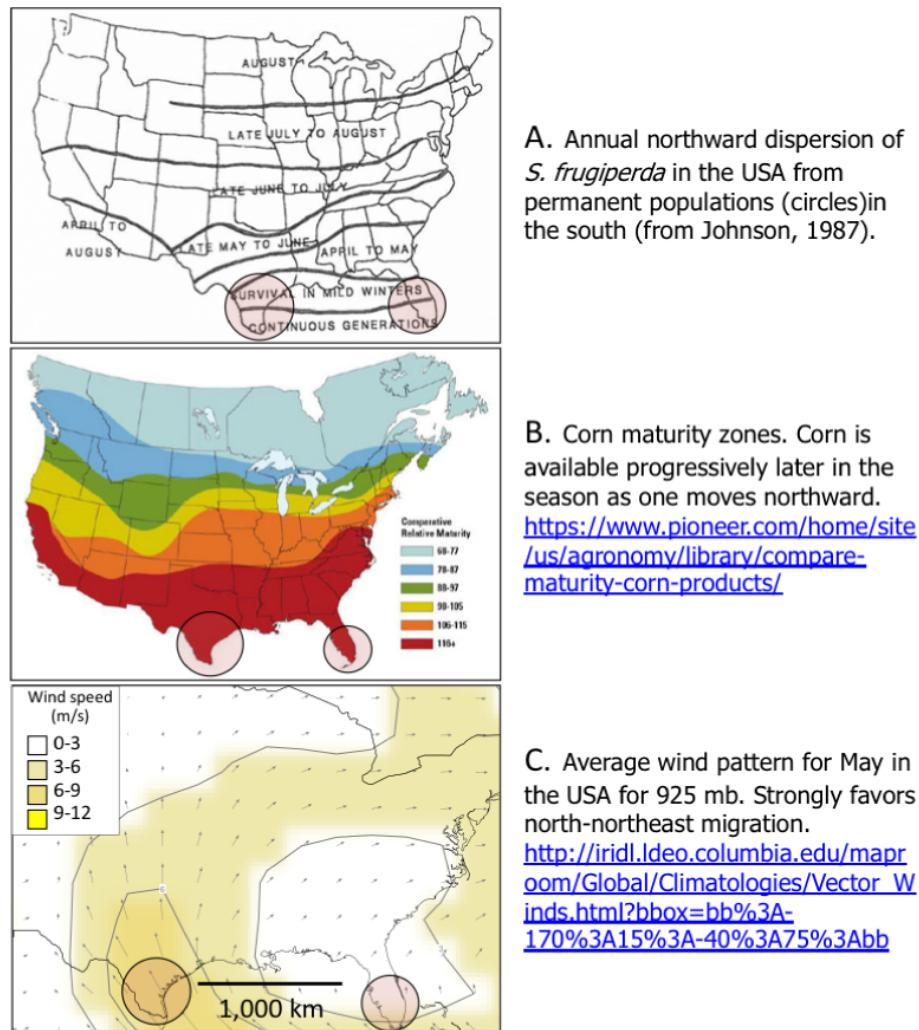
A. Annual northward dispersion of *S. frugiperda* in the USA from permanent populations (circles) in the south (from Johnson, 1987).

B. Corn maturity zones. Corn is available progressively later in the season as one moves northward. https://www.pioneer.com/home/site/us/agronomy/library/compare-maturity-corn-products/

C. Average wind pattern for May in the USA for 925 mb. Strongly favors north-northeast migration. http://iridl.ldeo.columbia.edu/maproom/Global/Climatologies/Vector_Winds.html?bbox=bb%3A-170%3A15%3A-40%3A75%3Abb

Figure M.1: Migration of *S. frugiperda* in the USA is supported by corn availability and wind patterns

6) Using haplotype ratios to distinguish between *S. frugiperda* from south-central USA (e.g. Texas) and south-eastern USA (Florida), Nagoshi et al. (2012) identified separate northward migration routes in North America. Generations derived from a Texas population migrated northwards following the Mississippi River valley, remaining west of the Appalachian Mountains; generations derived from Florida migrated north remaining east of the Appalachian Mountains. Model projections demonstrated that wind patterns, corn availability, and nocturnal flight behaviour could reproduce the North American migration pattern delineated by the genetic studies (Westbrook et al., 2016).

7) There is evidence that *S. frugiperda* will attempt long-distance flights over water as adults have been found on structures at sea, 250 km from land (Sparks, 1979). However, *S. frugiperda* populations in the Caribbean islands shows limited mixing indicating that the Caribbean Sea is an effective barrier segregating the North American and South American populations, probably because of unfavourable wind patterns (Nagoshi et al., 2017a,b).

M.2.   Other examples of long-distance flight by Noctuid moths

1) Pedgley et al. (1995) reviewed information on long-range windborne movements by winged insects in various climatic zones of Africa and Europe. They concluded that migrations are related to the weather and to seasonal changes of climate and prevailing wind. Large-scale movements are often dominated by a single weather system.

2) Chen et al. (1995) used entomological radar to demonstrate that *Mythimna separata* (Oriental armyworm) (Lep: Noctuidae) migrated from southern China to provinces in north east China, a distance of more than 1,000 km.

3) Chang et al. (2018) found pollen grains from plants in southern China attached to *Agrotis segetum* (Lep: Noctuidae) in north eastern China, indicating long-distance migration.

4) *Agrotis ipsilon* (Lep: Noctuidae) migrate long distances driven by meteorological events (Showers et al., 1989).

5) In Africa, migration direction of *Spodoptera exempta* is determined by seasonal wind patterns (Tucker et al., 1982; Rose et al., 1985).

6) Summarising research on *S. exempta*, Rose et al. (2000) noted that outbreaks can result from winds converging for a persistent period, causing adults to become concentrated locally. The adults mate and lay eggs. The concentration of adults and the subsequent development of their progeny can result in pest outbreaks. In contrast, adults that are not concentrated by wind convergence will disperse more widely and produce scattered low-density populations.

7) *Spodoptera exigua* is able to reach UK from North Africa and Spain (Sparks et al., 2005).

8) *S. exigua* has been reported migrating over 3,500 km in 9 to 11 days, from the Caspian Sea region to Finland; millions of both sexes reached Finland and neighbouring countries (Mikkola and Salmensuu, 1965; Johnson, 1969). However, Mikkola (1970) re-evaluated this event and only found evidence for nocturnal flight, concluding that over land migration was nocturnal and intermittent rather than continuous 'the bulk of the migrant swarm advanced intermittently, flying only by night'. They suggest the possibility of continuous flight but no evidence is presented.

9) Feng et al. (2003) reports radar and trap studies with *S. exempta* in China and found only nocturnal flight activity beginning at dusk, with most moths flying below 500 m AGL at 21–32 km/h and a flight duration of 5–8 h. This is very similar to the description of *S. frugiperda* by Westbrook (2008) and Westbrook et al. (2016).

M.3. Migration scenarios in Africa as exhibited by other Lepidoptera species

1) Heliothine moths typically migrate during evening hours, with long-distance flight occurring at below 1,000 m AGL (meters Above Ground Level) and for a period of 8–12 hours (Beerwinkle et al., 1995; Westbrook et al., 1995; Feng et al., 2005; Alerstam et al., 2011).

2) Four Lepidoptera species endemic in sub-Saharan Africa and with long-distance flight capability show different patterns of northward range expansion. These illustrate real life examples for the potential natural migration of *S. frugiperda* into Europe (Figure M.2). Two are represented by *Spodoptera* species believed to have originated in Africa and share many characteristics of *S. frugiperda*, including a broad host range, nocturnal flight behaviour, and no diapause. The absence of the latter is significant because it limits permanent populations to regions with mild winters.

3) Example 1 is represented by *S. exempta,* which has yet to become established in the Maghreb or Europe despite being endemic in most of sub-Saharan Africa. There is no evidence to date that substantial numbers of *S. exempta* are entering Europe by natural migration, indicating that the Sahara Desert and the Mediterranean Sea are an effective barrier against northward natural migration of this species.

4) Example 2 is represented by *S. littoralis*, whose geographical range extends into southern Europe. Significant numbers were observed in 1949 in southern Spain and permanent *S. littoralis* populations have become established in southern Spain, Cyprus, Greece, Italy, Israel, Malta, and Morocco (https://www.cabi.org/isc/datasheet/51070). It is noteworthy that the establishment of permanent populations in Europe have been largely limited to areas in or near the temperate Mediterranean region, delineating a northern limit for moths that cannot diapause.

