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Pest risk assessment of *Amyelois transitella* for the European Union

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Abstract

Following a request from the European Commission, the EFSA Panel on Plant Health performed a pest risk assessment of *Amyelois transitella* (Lepidoptera: Pyralidae), the navel orangeworm, for the EU. The quantitative assessment considered two scenarios: (i) current practices and (ii) a requirement for chilled transport. The assessment focused on pathways of introduction, climatic conditions and cultivation of hosts allowing establishment, spread and impact. *A. transitella* is a common pest of almonds, pistachios and walnuts in California, which is the main source for these nuts imported into the EU. Based on size of the trade and infestation at origin, importation of walnuts and almonds from the USA was identified as the most important pathways for entry of *A. transitella.* Using expert knowledge elicitation (EKE) and pathway modelling, a median estimate of 2,630 infested nuts is expected to enter the EU each year over the next 5 years (90% certainty range (CR) from 338 to 26,000 infested nuts per year). However, due to estimated small likelihoods of transfer to a host, mating upon transfer and survival of founder populations, the number of populations that establish was estimated to be 0.000698 year^{-1} (median, 90% CR: 0.0000126–0.0364 year^{-1}). Accordingly, the expected period between founding events is 1,430 years (median, 90% CR: 27.5–79,400 year). The likelihood of entry resulting in establishment is therefore considered very small. However, this estimate has high uncertainty, mainly concerning the processes of transfer of the insect to hosts and the establishment of founder populations by those that successfully transfer. Climate matching and CLIMEX modelling indicate that conditions are most suitable for establishment in the southern EU, especially around the Mediterranean basin. The median rate of natural spread was estimated to be 5.6 km/year (median, 90% CR 0.8–19.3 km/year), after an initial lag period of 3.1 year (mean, 90% CR 1.7–6.2 year) following the establishment of a founder population. If *A. transitella* did establish, estimated median yield losses in nuts were estimated to be in the order of 1–2% depending on the nut species and production system. A scenario requiring imports of nuts to be transported under chilled conditions was shown to provide potential to further reduce the likelihood of entry.

Keywords: Navel orangeworm, quantitative pest risk assessment, @Risk, pathway model, establishment, impact, EKE

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Summary

The EFSA Panel on Plant Health performed a quantitative pest risk assessment of *A. transitella* (Lepidoptera: Pyralidae), the navel orangeworm, for the EU. The assessment focused on pathways and likelihood of introduction, climatic conditions allowing establishment, availability of cultivated host plants, spread and impact.

A. transitella is a common pest of almonds, pistachios and walnuts in California, which is the main source area for these nuts imported into the EU. Besides these three main hosts, the insect also feeds on other crops, including figs, oranges, plums and pomegranates although it is mostly damaged and fallen fruit and fruit that is left after harvest which become infested. The panel evaluated the host range of *A. transitella* and assessed which commodities from which areas would provide pathways with the greatest potential for entry. Several commodities were excluded from quantification because the quantity of infested product shipped to the EU would be minor, often several orders of magnitude lower, when compared to other pathways. For example, figs, which can occasionally be infested both as fresh and as dried products but with import volumes often 1,000 times lower than imports of almonds and walnuts which are more favoured hosts. Similarly, pomegranates were not quantified as a pathway because of the small magnitude of the trade. Orange was excluded because the insect can infest oranges only if the rind is broken, making the fruit unmarketable. Furthermore, under the prevalent phenology of *A. transitella* in the USA, with three to four flight periods per year, oranges are not likely to be in a vulnerable stage at the time of flight of egg-laying adults. Pecan nuts were excluded from evaluation because they are not a host, despite the superficial similarity to walnuts, which are a main host. Pistachios were excluded as a pathway because the customary drying and heating treatments applied to pistachio, which target pathogens, also kill all contaminating insects. Thus, two commodities remained for further evaluation: walnuts and almonds. These crops are favoured hosts of *A. transitella* and are often found infested in the field. Furthermore, there is a large international trade of walnuts and almonds from California, where *A. transitella* is endemic, to the EU. While *A. transitella* has been reported to be present in southern Brazil (i.e. Sao Paulo state), pathways involving nuts (walnuts and almonds) from Brazil were not considered further given that only 31 kg of almonds was imported to the EU from Brazil between 2016 and 2020 (cf. approximately 1.2 million tonnes of almonds from USA during the same period).

Pathway models were quantitatively elaborated for walnuts inshell, shelled walnuts, almonds inshell and shelled almonds from the USA to the EU. The pathway models took into account the volume of trade, the level of infestation with *A. transitella* in the harvested nuts, the effectiveness of measures in the processing and packing houses to eliminate infested nuts and live insects in nuts from the trade and survival during transport to the EU. Upon arrival in the EU, the allocation of imports to regions with suitable or unsuitable climates and host plant presence were taken into account, as was the period of import, as conditions for transfer and establishment are more suitable during the growing season than in winter. The panel assessed the transfer of insects from infested nuts to hosts using expert knowledge elicitation (EKE). Likewise, the panel used EKE to assess the likelihood of mating and the founding and survival of new populations upon successful mating.

The panel evaluated the methods that are used in the USA to eliminate infested nuts and live insects from nuts. This includes optical laser and mechanical technology during sorting, chemical treatments (phosphine and sulfuryl fluoride) and heat treatments. There is no overview of the proportion of the harvested product that is subjected to different treatments; however, there is an overall aim of the industry to reach Probit-9 mortality, that is a survival of 32 insects out of one million. Given the effectiveness of fumigation treatments against *A. transitella*, this target efficacy of treatment was judged by the panel as feasible and it was taken into account in its assessment of the survival in the processing and packing houses.

Based on EKE and pathway modelling, a median estimate of 2,630 infested nuts is expected to enter the EU each year over the next 5 years (90% certainty range (CR) from 338 to 26,000 infested nuts per year). The median number of infested nuts entering each year into areas with suitable climates in the southern EU at a suitable time of year was estimated as 512 (median; CR: 54.7–5,550). By far the largest pathway contributing approximately 95% of infested nuts is shelled almonds (median 463; CR 37–5,400) mainly because shelled almonds represent 95% of the number of imported nuts.

A scenario of transport under cooled conditions (−3 to 0°C) was shown to provide potential to further reduce the likelihood of entry.

The panel estimated that the import of infested nuts results in a small probability of establishment of a founder population and this requires that the insects find a host, that sufficient insects co-occur at a place to initiate a viable reproducing population, and pest control or predation and parasitism by natural enemies fails to prevent establishment.

Due to estimated small likelihoods of transfer to a host, mating upon transfer and survival of potential founder populations, the number of populations estimated to establish was 0.000698 $year^{-1}$ (median, 90% CR: 0.0000126–0.0364 $year^{-1}$). Accordingly, the expected period between founding events resulting in establishment of a population is 1,430 years (median, 90% CR: 27.5–79,400 year). This implies that the likelihood of introduction is exceedingly low, in part due to the difficulty of establishing a founder population. Although infested nuts have been intercepted on several occasions across the world, so far *A. transitella* has not established anywhere outside the Americas, which is consistent with the panel's conclusion on a low probability of establishment. Thus, entry does occur, but establishment of populations is expected to be rare and so far has not been demonstrated outside of the Americas.

Recognising that the 90% certainty range for the time interval between new introductions is from 27.5 to 79,400 years, there is significant uncertainty regarding the likelihood of introduction, mainly due to uncertainties on the processes of transfer of the insect to hosts and the establishment of new founder populations by successfully transferring insects.