5) Example 3 is illustrated by *Helicoverpa armigera*, which has similar characteristics to the two *Spodoptera* species but can also diapause. This added cold tolerance substantially expands the northern range of resident populations.
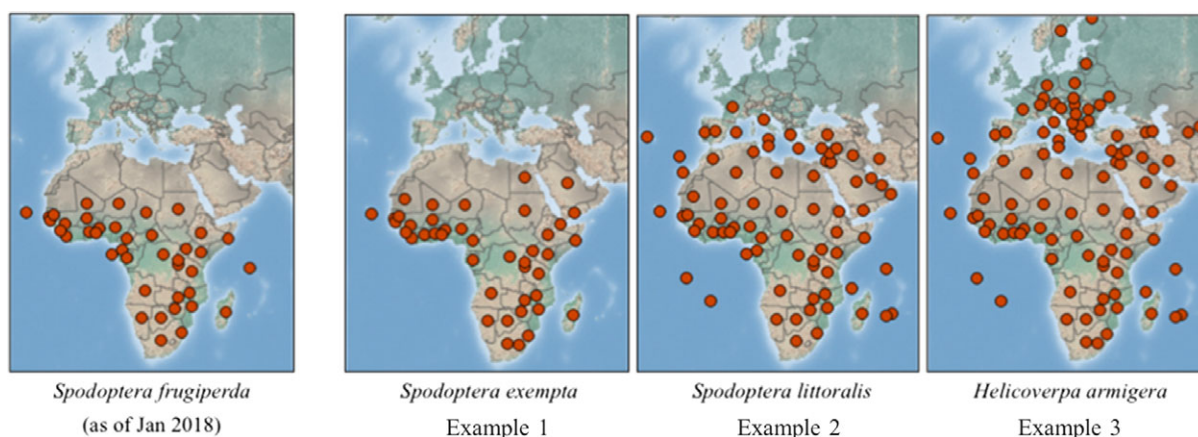
Figure M.2: Distribution of selected Noctuid moth pests in Africa and Europe. Source https://www.cabi.org/isc/

6) Example 4 is represented by the painted lady butterfly, *Vanessa cardui*, which undergoes annual migrations to and from Africa and Europe (Talavera and Vila, 2017). In this case, sub-Saharan Africa serves as a wintering reservoir from which large numbers of *V. cardui* migrate each spring to repopulate Europe (Stefanescu et al., 2012).

7) The *S. exempta* or *S. littoralis* examples seem most likely for *S. frugiperda* given similarities in morphology, physiology, and flight behaviour.

M.4. Migration route: sub-Saharan Africa (Sahel) to Europe by crossing the Sahara

M.4.1. The Sahara as a barrier

1) Northward migration of *S. frugiperda* from the Sahel is problematic because of the barrier imposed by the Sahara Desert. The distance from the Sahel to the Mediterranean coast is > 3,000 km and this pathway has none of the factors that facilitate long-distance migration in North America (Figure M.1).

2) There is evidence that *V. cardui* routinely undergoes a southerly migration from Europe to the Sahel, a distance of about 4,000 km in a single flight (Stefanescu et al., 2007, 2012, 2013, 2016; Talavera and Vila 2017).

3) It has been suggested that the springtime northward migration might also occur by a direct flight over the Sahara Desert to northern Africa (Talavera and Vila 2017), though the supporting wind currents that might facilitate this long migration are not specified. However, dust from Africa routinely drifts into Europe indicating frequent air transport between the two continents. Climatic conditions most favourable to northward migration from the Sahel occurs in the spring as indicated by the behaviour of *V. cardui*. Radar data from Europe, the Mediterranean, and western Africa (Mauritiana) showed that springtime (March–June) migrations of *V. cardui* were directed northward while summer/autumn (July–November) migrations moved southward, the latter consistent with a return migration from Europe to Africa (Stefanescu et al., 2012). These data suggest a March to June window for migration from Africa to Europe.

4) Figure M.3 shows average wind direction and velocity for the month of June, which has a pattern representative of the springtime period. At the lower altitude (925 mb or 762 mb) predominantly northerly winds in North Africa and the Sahara would seem to represent a significant barrier to northward migration (as compared to Figure C.1 for the USA). However, at a 3,000 m (700 mb) altitude the Sahel is dominated by an easterly wind flow that rotates into a south-westerly wind on the African western coast. If *S. frugiperda* can fly at the higher altitude, a plausible wind-supported pathway is possible that entails progressive migration from the Sahel to the western coast followed by north-easterly migration into the Maghreb.
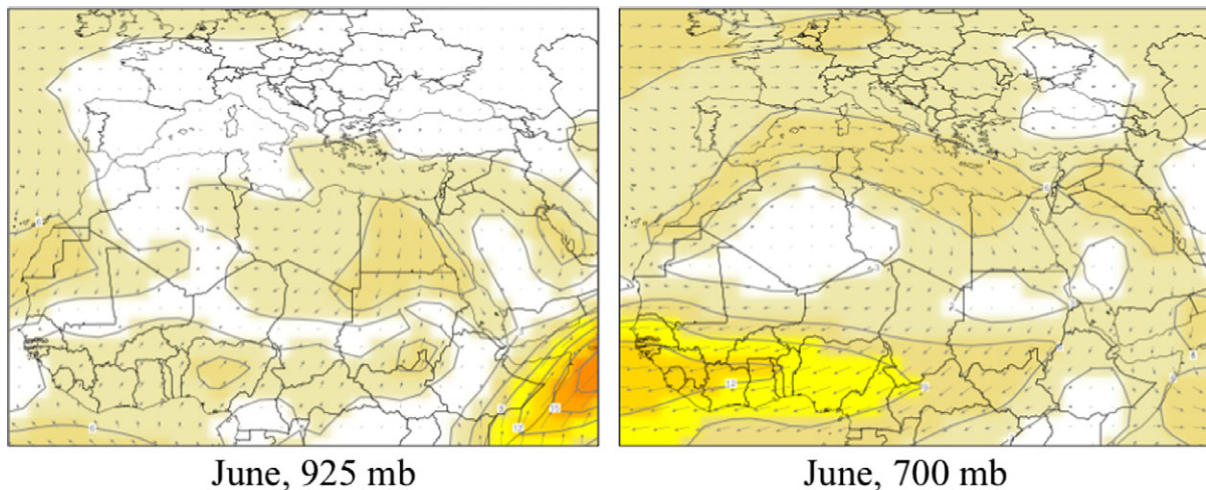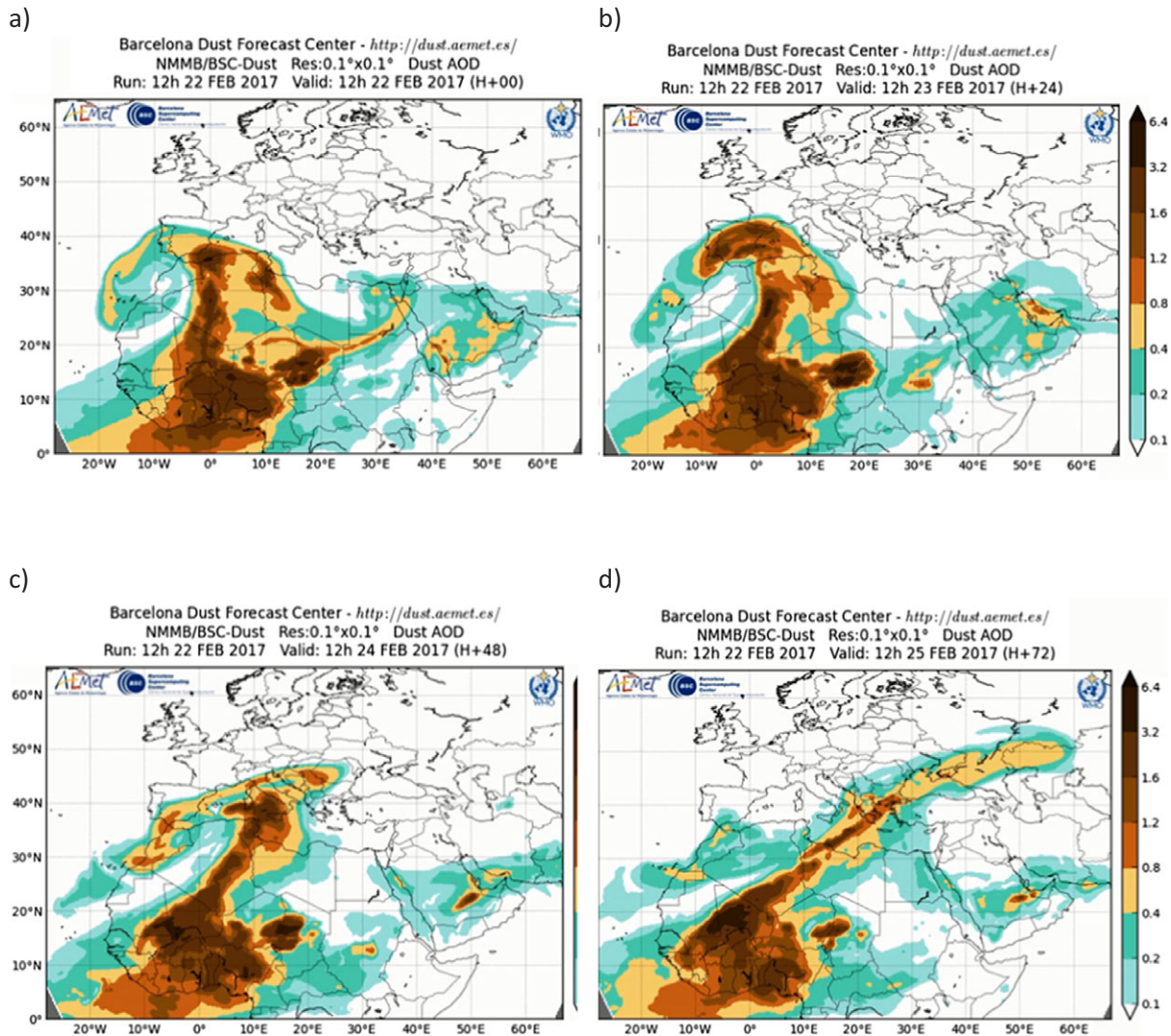
June, 925 mb

June, 700 mb

Figure M.3: Average wind pattern for June at two altitudes. Source: http://iridl.ldeo.columbia.edu/ maproom/Global/Climatologies/Vector_Winds.html?bbox=bb%3A-170%3A15%3A-40% 3A75%3Abb

M.4.2. Saharan Dust

1) Saharan and/or Sahelian dust is regularly transported in three general directions (i) northward across the Mediterranean to southern Europe, sometimes as far north as Scandinavia (ii) westward over the North Atlantic, and (iii) eastwards across the eastern Mediterranean (review by Goudie and Middleton, 2001).

2) Much of the dust comes from two distinct regions (i) a region covering eastern Mauritania, western Mali and southern Algeria and (ii) the Bodele depression in Chad (Middleton and Goudie, 2001). However, as noted above, the wind carrying the dust flows at a higher altitude (3000 m) than the altitude at which *S. frugiperda* migrates.

3) Dust storms from the Sahara are most common in late spring and early summer. Dust can spread across Europe and be carried north to Sweden. The Barcelona Dust Forecast Center prepares daily regional forecasts using an atmospheric model (Pérez et al., 2011; Haustein et al., 2012). Current three-day forecasts are available at https://dust.aemet.es/forecast. Figure 7a) to d) shows example forecast for February 2017 indicating wind flows carrying dust reaching into Spain from west Africa and moving east across Italy into Greece. https://dust.aemet.es/methods/the-nmmb-bsc-dust-model

4) During a year of monitoring, 20 dust events were measured on Corsica, with the dust originating for North Africa (reference in Goudie and Middleton, 2001).

5) Chapman et al. (2012) used an atmospheric dispersion model normally used to predict the trajectory of sedimenting particles, but which has also been used to model dispersal of midge vectors of bluetongue, to model the dispersal of *Autographa gamma* (Lep: Noctuidae) arriving in the UK from Europe.

Figure M.4: (a–d) Examples of 4 day dust flow projections spreading dust from Africa over Europe February 2017

6) However, extrapolations from dust distributions have to be treated with some caution. The average dust transportation altitude is 700 mb (3,000 m) (Varga et al., 2014), which is at the upper limit of what has been reported for *V. cardui* (Mikkola, 2003; Stefanescu et al., 2007) and well above that so far observed for *S. frugiperda* (Westbrook, 2008) and other Noctuid moths (Feng et al., 2003; Drake, 2012). This means that a substantial portion of dust is being transported by air currents not available to *S. frugiperda.* Transport of dust across the Sahara Desert typically occurs at speeds of 10–15 meters/sec (Varga et al., 2014), requiring multiple days to move from the Sahel to the Maghreb. This is substantially longer than the nocturnal flight duration typical of *S. frugiperda*. Therefore, using the dust air transport system to traverse the Sahara Desert would require substantially different behaviour from *S. frugiperda* relative to what has been observed in the Western Hemisphere.

7) Figure M.6 shows monthly mean wind speed and direction at 1,000 mb (ground level) and 925 mb (approximately 1,000 m) for each month of the year.

M.4.3.   Alternative dispersal model

1) The results of 12 simulations of *S. frugiperda* dispersing from the Khartoum area of Sudan and the Addis Ababa region of Ethiopia were presented in Heinrichs et al. (2017). Figure M.6 is taken from Heinrichs et al. (2017) and shows the output of each simulation. Simulations differ in the start date (December 1st to May 15th using 15-day intervals). The result for 15 March is expanded. Concentration (?) of *S. frugiperda* 120 days after the start of the simulation is colour coded, descending from red to violet. However, it seems that these projections were run with *S. frugiperda* flying for 120 consecutive days. *Any simulation run for a long time will show a wide dispersion pattern.*

2) Adult females are relatively short-lived (13–19 days at 26.8°C) (Johnson, 1987).