To identify where in the EU climate is suitable for establishment, a literature search was conducted to assemble a database with all known location records of *A. transitella*. In addition, a literature search was conducted to collect data on climate factors affecting life cycle parameters (development rate, survival, reproduction) of *A. transitella*. These data were used to develop eco-physiological relationships to model the potential for establishment using the modelling framework CLIMEX. Furthermore, presence locations were overlaid with Köppen–Geiger climate maps to identify climates conducive to establishment. Both CLIMEX and climate matching indicate that conditions are most suitable for establishment in the southern EU, especially around the Mediterranean basin. Hosts grown in the EU include almonds, apples, figs, oranges, pears, pistachios, plums and walnuts; hence, hosts are widespread, and establishment will be mostly limited by climate. If a founder population were to establish the Panel estimated that there would be a lag period of 3.1 year (median, 90% CR 1.7–6.2 year) before *A. transitella* would spread by natural means at an estimated rate of 5.6 km/year (median, 90% CR 0.8–19.3 km/year).

If *A. transitella* did establish and spread, median yield losses in EU almonds grown under conditions of intensive production were estimated to be 2.0% (90% CR 0.2–6.4%) whilst in non-intensive (traditional) almond production, median yield losses were estimated to be 0.9% (90% CR 0.2–2.9%). Pistachio production was estimated to suffer 1.3% yield loss (90% CR 0.1–4.0%) and walnuts 1.1% yield loss (90% CR 0.1–3.3%) due to *A. transitella*.

A scenario requiring imports of nuts to be transported under chilled conditions was shown to provide potential to further reduce the likelihood of entry.

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1. Introduction

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

1.1.1. Background

The new Plant Health Regulation (EU) 2016/2031, on the protective measures against pests of plants, is applying from 14 December 2019. Conditions are laid down in this legislation in order for pests to qualify for listing as Union quarantine pests, protected zone quarantine pests or Union regulated non-quarantine pests. The lists of the EU regulated pests together with the associated import or internal movement requirements of commodities are included in Commission Implementing Regulation (EU) 2019/2072. Additionally, as stipulated in the Commission Implementing Regulation 2018/2019, certain commodities are provisionally prohibited to enter in the EU (high risk plants, HRP). EFSA is performing the risk assessment of the dossiers submitted by exporting to the EU countries of the HRP commodities, as stipulated in Commission Implementing Regulation 2018/2018. Furthermore, EFSA has evaluated a number of requests from exporting to the EU countries for derogations from specific EU import requirements.

In line with the principles of the new plant health law, the European Commission with the Member States are discussing monthly the reports of the interceptions and the outbreaks of pests notified by the Member States. Notifications of an imminent danger from pests that may fulfil the conditions for inclusion in the list of the Union quarantine pest are included. Furthermore, EFSA has been performing horizon scanning of media and literature.

As a follow-up of the above mentioned activities (reporting of interceptions and outbreaks, HRP, derogation requests and horizon scanning), a number of pests of concern have been identified. EFSA is requested to provide scientific opinions for these pests, in view of their potential inclusion in the lists of Commission Implementing Regulation (EU) 2019/2072 and the inclusion of specific import requirements for relevant host commodities, when deemed necessary.

1.1.2. Terms of reference (ToR)

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

EFSA is requested to deliver 50 pest categorisations for the pests listed in Annex 1A, 1B and 1D. Additionally, EFSA is requested to perform pest categorisations for the pests so far not regulated in the EU, identified as pests potentially associated with a commodity in the commodity risk assessments of the HRP dossiers (Annex 1C). Such pest categorisations are needed in the case where there are not available risk assessments for the EU.

When the pests of Annex 1A are qualifying as potential Union quarantine pests, EFSA should proceed to phase 2 risk assessment. The opinions should address entry pathways, spread, establishment, impact and include a risk reduction options analysis.

Additionally, EFSA is requested to develop further the quantitative methodology currently followed for risk assessment, in order to have the possibility to deliver an express risk assessment methodology. Such methodological development should take into account the EFSA Plant Health Panel Guidance on quantitative pest risk assessment and the experience obtained during its implementation for the Union candidate priority pests and for the likelihood of pest freedom at entry for the commodity risk assessment of High Risk Plants.

ANNEX 1 List of pests

A)

1. *Amyelois transitella*.
2. *Citripestis sagittiferella*.
3. *Colletotrichum fructicola*.
4. *Elasmopalpus lignosellus*.
5. *Phlyctinus callosus*.
6. *Resseliella citrifrugis*.
7. *Retithrips syriacus*.
8. *Xylella taiwanensis*.

E)

List of pests identified to develop further the quantitative risk assessment (phase 1 and phase 2) methodology followed for plant pests, to include in the assessments the effect of climate change for plant pests (for more details see Annex 3).

1. *Leucinodes orbonalis*.
2. *Leucinodes pseudorbonalis*.
3. *Xanthomonas citri* pv. *viticola*.

1.2. Interpretation of the Terms of Reference

The Terms of Reference relevant to *A. transitella* specify that the requested opinion should address entry pathways, spread, establishment, impact and include a risk reduction options analysis. The panel therefore undertook a quantitative pest risk assessment according to the principles laid down in its guidance on quantitative pest risk assessment (EFSA PLH Panel, 2018).

2. Data and methodologies

Four steps were distinguished; the assessment of (1) entry including transfer, leading to the initiation of a founder population, (2) establishment, (3) spread, (4) impact.

Assessment was based on a combination of literature review, meta-analysis, interviews with hearing experts and expert knowledge elicitation with experts or panel members and EFSA staff to assess quantities that could not be well identified from literature or databases alone (EFSA, 2014). To link pest entry with establishment potential, the distribution of infested plant material entering the EU was assessed using NUTS 2 spatial resolution. Phytosanitary measures that may be considered to reduce likelihood of pest entry were evaluated by comparing scenarios with and without additional measures in place.

2.1. Entry

According to ISPM5 and ISPM 11 (FAO, 2017, 2022), a pathway is any means that allows the entry or spread of a pest. In this opinion, the term 'potential pathway' is used to denote a candidate pathway for which it is uncertain whether it allows the entry or spread of a pest, for instance because of uncertain host status of a commodity, or insufficient information on association between the pest and the commodity.

A pest categorisation identified a variety of host nuts, fruits and plants for planting as potential pathways for *A. transitella* (EFSA PLH Panel et al., 2021). More detailed consideration during the early stages of this assessment, including discussions with hearing experts from USDA, led to some of the potential pathways being ruled out (see Section 3.1.7) and the assessment of entry then focused on walnuts inshell and shelled, and almonds inshell and shelled. Evidence for ruling out pathways is provided in Section 3.1.7.

Following the development of a pathway model (Section 2.1.1), each pathway was assessed individually using @Risk for Microsoft Excel under two scenarios. Scenario A0 is a baseline with existing industry practices and any relevant phytosanitary measures. Fresh fruit and nuts have been regulated in recent years and require a phytosanitary certificate for entry into the EU (EC 2019/2072, Annex XI, Part A) unless exempt by being listed in 2019/2072 Annex XI, Part C; Scenario A1 considers the effect of additional phytosanitary measures, in this case the implementation of cooled transport to the EU (Table 1). Background information and data from literature summarised as 'evidence dossiers' (Appendices A and C) were combined with information from hearing to elicit parameters for each component of four pathway models (Appendices B and D). Estimates were determined following expert knowledge elicitation (EKE) (EFSA, 2014). @Risk was used to calculate the likelihood of entry by combining all pathways.