3) The farther one strays from the normal biology and flight behaviours of *S. frugiperda*, the less realistic the simulations become. *S. frugiperda* is a nocturnal flier. It may be possible to extend that flight a few hours beyond the scotophase but factors like dehydration become an increasing issue.
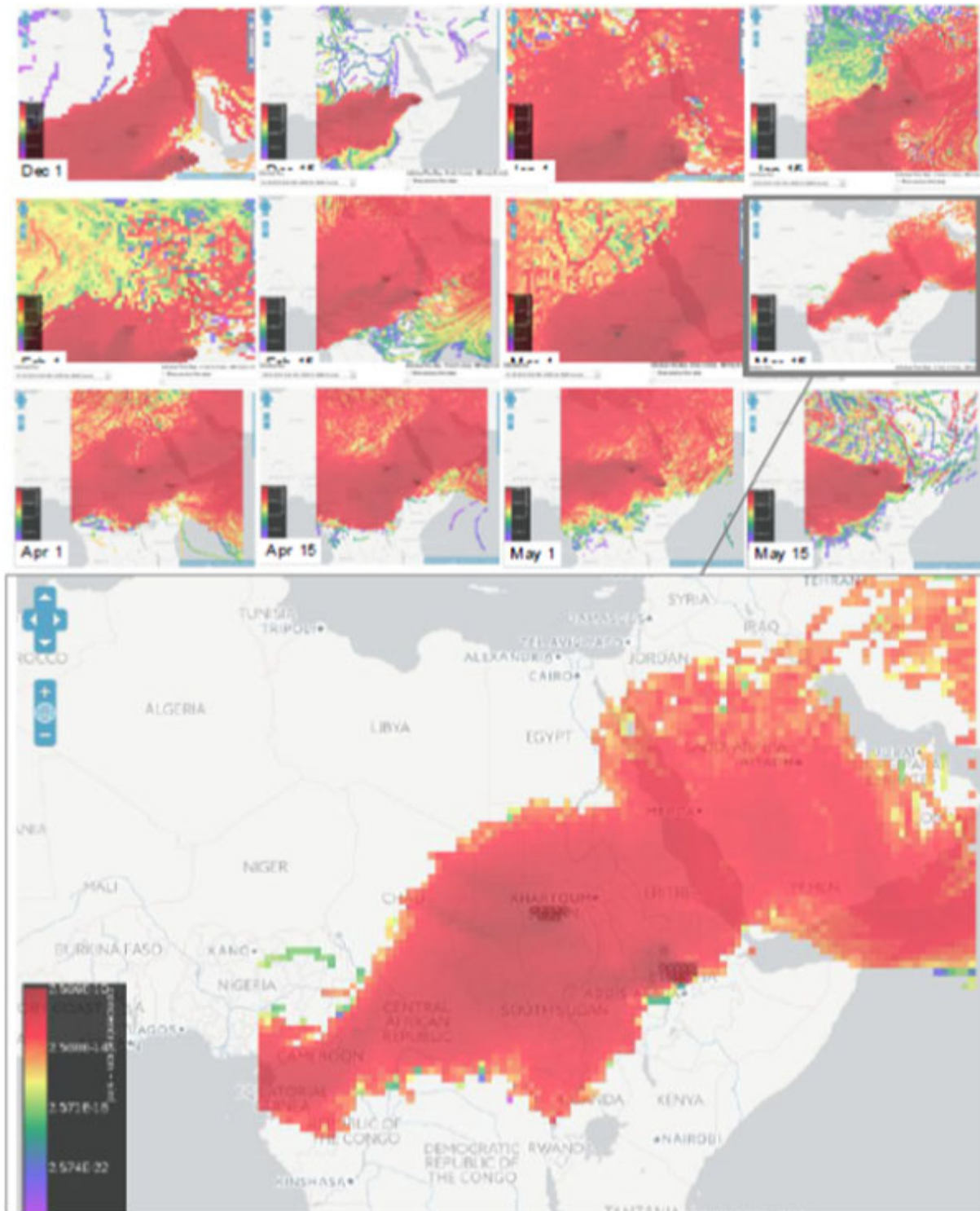
Figure M.5: Projected dispersal of *S. frugiperda* over 120 days from the Khartoum area of Sudan and the Addis Ababa region of Ethiopia (Source: Heinrichs et al., 2017)
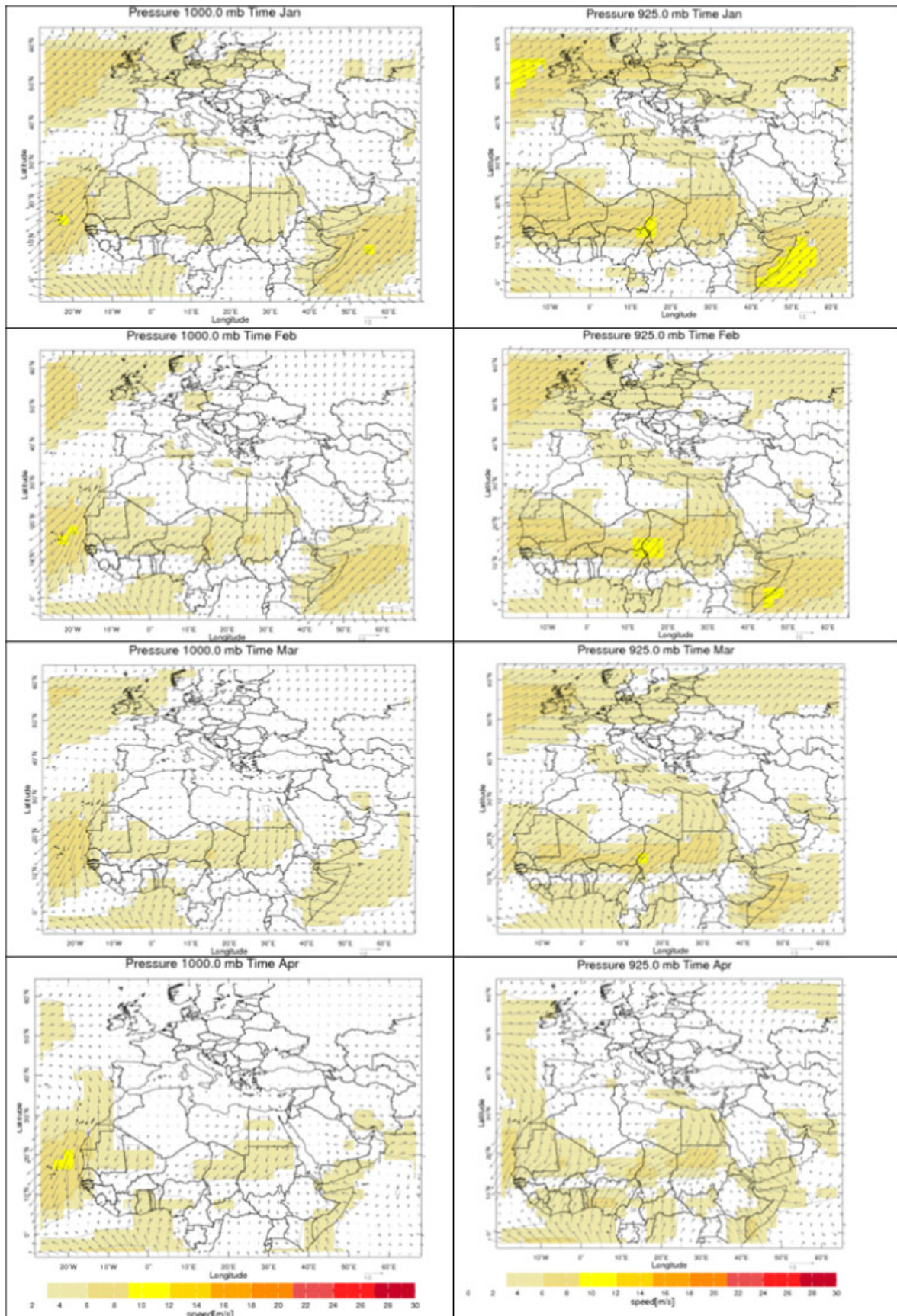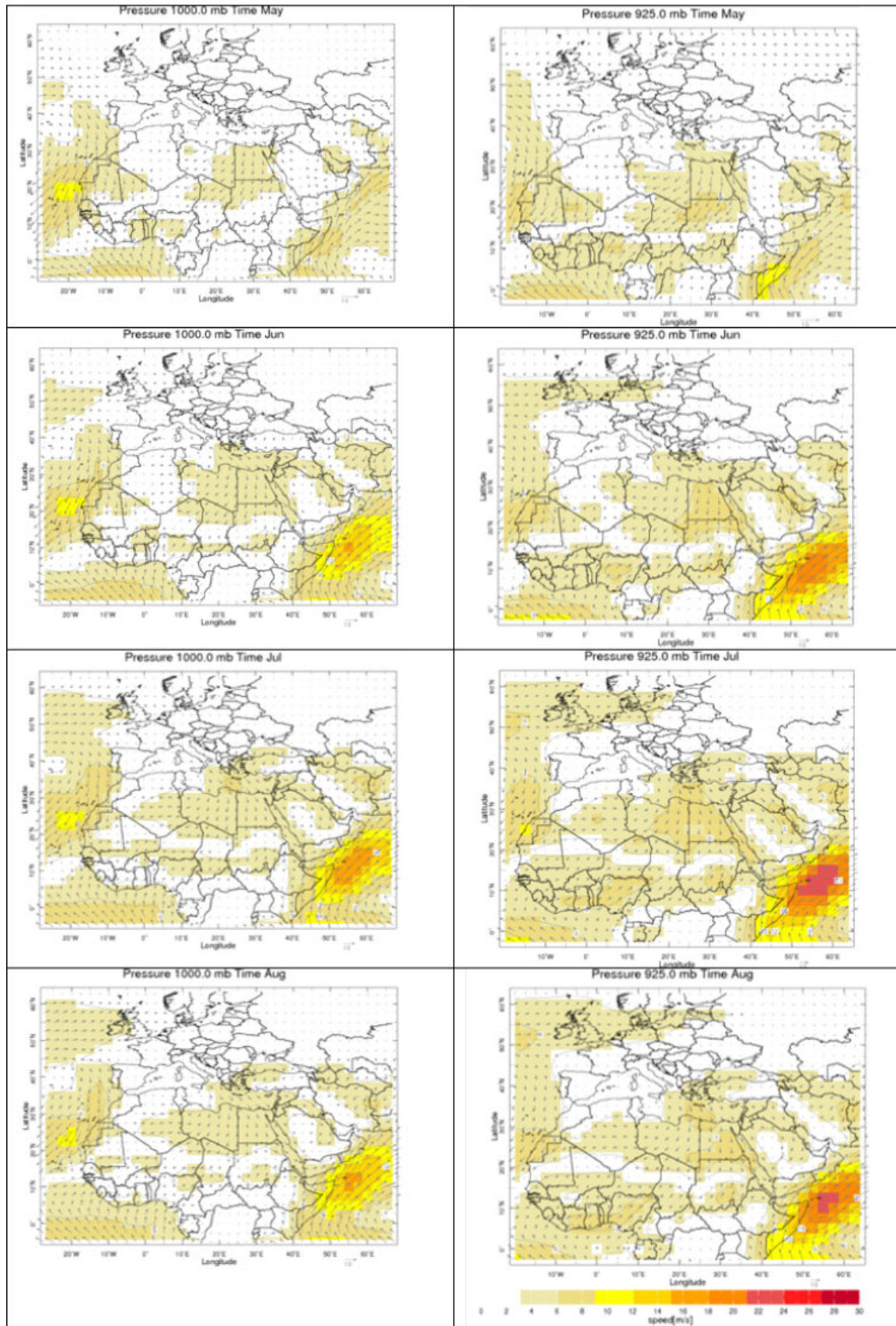
Figure M.6: Monthly mean wind speed and direction at 1,000 mb (ground level) and 925 mb (approximately 1,000 m) for each month of the year
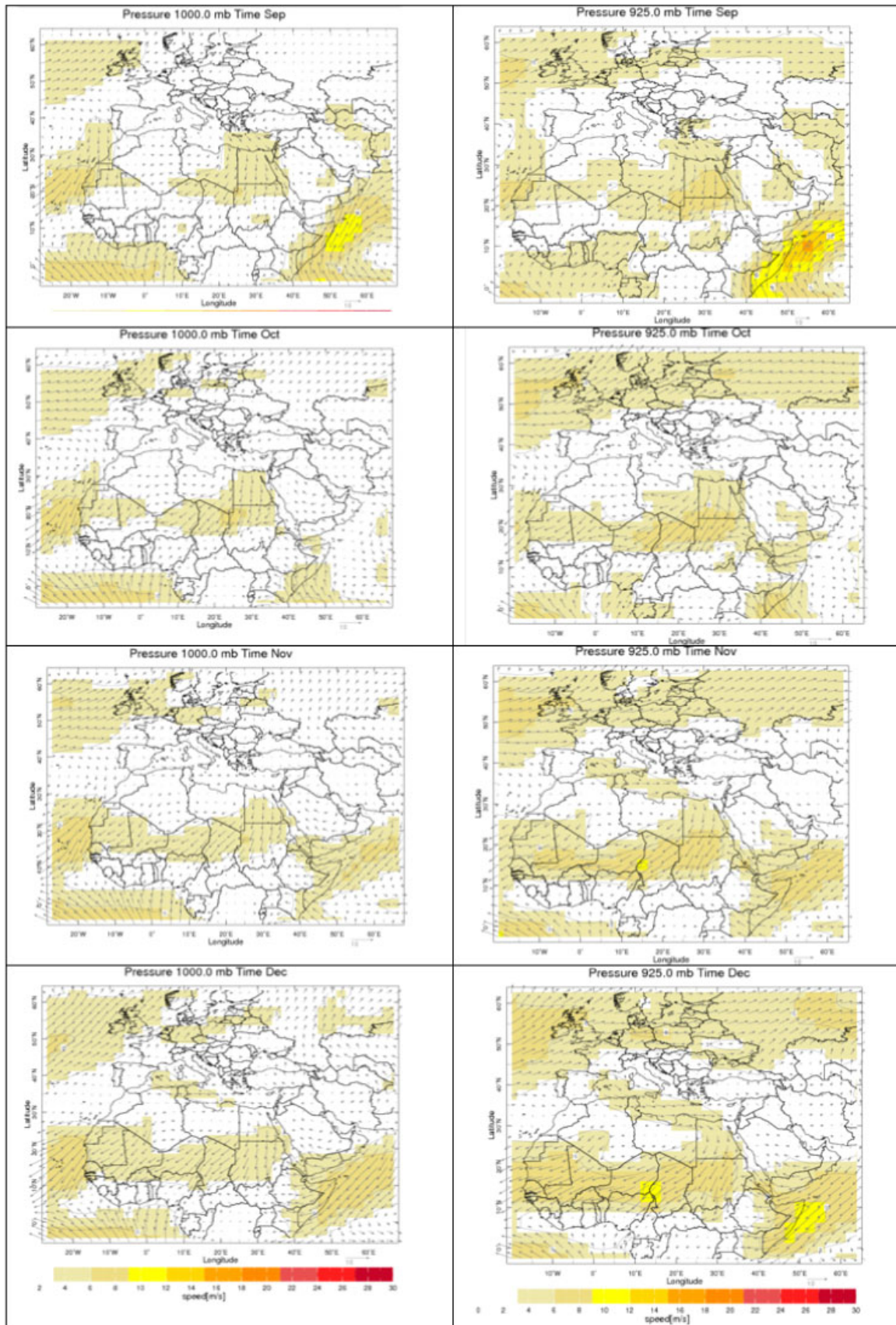
Figure M.6: Continued

Figure M.6: Continued

M.5.   Conclusions

- We know of no documented example of a moth species migrating in continuous flight for multiple days.
- We know of no studies demonstrating *Spodoptera* species undergo significant daytime flight. Perhaps the best method to observe migratory flight time is with radar, which shows *Spodoptera* flying primarily, if not solely, at night (Feng et al., 2003).
- There is no evidence that *S. frugiperda* can travel 3,000 km in a single flight without extraordinarily favourable wind conditions at the correct altitude. Such conditions are not present in sub-Saharan Africa for northward migration.
- Taking the above evidence into account the entry of *S. frugiperda* directly into the EU from populations in sub-Saharan Africa is judged not feasible and was therefore not quantified.

Appendix N – Evidence dossier: Entry via migration from North Africa

1) There are multiple examples of Lepidoptera species for which there is evidence of migration from northern Africa to Europe on a seasonal basis. These include the Noctuid moth *Autographa gamma* (Chapman et al., 2012) and the butterfly *Vanessa cardui* (Stefanescu et al., 2007). In addition, the distribution pattern of *Spodoptera littoralis*, a native of Africa, is consistent with a progressive northward migration into northern Africa and eventual establishment in southern Europe.

2) *Spodoptera* species are capable of long-distance migration with continuous flight limited to scotophase (dark period). This has been demonstrated for *S. frugiperda* (Rose et al., 1975; Westbrook, 2008), *S. exempta* (Rose et al., 1985; Riley et al., 1992), *S. exigua* (Mikkola, 1970), and *S. litura* (Saito, 2000). The speed and direction of flights is primarily dictated by wind vectors above the flight boundary layer, i.e. above the layer of air in which insects are capable of directed flight. Long-distance moth migration is passive downwind flight occurring above the flight boundary layer and usually occurs at altitudes from 100 m to 1,500 m (1,000 mb to 850 mb) above ground level (Srygley and Dudley, 2008). Documented instances of long-distance (> 1,000 km) migration by *Spodoptera* species include annual migrations in North America by *S. frugiperda* (Westbrook et al., 2016), a mass migration in northern Europe by *S. exigua* (Mikkola, 1970), seasonal migration over the Bohai Sea by *S. exigua* (Fu et al., 2017), and seasonal migration in eastern Asia by *S. litura* (Fu et al., 2015). Based on these observations, the migration of *S. frugiperda* from northern Africa to Europe across the Mediterranean Sea is assumed to require favourable wind conditions and resting areas within a single night flight of the origin.

3) There are low altitude regional winds that would support moth flight into the Mediterranean region (Figure N.1). The 'leveche' is a hot, dry southerly wind which blows along the south-east coast of Spain ahead of low pressure. It often carries dust and sand from Africa. The 'khamsin' is a southerly wind blowing over Egypt in front of depressions passing eastwards along the Mediterranean or North Africa when there is high pressure to the east of the Nile. The wind blows from the interior of Africa and is hot and dry, and often carries much dust. It is most frequent from April to June.

Leveche   Khamsin

Figure N.1: Maps illustrating regional winds from Africa to Europe

4) Detailed examination of seasonal wind patterns indicate favourable air transport for migrations from Morocco into Spain and northern Tunisia into Sicily during at least some portions of the year (Figure N.2). In both cases, overwater flight would be less than 300 km. The dispersion pattern based solely wind patterns can be estimated using the HYSPLIT trajectory model (Stein et al., 2015). A subset of extrapolated trajectories based on a single 12-h flight from Morocco and Tunisia reached Spain and Sicily, respectively (Figure N.3).
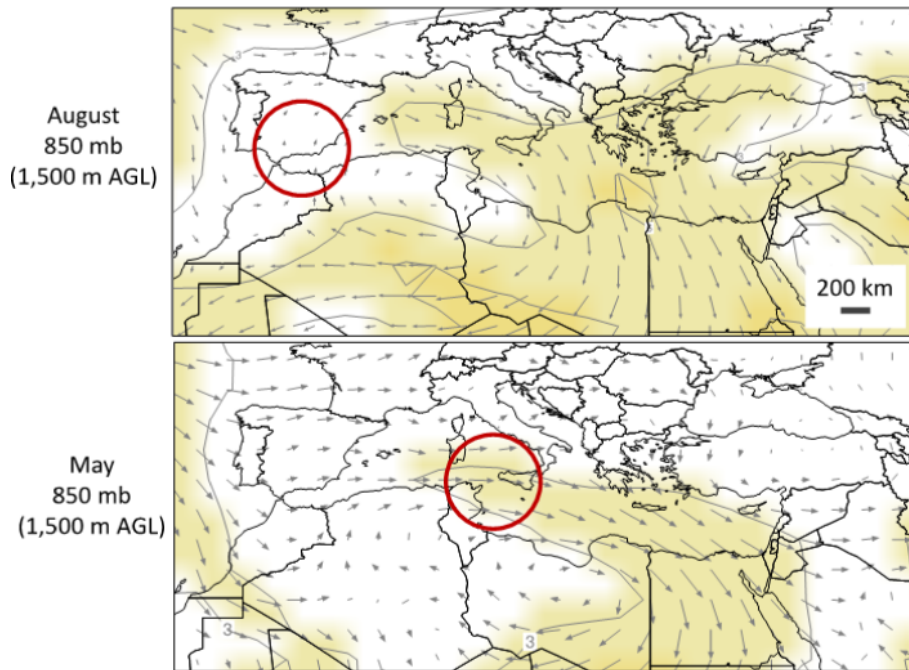
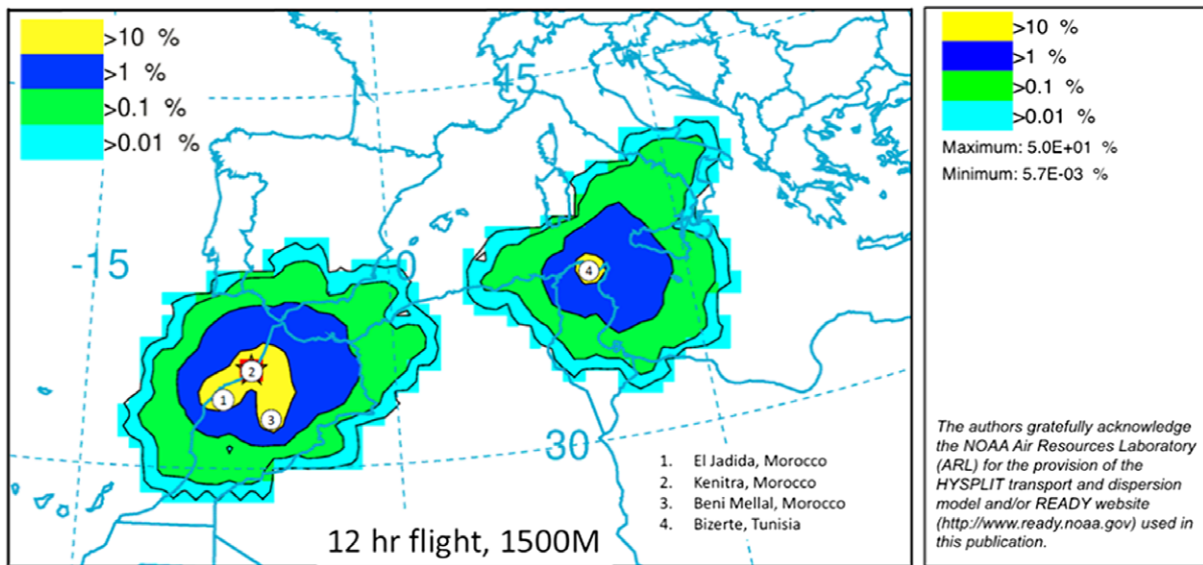**Figure N.2:** : Seasonal wind patterns over northern Africa