Table 1: Pathways and scenarios assessed

Pathway	Scenario A0 (baseline)	Scenario A1 (with additional measure)
Walnuts, inshell from USA	Existing industry practices and phytosanitary measures	Existing industry practices and phytosanitary measures with additional requirement for chilling during transport
Walnuts, shelled from USA	"	"

Pathway	Scenario A0 (baseline)	Scenario A1 (with additional measure)
Almonds, inshell from USA	"	"
Almonds, shelled from USA	"	"

The ability of a pest to transfer to a host is a critical and little studied component of invasion biology and forms a link between pest entry and establishment (Devorshak, 2012). For a pest to be introduced into a new geographic area, it has to both enter and establish (IPPC, 2017). The panel developed pathway models for entry (including transfer), and additionally included the steps of mating after transfer and likelihood of survival of founder populations, to assess the potential of entry to result in populations of *A. transitella* in EU. The pathway model for establishment of founder populations followed the conceptual approach of van der Gaag et al. (2019) estimating the number of potential founder populations that would arise in the EU, taking into account biotic and abiotic factors.

The literature on the biology and control of *A. transitella* was synthesised to summarise the insect's biology and life cycle and to assess the principal methods of control used in the field and the subsequent prevalence of infestation of commodities under field conditions in California. California is the main area of production of walnuts and almonds destined for export to EU. Walnuts and almonds were identified as the most important pathways for introduction of *A. transitella*. Pest information, on hosts and distribution, was retrieved from the EPPO Global Database (EPPO, 2021, accessed on 1 September 2021) and information gathered during the pest categorisation on *A. transitella* (EFSA Plant Health Panel, 2021) was further updated with literature and reports, including both peer-reviewed and grey literature sources. The data on hosts were supplemented with additional hosts retrieved from the database of the World's Lepidopteran Hostplants curated by the Natural History Museum (NHM, 2022), UK and freely available online: https://www.nhm.ac.uk/our-science/data/hostplants/search/index.dsml.

Data on EU imports of key hosts from third countries were obtained from the Eurostat Easy Comext platform: inshell walnuts (CN code 08023100), shelled walnuts (CN code 08023200), inshell almonds (CN code 080211), shelled almonds (CN code 080212). Import data including information on the type of the transport (by air and by sea) was extracted from Eurostat in March 2022 (years 2000–2021). Data regarding plants for planting were sourced from the Netherlands Food and Consumer Product Safety Authority. Data and information regarding the transport of commodities was obtained from CargoHandbook.com. Data on human population at NUTS 2 level were extracted from EUROSTAT.

Data on EU interceptions of *A. transitella* were checked in Europhyt (1994 to June 2020) and Traces (June 2020 to ongoing) but produced no records (last check: 1 June 2022). Publications about findings in the EU were obtained and included in the assessment (Trematerra, 1988; Burmann, 1995; Essl et al., 2002).

A literature review was conducted on the efficacy of phosphine and sulfuryl fluoride, suggested as the most common post-harvest treatments in *A. transitella* handling, by Spencer Walse, a post-harvest specialist from the USDA.

Relevant publications were searched in Web of Science (topic search and all databases) and Google Scholar (generic search with no limitations). An initial search with "Lepidoptera" AND "phosphine" resulted in a list of 162 publications. After screening, 20 papers were selected for further analysis, 14 of which were used for data extraction. Papers were eliminated at the initial stage because (i) the focus of the experiment was not Lepidoptera; (ii) the paper was not a primary study, but a review; (iii) studies were older than 1990; (iv) studies were done with methyl bromide, while phosphine was mentioned without providing data; (v) duplicated data were presented that were present in other, more comprehensive, sources. Similar analyses were done for sulfuryl fluoride. An initial search with "Lepidoptera" AND "sulfuryl fluoride" resulted in 477 documents. After screening, seven papers, three of which targeting *A. transitella*, were retained and used for data extraction. All the other documents were not used because (i) the focus was not Lepidoptera; (ii) no efficacy trials were reported; (iii) sulfuryl fluoride was only mentioned and was not the subject of the paper; (iv) duplicates were removed. Data were also retrieved from papers reporting efficacy trials on other pests (namely Coleoptera and Psocoptera). The following values were extracted: dose, unit, temperature, treatment concentration × time (CT), species of Lepidoptera, stage, trial conditions, percentage of mortality. Summary tables of the review on efficacy of phosphine and sulfuryl fluoride are given in Appendix E.

2.1.1. Pathway modelling

Pathway modelling aims to decompose the process of pest introduction into its components and assess each component quantitatively to assess its contribution to pest introduction and its contribution to uncertainty in the assessment of introduction.

The process of pest introduction is defined by the IPPC as the entry[1] of a pest resulting in its establishment[2] (FAO, 2022). Introduction can therefore be divided into the assessment of pest entry and the assessment of pest establishment. The process of pest transfer to a host is a key step that links entry to establishment.

The panel developed four pathway models, one for each of the four pathways considered potentially most important: (1) walnuts inshell from the USA, (2) shelled walnuts from the USA, (3) almonds inshell from the USA and (4) shelled almonds from the USA. Each pathway model comprised a multiplication of 11 quantities to determine the number of new founder populations of *A. transitella* in EU as a result of the pathway. The 11 quantities are:

1) Trade volume (kg/year)*
2) Individual nut weight (kg)*
3) Proportion of nuts shipped in the same year as they were produced (constant calculated from data)#
4) Proportion of nuts infested with *A. transitella* arriving at packing house after harvest*
5) Survival of measures taken at the packing house to kill *A. transitella* eggs, larvae and pupae inside nuts or remove infested nuts from trade flow at packing line (proportion of surviving insects)*
6) Proportion of eggs and larvae in infested nuts surviving transport from USA to EU*
7) Proportion of nuts transported to NUTS-2 regions with suitable climate#
8) Proportion of nuts imported during suitable parts of the year (this excludes the winter months)#
9) Probability of pest transfer from infested nuts to hosts in EU territory, given its natural behaviour and proximity of a suitable site*
10) Probability of sufficient numbers of *A. transitella* being present to lead to mating following transfer*
11) Probability that pest management regime and natural mortality factors on the vulnerable host will allow survival of a founder population, taking into account that small populations can go extinct easily due to demographic stochasticity*

The eight quantities marked with an asterisk (*) were elicited by expert judgement including assessment of uncertainty. Three parameters marked with a hash tag (#) were determined directly from data as point estimates, not considering uncertainty.

The expected number of newly established populations per year due to product import via a given pathway is calculated by simple arithmetic using Monte Carlo simulation to take into account uncertainty in elicited parameters. This procedure is illustrated in Figure 1.

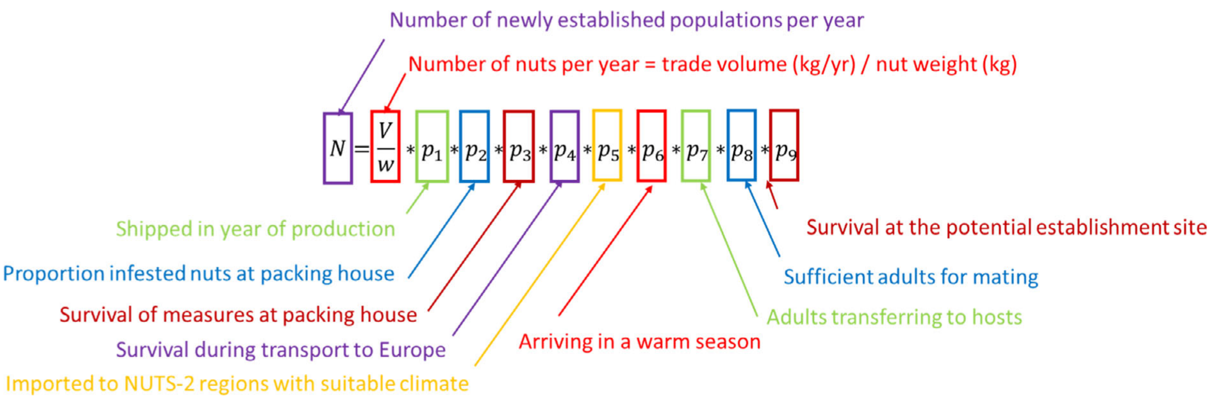

Figure 1: Annotated pathway model

[1] Entry (of a pest): Movement of a pest into an area where it is not yet present, or present but not widely distributed and being officially controlled (FAO, 2022).
[2] Establishment: Perpetuation, for the foreseeable future, of a pest within an area after entry (FAO, 2022).