Figure N.3: HYSPLIT trajectory projections for a 12 h flight at 1,500 m. Origins in Morocco are marked 1, 2, 3; in Tunisia 4. Different colours indicate the percentage of trajectories originating in the source area that cross the coloured zones. For instance: yellow areas are crossed by more than 10% of the 1,500 m height wind trajectories that originate in the source areas during a travel time of 12 h. Blue areas are crossed by 1-10% of those wind trajectories, etc. Further information is given in Stein et al. (2015)

5) Stefanescu et al. (2007), examined the frequency and sources of *Vanessa cardui* migrating into southern Europe from North Africa using experimental data and applying a source-receptor model. They reported a strong association between migration of *V. cardui* and synoptic-scale wind currents. During observation periods in late spring – early summer from 1997 to 2006 (excluding 2005), there were 32 weeks in which there were significant increases in *V. cardui* populations. 23 of the 32 weeks also had favourable winds from North Africa. In Figure 4, dark blue areas in North Africa represent most likely sources of

immigrant *V. cardui* into Europe (blue regions in to the north of UK are a model artefact explained by the authors)
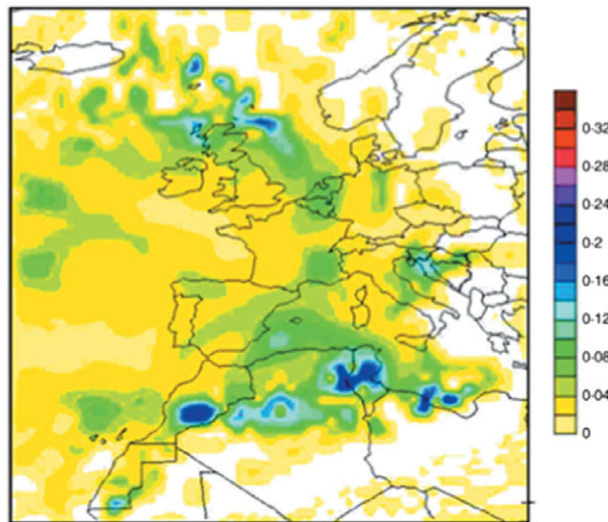

Figure N.4: Abundance of *Vanessa cardui* (individuals per 100 m transect) computed with a source-receptor model applied to count data March-June 2000 – 2004 and 2006. (Stefanescu et al., 2007)

6) The importance of the Maghreb as the primary source of migration into Spain was further indicated by the finding of substantial breeding grounds for *V. cardui* in locations in Morocco that were predicted by the pattern of synoptic winds believed to be directing the flight (Stefanescu et al., 2017).
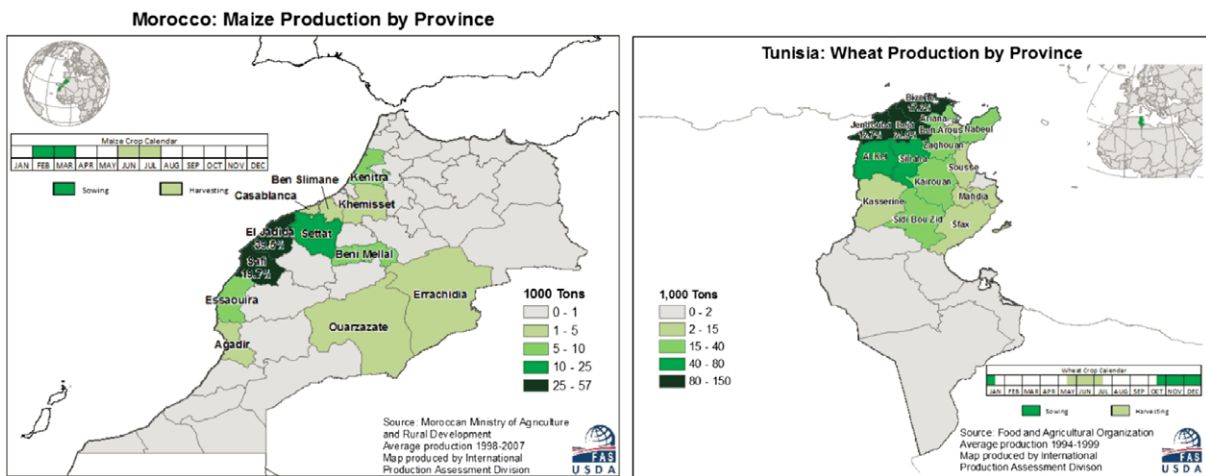

Figure N.5: production of maize and wheat in Morocco and Tunisia

7) Were *S. frugiperda* to establish in North Africa, then maize and sorghum growing areas could provide a source for migratory populations to reach the EU. A study of *S. frugiperda* density during an infestation outbreak at two intensive corn-growing sites in Texas, USA, found average densities as high as 3.97 pupae/m^2 (Pair et al. 1989, 1991). In 2017, Morocco corn and sorghum area were an estimated 140,000 ha. (http://www.fao.org/), which based on the Texas data could produce as much as 500 million moths. The HYSPLIT projection estimates that approximately 1% of drift trajectories will enter Spain. However, not all of the source population will migrate. A HYSPLIT projection for Tunisia (2,200 ha) also indicates that 1% of the trajectories of migrating adults could reach Sicily.

8) *S. frugiperda* is a secondary and sporadic pest of wheat so maize and sorghum are the most relevant source of migratory populations because *S. frugiperda* density in non-preferred hosts do not grow so large that they lead to large migratory populations.

9) If *S. frugiperda* becomes established in northern Africa (the Maghreb), then proximity and wind patterns indicate a high probability of periodic migration into Europe.

10) Proportion of a population that will migrate: Estimating the proportion of a population that migrates is a challenge. It is so far not possible to distinguish migratory from non-migratory individuals. Probably the best (and perhaps only) estimation is 10% of *S. frugiperda* from early stage corn and 90% from late stage will migrate (Westbrook and Lopez, 2010; Westbrook et al., 2016).

11) Proportion that survive migration: This calculation is also difficult and will be location dependent. Migration viability in the US cornbelt will likely be relatively high since plant hosts are plentiful and humidity high, while migration over the Sahara Desert will be low for the opposite reasons. I suspect migration from the Maghreb to southern Spain will be moderate with some *S. frugiperda* being lost over water.

12) Using vertical entomological radar, Chapman et al. (2002) made a conservative estimate that over four consecutive nights in May 2000, approximately 3,000 *Plutella xylostella* (Lep: Yponomeutidae) per kilometre of migration front entered the UK from continental Europe (Netherlands, Belgium, Germany) using favourable winds.

13) Combining data from entomological radars and ground-based light traps Chapman et al. (2012) estimated that 10–240 million *Autographa gamma* (Lep: Noctuidae) reached the UK each year from continental Europe.

Estimation: Taking the above information into account, expert judgement was used to estimate five quantiles for each substep in the migration pathway.

	Substep	Percentile				
		1st	25th	Median (50th)	75th	99th
P0	Area of host crop	Fixed/constant (FAO stat)				
P1	Proportion of crop acting as a source for migrating adults	0.10	0.55	1.00	1.00	1.00
P2	*S. frugiperda* density in source crops	0.1	0.4	1.0	2.5	10.0
P3	Proportion of adults engaging in migration	0.1	0.35	0.5	0.65	0.9
P4	Proportion of trajectories that connect source populations to the EU	0.01	0.03	0.1	0.3	1.0
P5	Proportion of adults surviving migration to reach EU	0.001	0.01	0.1	0.3	0.9

P1: This proportion is considered to be fairly large (ranging from 0.1 to 1 with 1 as a median) because of the large potential of the insect to disperse within-season, but uncertainty is also included.

P2: This represents the density of the insect in host crops. Evidence from the USA points to *S. frugiperda* densities of 0.39 to 3.9 adults produced per m^2 in maize crops in Texas (Pair et al., 1991). A broader range than this (0.1 to 10 adults produced per m^2) was adopted in the elicitation to reflect a lack of information from the region (*S. frugiperda* is not established in North Africa). Low densities would reflect marginal conditions for the insect, either due to climate or low input agriculture resulting in host crops with low nitrogen content. High densities would indicate good conditions for the insect, assuming high inputs, e.g. irrigation and fertiliser, but poor control.

P3: The proportion of adults engaging in long-distance flight was based on information in Westbrook et al. (2016) who built a model for the seasonal migration of *S. frugiperda* in the USA. These authors used values for the proportion of adults engaging in long-distance flight of 0.1 and 0.9 in their model, depending on the developmental stage of the maize crop. The elicitors adopted a range for P3 from 0.1 to 0.9, with a symmetric distribution and 0.5 as a centre.

P4: This parameter is related to the weather systems that can transport the moth from northern Africa to Europe. Based on simulations with the HYSPLIT model (Stein et al., 2015), the probability of aerial trajectories starting in source locations reaching Europe within the maximum flight duration of the moth (not more than 12 h as it is a night flier) was estimated to range from 0.001% to 1%. There is thus high uncertainty about the value of this parameter.

P5: This is the proportion of moths surviving flight. There is no virtually no information on this parameter, other than general knowledge that some butterflies are able to migrate from Africa to southern Europe in substantial numbers (*Vanessa cardui*; Stefanescu et al., 2007) while on the other hand, the exposure during a long flight is expected to take a death toll due to exhaustion, desiccation, predators, etc. A broad range was elicited, from 0.001 to 0.9 to express lack of substantial information.

Appendix O – Evidence dossier: Establishment

O.1.   Ensemble modelling

Maps from SDM ensemble modelling with various thresholds are presented below.

0.452 (coded in Figure O.1 as 450) is the threshold that encompasses 95% of the 407 presences used to make the models. This threshold results in an average of 67% ($\pm$ 0.02 stdev) of the 407 pseudo-absence locations being correctly predicted to be unsuitable. This could be interpreted as a 33% likelihood of an **orange** or **blue** site in fact being unsuitable, and a 5% chance of a non-coloured site in fact being suitable. (Note this result is the composite result of hundreds of randomly generated pseudo-absence sets).

0.58 (coded as 580 in Figure O.1) is the threshold that encompasses 90% of the 407 presences used to make the models. This threshold results in 76% ($\pm$0.02 stdev) of the 407 pseudo-absence locations being correctly predicted to be unsuitable. This could be interpreted as a 24% likelihood of a **blue** site in fact being unsuitable, and a 5% chance of a non-coloured or **orange** site in fact being suitable. This result is the composite result of hundreds of randomly generated pseudo-absence sets. The blue sites are a subset of the orange sites.
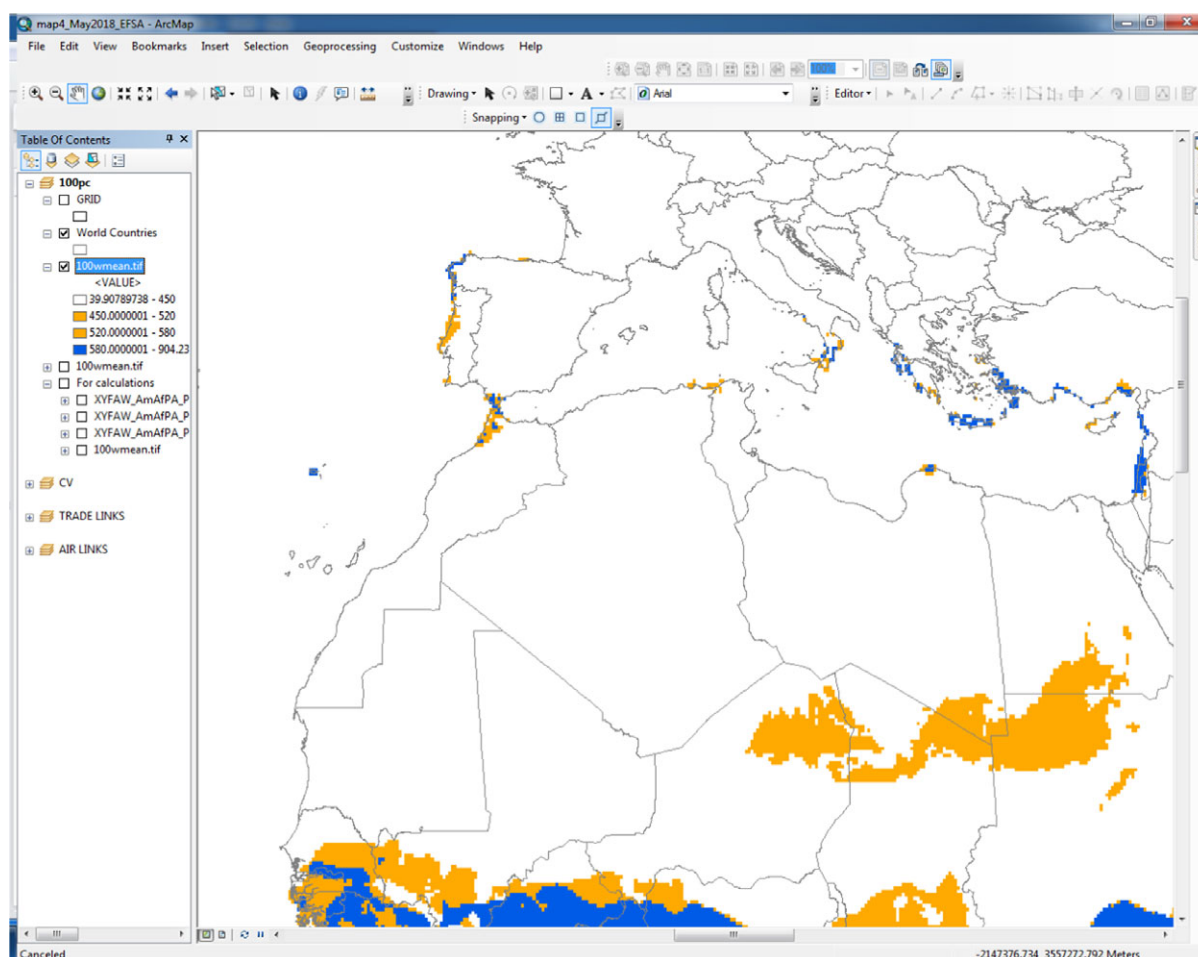

Figure O.1: Locations in northern Africa and Europe where ensemble modelling indicates the environment is suitable for establishment of *S. frugiperda* (based on a threshold of 0.452). See text for further explanation

The reason that parts of the Sahara desert is shown as suitable is perhaps because some of the hot areas *S. frugiperda* occupies in the Americas are irrigated, but irrigation is not accounted for in the SDMs. Therefore, the models think these sites are hot and dry rather than hot and wet. The relevant occurrence data are in the east of Chile (SumWet values of 5, 25, 50, 60 mm) and the centre of Mexico (93, 112 mm). The driest place occupied in Chile is just north of Lima in Sechura desert. The

other points are also in the Sechura desert. According to Wikipedia 'Short rivers flowing across the desert from the Andes support intensive irrigation-based agriculture.' This impression is borne out by looking at the driest populations in Chile, where the populations are encompassed by orange cells but not blue.

The Mexican populations in very dry areas are predicted to be unsuitable by the lower threshold, but this is probably because they are too cold as well as too dry. This could also be true for the unpredicted Chilean population and the unpredicted Texas population.
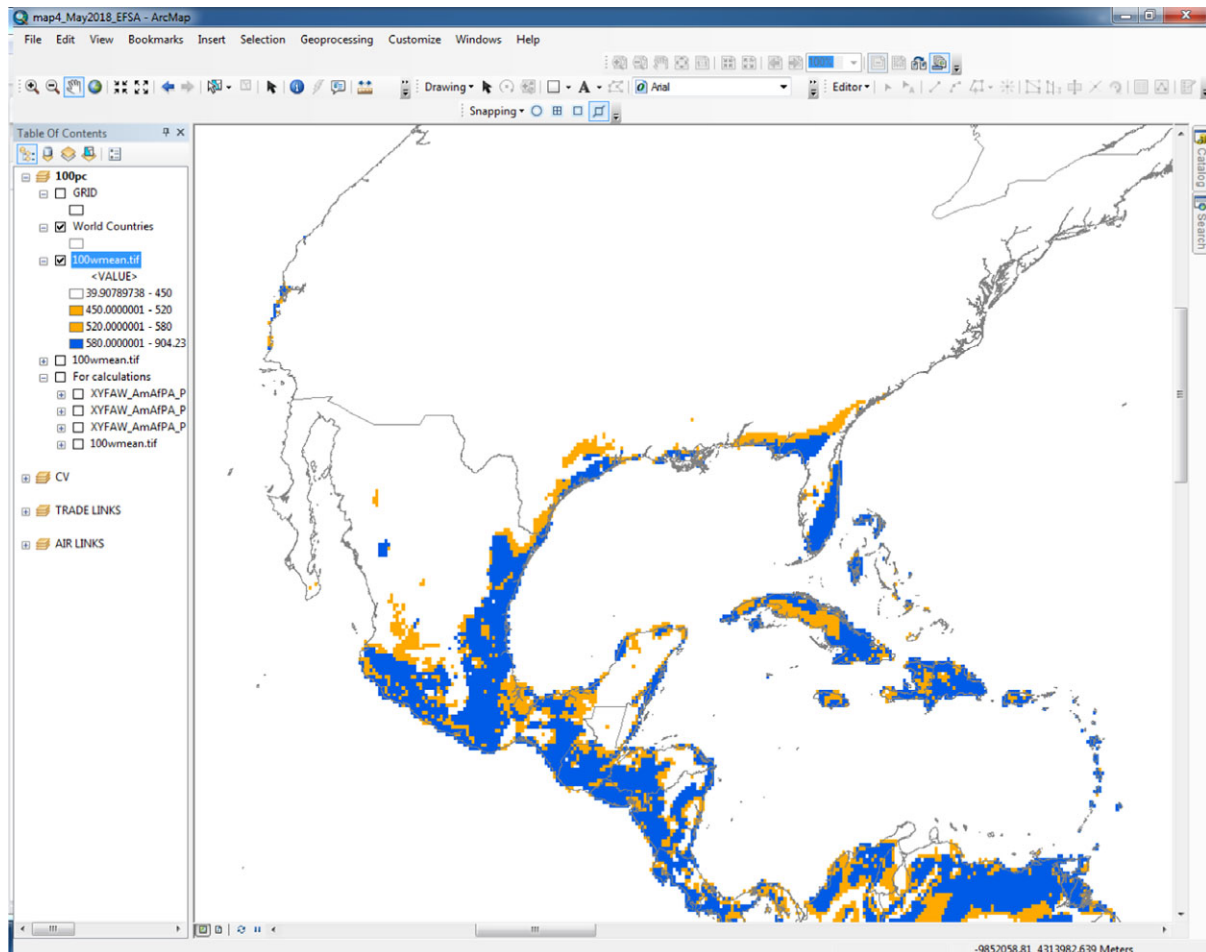

Figure O.2: Locations in Central and North America where ensemble modelling indicates the environment is suitable for establishment of *S. frugiperda* (based on a threshold of 0.452). See text for further explanation

O.2.   Uncertainty in agreement between models in ensemble

Uncertainty between SDM models in the ensemble can be considered as the uncertainty that the **ensemble** accurately represents the favourability of the environment for *S. frugiperda* population growth, given the different measures of favourability that result from different data sets and models. It could also indicates the relative suitability between sites.