The panel selected the four pathways on almond and walnuts from the USA because they represent a large trade volume while infestation with *A. transitella* is prevalent under field conditions in California, the main growing area in the USA. Each pathway model consists of 11 steps, and 8 of 11 parameters of the model were elicited as distributions expressing certainty of the estimates on the basis of the information available. Three parameters were directly estimated from data without quantifying uncertainty.

The first component in the pathway model is trade volume (V in Figure 1). Data on trade volume were obtained from Eurostat for the years 2000–2021. A projection was then made for the years 2022–2026 to describe the average yearly import of the category of nuts over a 5-year time frame in the immediate future (Section 2.4).

The second component is the nut weight (w in Figure 1). Data from the literature and the internet were used to elicit a distribution of the weight of nuts with and without shell.

Component 3 (p_1 in Figure 1) accounts for a proportion of nuts that are kept in cold storage for marketing the next year. *A. transitella* does not survive extended cold treatment (Tebbets et al., 1978; Johnson, 2007). The parameter p_1 is the proportion of nuts traded in the year of production, i.e. those nuts that may contain live insects not affected by long duration cold storage.

Component 4 (p_2 in Figure 1) is the proportion of infested nuts at the packing house before treatments. This proportion of infested nuts represents what is coming from the orchards, and information from publications on pest control of *A. transitella* was used to elicit distributions.

Component 5 (p_3 in Figure 1) is the survival of treatments and practices in the packing house. Treatments in the packing house aim at minimising the number of nuts leaving the packing house with viable insects (eggs, larvae or pupae) in or on them. The panel analysed information on efficacy of fumigation products, such as phosphine and sulfuryl fluoride and found that high control efficacy (Probit-9; Appendix I) can be achieved. Furthermore, packing houses may make use of pasteurisation and 'puffing', a practice whereby light nuts, i.e. those that are infested, are blown off a conveyor belt. Such measures would be expected to reduce the proportion of infested nuts leaving the packing house. The panel did not estimate the efficacy of these measures separately as no information was available on the frequency of treatments with different products. Instead, an overall assessment of the efficacy of measures was made taking into account the efficacy of available products and the importance for nut exporters to make the product pest free. Survival was assessed at the level of the nuts. In the elicitation, the panel assessed which proportion of nuts containing live eggs, larvae or pupae when entering the packing house would still be present with live insects in them when leaving the packing house.

Component 6 (p_4 in Figure 1) is the overall proportion of survival during transport or transport across the US from west to east coast before shipping, during dwell time at the harbour and during transport across the Atlantic to the EU. This survival is affected by cooling, the effectiveness of which was assessed in a scenario comparison.

Component 7 (p_5 in Figure 1) is the proportion of imported nuts that is allocated to NUTS-2 regions that have climatic conditions suitable for establishment. The CLIMEX maps described in Section 3.2 were used to identify the regions to which entry might result in establishment, and the panel calculated the proportion of imported nuts going to such regions, making the simplifying assumption that import would be proportional to human population size.

Component 8 (p_6 in Figure 1) is the proportion of nuts arriving during the warmer months of the year, when conditions for survival and reproduction of moths are considered more favourable. This excluded the winter months (November–February) which are considered unconducive to establishment. This proportion was estimated separately for each pathway on the basis of monthly trade data from Eurostat.

Component 9 (p_7 in Figure 1) represents the probability that the pest reaches a site and host suitable for establishment given its natural behaviour and the proximity of a suitable site. This probability was assessed using EKE.

Component 10 (p_8 in Figure 1) represents the probability that at a site suitable for establishment, sufficient individuals are present for male and female adults to locate each other and mate. This probability was assessed using EKE.

Component 11 (p_9 in Figure 1) represents the probability that the pest management regime and natural mortality factors at a suitable site, such as severe weather and birds or other natural enemies, will allow population initiation by an arriving pest, considering that small founder populations can go extinct easily due to demographic stochasticity. The model equation is:

$$N = \frac{V}{w} * p_1 * p_2 * p_3 * p_4 * p_5 * p_6 * p_7 * p_8 * p_9$$

where the meaning of symbols and their units is given in Table 2.

The pathway model is essentially a multiplication and division formula, in which each component is represented as a distribution to represent uncertainty about the exact value.

Table 2: Key to pathway model, consisting of entry, transfer and initiation and survival of a founder population

Entry		
N	Number of founder populations	
V	Trade volume	
w	Weight of one nut	
p_1	Proportion of nuts traded in the year of production (i.e. not kept in cold storage until the next year))	
p_2	Proportion of infested nuts at packing house	
p_3	Survival (proportion) of measures at packing house	
p_4	Survival during transport to the EU	
p_5	Proportion of nuts allocated to NUTS-2 regions that are suitable for establishment	
p_6	Proportion of nuts not imported during the coldest months of the year (November–February)	
Transfer		
p_7	Probability of finding a suitable site	–
p_8	Probability that sufficient numbers are present to allow successful mate finding at establishment location	–
Establishment and survival of founder population (initiation of founder population)		
p_9	Probability of surviving measures, practices and biological control at potential establishment location	–

The model is illustrated in Figure 1.

The consequences of the four pathways together were assessed by developing a model in which the four pathways were jointly simulated. Thereby correlation between parameters in different pathways (e.g. the level of infestation for shelled almond and almonds inshell) was taken into account.

2.1.2. Specification of the entry scenarios

Two scenarios were elaborated:

Scenario A0, the baseline. This is the situation representing the industry practices and regulatory conditions applied to each of the pathways when this assessment was started in June 2021. Scenario A1 is an imagined future situation where the pathways are all specifically regulated with respect to *A. transitella*, i.e. an additional risk reduction option (RRO) is in place, specifically the requirement for the commodities to be transported in controlled (chilled) conditions (−3 to 0°C). Experts evaluated the available evidence and discussed the effectiveness of the measure following EKE procedures (EFSA, 2014). Results from EKE were used to parameterise the pathway models for Scenario A1 and the effects on entry were calculated using the pathway model in @Risk. *A. transitella* is not a regulated pest in the EU 27, so a deregulation scenario was not analysed.

It was assumed that plants and plant products providing a pathway into the EU would be distributed within the EU in proportion to human population. Although there is regional difference when comparing diets within the EU, Elsner and Hartmann (1998), Mauracher and Valentini (2006) and Schmidhuber and Traill (2006) found European diets were becoming more similar, supporting the approach of allocating imported nuts within the EU by population. In this assessment, imports were spatially distributed by NUTS-2 region.