In Figure O.3 below, the green cells are above the higher threshold of 0.572 (which has a type I error rate of 0.1). A high (more green) value means the prediction in the cell is more precise, i.e. it's agreed upon by more models. The quantiles are based on the level of agreement between model global predictions, so the 50th percentile represents the median level of agreement worldwide. All but one point have agreement between models above 50% (there is one point in yellow on the north coast of Spain).
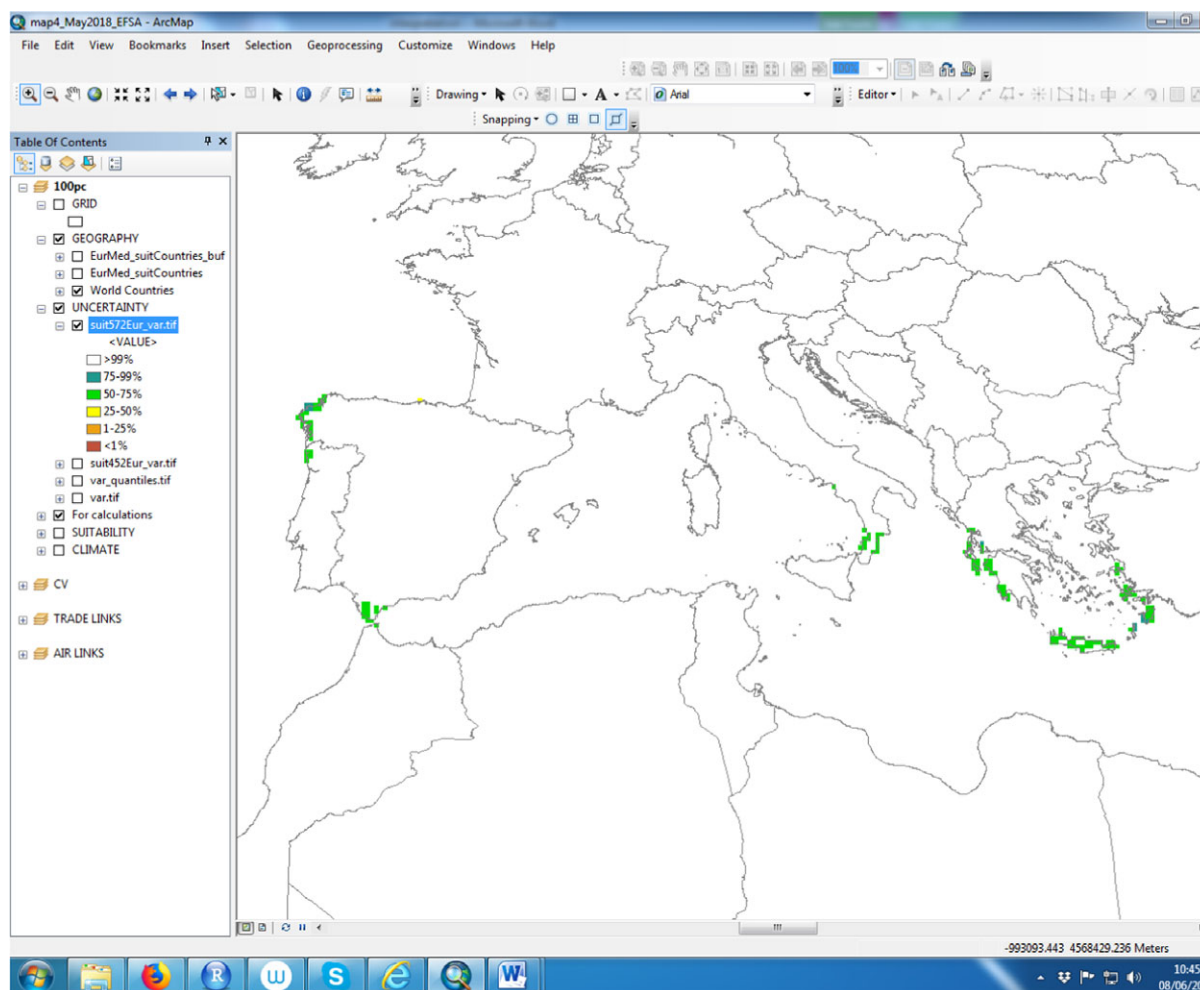
Figure O.3: Locations Europe where ensemble modelling indicates the environment is suitable for establishment of *S. frugiperda* (based on a threshold of 0.452). See text for further explanation
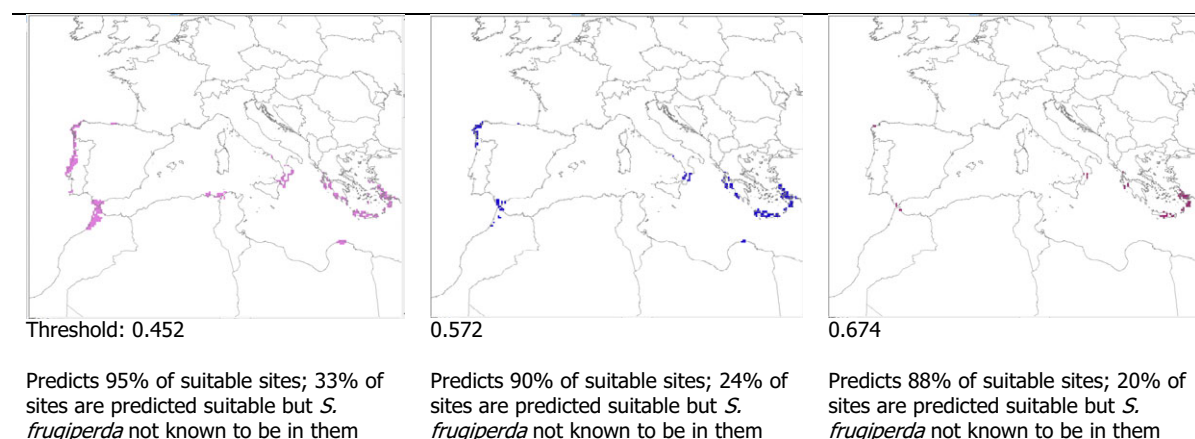
O.3. Uncertainty in the lower limit of suitability for *S. frugiperda* year-round establishment

This is the uncertainty in where the **threshold** should be drawn, above which we are confident that *S. frugiperda* can establish year-round populations, or complete a single generation. Four thresholds were applied.

Rationale	Threshold	% of known *S. frugiperda* sites predicted to be unsuitable (Type I error or the inverse of sensitivity) (±standard deviation)	% of sites where *S. frugiperda* is not present, predicted to be suitable, (Type II error or the inverse of specificity) (±standard deviation)
Predicts all but 5% of known *S. frugiperda* sites to be suitable	0.452	5%	33% (±0.02)
Predicts all but 10% of known *S. frugiperda* sites to be suitable	0.572	10%	24% (±0.02)
Maximises the sum of the accuracy of predicting	0.674	12% (±0.02)	20% (±0.03)

Rationale	Threshold	% of known *S. frugiperda* sites predicted to be unsuitable (Type I error or the inverse of sensitivity) (±standard deviation)	% of sites where *S. frugiperda* is not present, predicted to be suitable, (Type II error or the inverse of specificity) (±standard deviation)
occupied sites to be suitable and unoccupied sites to be unsuitable (i.e. sum of sensitivity and specificity)			
Minimises the difference between the accuracy of predicting occupied sites to be suitable and unoccupied sites to be unsuitable (i.e. difference between sensitivity and specificity)	0.625	17% (±0.02)	17% (±0.01)

If thresholds are used when generating a map, the threshold to use should align with the level of uncertainty that is acceptable (to the risk manager). However, selection of threshold should also be based on the known problems with the data used to calculate specificity. There are accurate records of the presences, but not the absences of *S. frugiperda*. The absence data are much more likely to be wrong than the presence data. This suggests that sensitivity should be weighted more highly than specificity.

Threshold: 0.452

Predicts 95% of suitable sites; 33% of sites are predicted suitable but *S. frugiperda* not known to be in them

0.572

Predicts 90% of suitable sites; 24% of sites are predicted suitable but *S. frugiperda* not known to be in them

0.674

Predicts 88% of suitable sites; 20% of sites are predicted suitable but *S. frugiperda* not known to be in them

The sequence of maps for different thresholds clearly shows how the area of potential establishment of *S. frugiperda* is shrinking as the type II error rate is reduced (i.e. the proportion of absence locations classified as suitable). It shows that the actual area of potential establishment where winter survival is possible in Europe and northern Africa could be very marginal indeed.