2.1.3. Uncertainty analysis of entry

The influence of parameter uncertainty in the pathway models for the default scenario (A0) was assessed using a statistical analysis of simulated data. First, each pathway model was run 50,000 times, drawing for each run parameter values from the distribution fitted to the elicited parameter estimates. This resulted for each pathway model in a data set of 50,000 records with for each record the simulated number of founder populations and the random values of the nine parameters of the model for each run. To express the contribution of uncertainty in the parameter to uncertainty of the overall outcome, the number of founder populations was regressed on the influencing parameters as independent variables using multiple linear regression. The influence of each parameter on the uncertainty of the outcome was expressed as partial R squared of each regressor (parameter), calculated and expressed as a percentage of the overall R squared of the regression model.

2.2. Establishment

The panel used two approaches for mapping climate suitability for establishment of *A. transitella*. The first is Köppen–Geiger climate classification which was used for comparing climates in the EU with those in known presence locations of *A. transitella* in the Americas. The SCANClim tool maps those areas that fulfil two conditions: (i) The organism has been found to occur in them in its endemic range, (ii) the climate type occurs in EU. Thus, if the organism occurs in a climate type that does not occur in the EU, this climate is not mapped as a relevant climate for the assessment. The panel used the implementation of Köppen–Geiger climate classification in SCANClim (EFSA and Maiorano, 2022). Secondly, the panel made use of maps produced using the fundamental niche model CLIMEX (Kriticos et al., 2015). CLIMEX uses ecophysiological requirements of an organism to assess its potential to fulfil the life cycle across a geographic region, given historic climate data. CLIMEX assesses the influence of weather-related stress factors (cold, heat, drought, humidity) on survival. The two factors (growth potential and survival) are integrated to provide an integrated index (the EI: ecoclimatic index) for establishment potential, given climate. CLIMEX is calibrated using presence records. Details on the two approaches are available on the Zenodo platform (Campese et al., 2022).

An extensive literature search for *A. transitella* global distribution and ecophysiological parameters influencing distribution was conducted by Campese et al. (2022).

The literature search was conducted on Web of Science (all databases, excluding Data Citation Index and Zoological Record) and Scopus on 2 August 2021. The search string was: ("Amyelois transitella" OR "Myelois duplipunctella" OR "Myelois notabilis" OR "Myelois notatalis" OR "Myelois solitella" OR "Myelois venipars" OR "Paramyelois transitella" OR "A transitella" OR "M duplipunctella" OR "M notatalis" OR "M solitella" OR "M venipars" OR "P transitella" OR ("navel orange" NEAR/3 worm*) OR (navel NEAR/3 (caterpillar* OR orangeworm*))). No other keywords were used (e.g. "biology", "physiology", "temperature", etc.) in order not to limit the retrieval of distribution data, often reported as secondary information (Campese et al., 2022). The search yielded 811 documents in total. Six additional references with information on physiology and distribution were added while gathering generic information on the pest in the very first stages of the assessment. All references were exported to the reference manager software EndNoteX9 (The EndNote Team, 2013) and checked for duplicates. References were then imported (as compressed Endnote library) in the software DistillerSR (Evidence Partners, 2021) and screened. Title and abstract of 771 documents were then assessed as a first-level screening. Out of these, 191 documents were selected for full-text screening (second level). Documents were considered eligible when providing information on the ecology, physiology and distribution of the pest. A total of 97 papers were used for the data extraction out of which 69 included information on *A. transitella* distribution and 51 information on its ecophysiology (Figure 2).

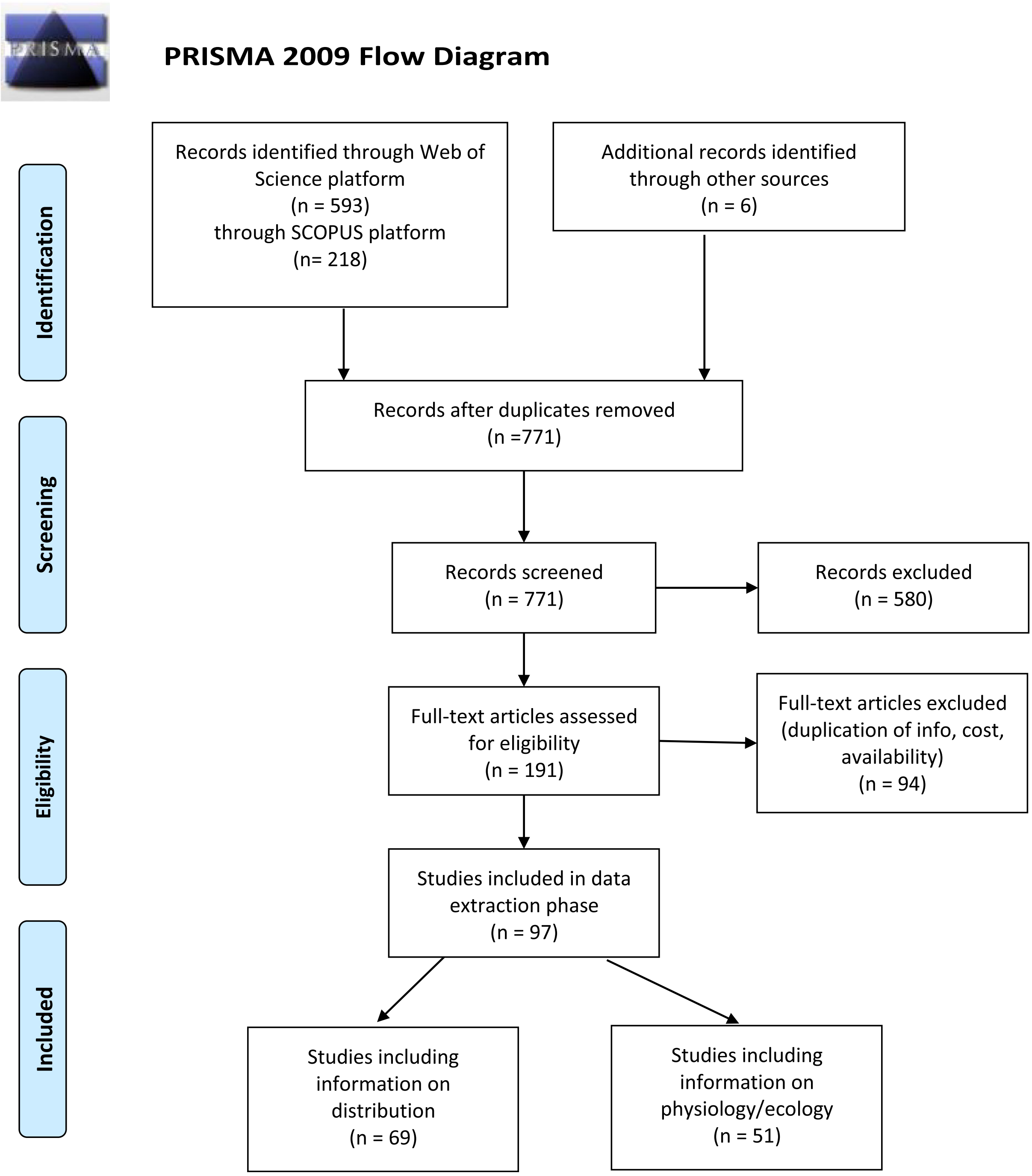

Figure 2: PRISMA diagram (according to Moher et al., 2009) describing the process followed to identify, screen and include eligible information on the ecology, physiology and distribution of the pest *Amyelois transitella*

All points of documented establishment of *A. transitella* were overlaid with climate maps to identify climate conditions allowing establishment. Furthermore, data on ecological requirements of the insect were retrieved from the literature to develop a CLIMEX model to refine the potential area of establishment in the EU. Distribution of the pest was first based on information in the EPPO Global Database (accessed on 2 August 2021) and the CABI Crop Protection Compendium (accessed on same date). Those findings were supplemented with the literature search described above (Campese et al., 2022). The search in scientific databases was completed on 15 September 2021 (Table 3).

Table 3: Scientific names (synonyms) and common names used in combination with other keywords during literature searches on *Amyelois transitella* whilst searching for information to inform the assessment of establishment

Scientific names	Source
Amyelois transitella	EPPO, CAB Thesaurus
Myelois duplipunctella	CAB Thesaurus
Myelois notabilis	CAB Thesaurus
Myelois notatalis	CAB Thesaurus
Myelois solitella	CAB Thesaurus
Myelois venipars	EPPO, CAB Thesaurus
Paramyelois transitella	EPPO, CAB Thesaurus
Common names	
Navel orangeworm	EPPO, CAB Thesaurus
Navel caterpillar	EPPO, CAB Thesaurus
Navel orangeworm	CAB Thesaurus

2.3. Spread and impact

An evidence dossier on spread and impact was assembled by EFSA staff and Working Group members and analysed by the panel to conceptualise the spread process and impact, to allow expert knowledge elicitation (EKE). The assessment of spread of *A. transitella* considered both natural dispersal and local human-assisted spread (3.3). Five experts were invited to take part in formal EKE using behavioural aggregation (EFSA, 2014). Three experts on European cultivation methods (from Italy, Spain and France) and two American experts on biology and integrated pest management of *A. transitella* contributed to the EKE process. The collected evidence was reviewed during the EKE and is summarised in Appendix H.

2.3.1. Scenario definition for spread

In order to estimate the spread rate, the panel developed a general scenario with the following characteristics:

- The pest is present in an isolated focus somewhere within the area of potential establishment.
- In the isolated focus, a small population has established on suitable host(s). It is assumed that the pest will not become extinct following establishment, but may not start spreading until a lag phase has passed. During this lag phase, the population size in the isolated focus increases to a local steady state. The organism gradually builds up a density gradient with higher densities in the centre of the focus and lower densities at the edge. This 'density frontier' of the population will gradually start moving away from the centre at a rate equal to the rate of range expansion.

After the lag period, the size of the pest populations is assumed to have reached the local habitat carrying capacity, meaning that it is sufficiently abundant and adapted to local conditions to allow it to survive, reproduce and spread effectively.

- Assuming that:
  - Host availability is not a limiting factor for pest establishment after a dispersal event.
  - The contribution of the different susceptibilities of host plants (e.g. species, varieties, rootstocks) or the biological characteristics of pest (e.g. dispersal rate, feeding activity) are not considered.
  - The current climatic conditions are those in place for population growth/epidemics and spread of the pest.

The assessed spread rate is the outcome of the combined contributions of natural dispersal and local human-assisted spread, where the human-assisted component only includes operations related to production and local movement (e.g. common agricultural practices) but not spread due to post-harvest movement, such as the trade in commodities.

2.3.2. Scenario definition for impact

In order to estimate the impact, a scenario with the following characteristics was defined:

- The pest has spread to its maximum extent:
  - Within the area of potential establishment, pest presence depends on the heterogeneity of the patches where the host occurs. It is therefore not necessarily the case that the pest is present in all suitable patches.
  - In each location where the pest occurs, its abundance is in equilibrium with the available resources (e.g. host plants) and environmental conditions (including climate, ecosystem resistance and resilience) and current crop production practices (e.g. pest control, such as the efficacy of the pesticides targeted at other pests and current quarantine measures).
- The maximum potential abundance is the driving factor for the estimation of losses and is evaluated in a time frame long enough to take into account the possible effects of the temporal variation in pest population dynamics (e.g. population fluctuations), impacts and cropping practices (e.g. sanitation by removal of mummy nuts, i.e. desiccated infested nuts remaining on the trees or on the ground over winter).
- Cropping practices and management options are those currently in place in the area of potential distribution, considering differences with those applied in the USA and other countries where *A. transitella* is present (and evidence was collected). The effect of currently applied control against other pests is taken into account, while there are no eradication or containment programmes targeted to *A. transitella*.
- Transient populations were not considered.
- The contribution of the different susceptibilities of host plants (e.g. species, cultivars, rootstocks) or the biological characteristics of *A. transitella* (e.g. dispersal rate, feeding activity) are not considered in detail.

2.4. Temporal and spatial scales

The pathway model calculates the flow per year, on average, over the next 5 years (2022–2026).

The Köppen–Geiger climate classification and CLIMEX both used 30 years of climate data, 1981–2010. The Köppen–Geiger climate classification uses a 10-km world grid and CLIMEX a 0.5° world grid.

3. Assessment

3.1. Pest introduction

Pest introduction is the combination of entry (which includes transfer to hosts) and establishment. In this section (3.1), the panel covers the biology of *A. transitella* and discusses some aspects of the production of commodities (nuts) that can act as a pathway. The section also includes calculations on establishment of founder populations as it is closely connected to the pathway model that was developed to assess entry and transfer. Climatic factors and host distribution in the EU affect potential for establishment across the EU and are covered in Section 3.2.

Information gathering and synthesis led to greater understanding of the biology of *A. transitella* and the nut production systems (walnuts and almonds) which were the focus of quantitative analysis with respect to entry pathways. This section first provides summaries of the biology of *A. transitella* and the production systems of walnut and almond in the USA. It then presents the results of pathway modelling and presents rationale why some pathways were not quantitatively analysed.

3.1.1. Pest Biology

Although *A. transitella* (Figure 3) was given the common name 'navel orangeworm' after it was found infesting oranges in Arizona in the 1920s, it is actually a secondary pest of citrus. It can only feed and develop on oranges whose rind has already become cracked or has been damaged by another pest or by abiotic factors such as hail or by rind splitting. This is so because *A. transitella* larvae do not chew through the rind of oranges (Wade, 1961).

A description of the biology of *A. transitella* is provided in the EFSA pest categorisation (EFSA PLH Panel, 2021) with more details in Wade (1961) and Wilson et al. (2020). Here, we provide a summary overview.

Climatic conditions and the availability of susceptible hosts influence the number of generations of *A. transitella* developing per year. There are typically three to four generations of *A. transitella* in California, USA, each year; four is typical for the southern San Joaquin Valley; three for the cooler northern Sacramento Valley. The first generation of adults emerges in the spring (March–April) from nuts and other host fruit that have remained in orchards since the previous year. Having overwintered as larvae, pupation takes place in the host fruit and adults emerge from pupae during spring evenings. Adult *A. transitella* are nocturnal, and females attract males using a pheromone (Wang et al., 2010). Mating takes place within one or two nights of emergence. Oviposition occurs over a few nights shortly after mating. Females lay single eggs on cracked, damaged or overripe fruits or on fresh nuts after hull split (Curtis and Barnes, 1977; Strand, 2002). Females can lay approximately 100–200 eggs each (Burks, 2014). Eggs hatch in 4–23 days, depending on temperature. Engle and Barnes (1983) report the lower threshold for development as 12.8°C with 56 degree days (DD) required for egg development. Larvae enter the nut shortly after egg hatch and progress through five to six larval instar stages. A single nut can contain multiple larvae. 113 DD are required for larvae to complete development. However, development thresholds and rates can vary according to host and host quality (Sanderson et al., 1989a). Larvae feed directly on the nut meat, which reduces crop yield and quality (Reger et al., 2020). Larvae often form pupae within the nut in which they developed but pupae are also formed outside of the shell. A feature of *A. transitella* is its ability to move between orchards of different host crops, and its multivoltine nature enabling it to move from early-maturing crops (e.g. almonds) to late-maturing crops (e.g. pistachios and walnuts) (Higbee and Burks, 2021).

Figure 3: (A–C): Photos of *Amyelois transitella* (A) Larva in walnuts (a courtesy of Richard Rice (UC Davis)), (B) larva in pistachio (a courtesy of Kent Daane University of Berkeley), (C) Pupa on almonds (photo courtesy of Kent Daane University of Berkeley)

The second generation of adults occurs between late June and early August. The emergence of the second generation coincides with almond and pistachios nuts being susceptible to infestation. The third generation of adults occurs between late August and late September when walnuts are susceptible to infestation. Fourth-generation adults can occur from late September until late October and oviposit on host fruit and nuts that remain on trees after harvest. Larvae that develop on these will overwinter to emerge as adults the following spring (Wilson et al., 2020). The list of hosts was enlarged after the supplementary search and is available in Table 4.

Table 4: List of hosts of *Amyelois transitella* (amended from EFSA PLH Panel et al., 2021 pest categorisation)

Plant family	Host name	Common name	Reference
Anacardiaceae	*Pistacia vera*	Pistachio	DROPSA (2016)
	Mangifera indica	Mango	US interception/NHM (2022)
Arecaceae	*Phoenix dactylifera*	Date palm	DROPSA (2016)
Asparagaceae	*Yucca* sp.		DROPSA (2016)
Fabaceae	*Acacia farnesiana*	Sweet acacia	DROPSA (2016)
	Caesalpinia pulcherrima	Poinciana, peacock flower	NHM (2022)
	Cajanus cajan	Pigeon pea	NHM (2022)
	Cassia grandis	Pink shower tree, carao	NHM (2022)
	Ceratonia siliqua	Carob	DROPSA (2016)
	Gleditsia triacanthos	Honey locust	DROPSA (2016/NHM (2022)

Plant family	Host name	Common name	Reference
	Hymenaea courbaril	Courbaril or West Indian locust	NHM (2022)
	Pithecellobium ebano	Texas ebony,	NHM (2022)
	Pithecellobium flexicaule	Texas ebony or Ebony Blackbead	DROPSA (2016)
	Robinia sp.	Locusts	NHM (2022)
	Tamarindus indica	Tamarind	Muñoz Agudelo et al. (2014/USA interception) NHM (2022)
Hippocastanaceae	*Aesculus glabra*	Ohio Buckeye	NHM (2022
Juglandaceae	*Carya illinoensis*	Pecan	DROPSA (2016)
	Juglans regia	Walnuts	DROPSA (2016)
Malvaceae	*Brachychiton* sp.	Narrowleaf bottle tree	DROPSA (2016)
	Theobroma cacao	Cacao tree	Brazil
Moraceae	*Ficus* sp.	Fig	DROPSA (2016)
Paeoniaceae	*Paeonia sp.*	Peony	US interception/NHM (2022)
Palmae	*Phoenix dactylifera*	Date palm	NHM (2022)
Punicaceae	*Punica granatum*	Pomegranate	DROPSA (2016)
Rhamnaceae	*Ziziphus* sp.	Jujube	DROPSA (2016)
Rosaceae	*Prunus dulcis*	Almond	DROPSA (2016)
	Cydonia oblonga	Quince	DROPSA (2016)
	Eriobotrya japonica	Loquat	DROPSA (2016)
	Heteromeles arbutifolia	Toyon	DROPSA (2016)
	Malus domestica (syn. *pumila*)	Apple	DROPSA (2016)
	Prunus armeniaca	Armenian plum	DROPSA (2016)
	Prunus domestica	Common plum	DROPSA (2016)
	Prunus dulcis	Almond	NHM (2022)
	Prunus persica	Peach	NHM (2022)
	Pyrus communis	European pear	DROPSA (2016)
Rubiaceae	*Coffea* sp.	Coffee	DROPSA (2016)
	Randia sp.	Indigoberry	NHM (2022)
	Genipa americana	Genipapo	DROPSA (2016)
Rutaceae	*Citrus limon*	Lemon	DROPSA (2016)
	Citrus sinensis	Orange	DROPSA (2016)
	Citrus paradisi	Grapefruit	DROPSA (2016)
Sapindaceae	*Ungnadia speciosa*	Mexican buckeye	Lara-Villalón et al. (2017)
	Sapindus saponaria	Wingleaf soapberry	NHM (2022)
Vitaceae	*Vitis vinifera*	Grapevine	DROPSA (2016)

Since 2010, *A. transitella* damage has increased in tree nut orchards in California perhaps due to *A. transitella* quickly adapting to changing landscapes and local environmental conditions, including climate change (Rijal et al., 2021). Insecticide usage in California has increased in recent years with *A. transitella* being a key driver (Doll et al., 2017). Insecticide resistance has been reported in Californian *A. transitella* populations since 2013 (Calla et al., 2021). Moreover, the introduction of mating disruption and insecticide use in California agriculture for the control of *A. transitella* have reduced from levels of 2% of infested almonds that were considered acceptable in the past to levels of approximately 0.1–0.2% nowadays, levels at which natural enemies are ineffective (K. Daane pers. comm. February 2022).

3.1.2. Walnut production

A summary of aspects of walnut production and *A. transitella* biology is provided to help understand the pathway model. Appendix A describes the production, processing and export of walnuts with a focus on production in California. It also includes aspects of the biology of *A. transitella* and information about pest management which, along with other information, was used to inform the estimates made during the EKE process (Appendix B).

The majority of walnut production in California is based on six walnut varieties, 'Chandler', 'Hartley', 'Howard', 'Tulare', 'Serr' and 'Vina'. Due to differences in phenology, not all cultivars are equally susceptible to becoming infested by *A. transitella*. 'Vina' and 'Serr' mature during peak abundance of third-generation adults so are most susceptible. *A. transitella* relies on damaged, cracked or split nut surfaces for it to access walnut kernels (Khan et al., 2016).

There are three important steps growers follow when managing *A. transitella*, (i) winter sanitation, i.e. clearing fallen walnuts to prevent overwintering of the pest, (ii) monitoring the development of the crop and insect phenology to inform insecticide spray decisions during the growing season and (iii) timely harvest to minimise the exposure of walnuts to late season *A. transitella* populations (Wilson et al., 2020). Sterile insect technique (SIT) and mating disruption with sex pheromones are also used to suppress populations of *A. transitella* (Burks et al., 2008).

Harvesting begins when the green walnut hulls start to split (exposing the nuts to *A. transitella*) and generally takes place from late August until late November (depending on cultivar). Following harvest, walnuts are taken for 'hulling' where the outer green hull is removed. The longer the hulls remain on nuts after harvest, the more the nut quality deteriorates (Perry and Sibbett, 1998). Processors and exporters have a very low tolerance for *A. transitella* damage in all nut crops (Wilson et al., 2020).

De-hulled nuts are air-dried to reduce moisture and inhibit fungal growth (Kader, 2002). Walnuts are then stored inshell. CargoHandbook.com (2022) reports dried walnuts can be stored for 1 year at between −3 and 0°C. From storage walnuts are graded and either packed inshell or shelled then packed.

Johnson et al. (2010) reported that inshell walnuts for export could be infested with *A. transitella*, and therefore, exports were fumigated with methyl bromide to disinfest consignments. *A. transitella* was intercepted three times in walnuts in Japan (Choi et al., 1996). Trematerra (1988) reported on finding *A. transitella* in walnuts imported to the port of Ravenna (Italy); no established populations have been reported in Italy (or elsewhere in the EU).

3.1.3. Almond production

A summary of aspects of almond production and *A. transitella* biology is provided to help understand the thinking and logic behind the pathway model. Appendix C describes the production, processing and export of almonds with a focus on production in California. It also includes aspects of the biology of *A. transitella* and information about pest management which, along with other information, was used to inform the estimates made during the EKE process (Appendix D).

Adult *A. transitella* emerge during the summer (June–August) and mated females can lay eggs to infest the developing almond crop on trees (Hamby et al., 2011). Females lay eggs on maturing almond fruit just before the hull splits although many eggs are laid after hull split and eggs can be laid on the inside of the hull or on the exposed shell of the nut (Curtis and Barnes, 1977). The third generation is generally the largest population and the generation which can cause most damage to almonds. Almonds are susceptible to *A. transitella* once the hull splits open (July–August) which provides access to the larvae because *A. transitella* larvae are unable to bore through the hull of almond fruit (Wilson et al., 2020). Control of *A. transitella* requires precise timing and targeted insecticide delivery at the early hull split stage to prevent egg laying and subsequent larval damage on the newly exposed nut (Li et al., 2021).

Almonds are harvested between early August and late October using mechanised tree shakers once the hulls have split open and the kernel (almond 'nut') begins to dry. The fruit can be left on the ground to dry for 7–10 days before being gathered using a mechanical harvester. After harvest, the hulls are removed then graded and sized. At this point, electronic sorting technology is used to remove damaged and infested almonds (Melmerstein, 2013; Almond Board of California, 2016). Following sorting and grading, almonds are kept in controlled storage until they are either shipped or further processed for a variety of culinary uses (California almonds, 2022). Almonds can be stored for about 1 year at temperatures between −3 and 0°C at 65–70% r.h. (Perry and Sibbett, 1998; Robins, 2019;

TIS, 2022a). During the 10 years up to 2021–2022, an average of 18.3% of each year's harvest was held in cold store and marketed the following year.

To minimise infestation of the nut crop with *A. transitella*, winter sanitation (i.e. removal of mummy nuts) is crucial. Other important factors are (i) to harvest the nuts at the earliest possible date to prevent *A. transitella* that emerge later in the season from infesting the crop; (ii) to dry the nuts as soon as possible, (iii) to fumigate the nuts as soon as they are dried (phosphine or sulfuryl fluoride are used) (Appendix E) and (iv) to keep storage areas cool and dry. In general, *A. transitella* is a more serious problem in smaller orchards.

Exports of almonds from the USA to the EU occur every month of the year with shelled almonds being exported in greater volume, in the order of 100 times more than inshell almonds. The vast majority of almonds will be transported by rail or road from California to ports on the east coast of USA for export to the EU. Transport across the continental USA from the west to the east is assumed to take 5 or 6 days whilst crossing the Atlantic on a container ship may take 8–14 days or more. Allowing for some dwell time in port, onward distribution and storage within the EU, total transport time could be approximately 15–30 days or longer (Appendix B).

3.1.4. Aggregate assessment of introduction via walnuts and almonds: Scenario A0 (baseline)

Figure 4 presents the results of combining all four pathways assessed to show the descending cumulative probability from the mean number of nuts (walnuts plus almonds, both shelled and unshelled) imported into the EU over the next 5 years (blue line, right hand side of Figure 4) to the mean number of founder populations establishing in the EU over the next 5 years (dark-grey line, left hand side of Figure 4). The underpinning of elicited values of the parameters of the pathway model underlying these results is detailed in Appendices B and D. Results for individual pathways are shown in the following sections.

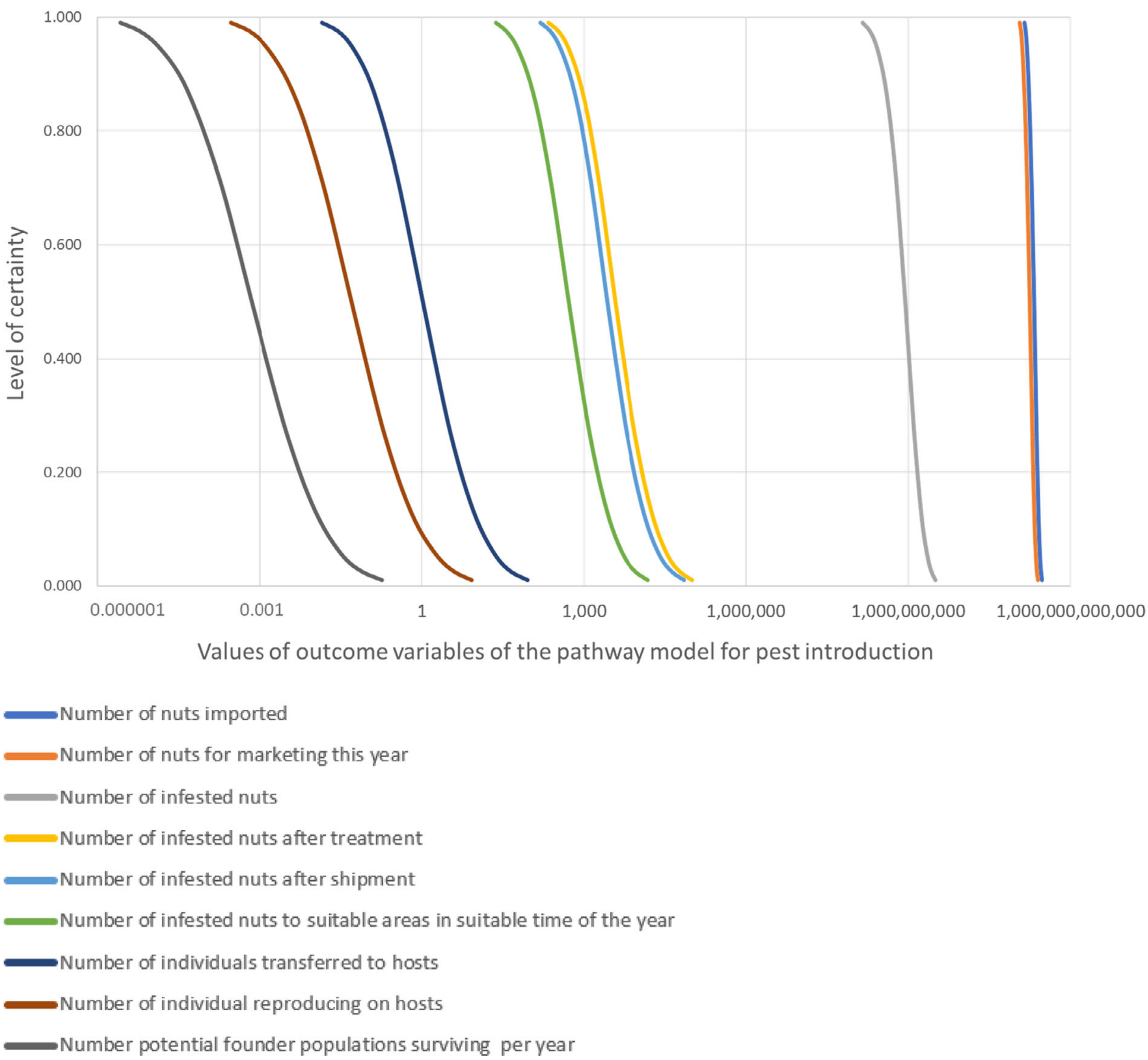

Figure 4: Descending cumulative probability distributions of nine output variables of the pathway model for pest introduction in the default scenario A0 (current practices and regulations). Points on each line represent the panel's level of certainty (y-coordinate of the point) that the number is larger than the values given along the x-axis. From right to left, the curves represent: (1) Number of imported nuts per year (walnuts plus almonds, both shelled and unshelled) (blue line), (2) number of infested nuts marketed in the year of harvest (dark orange line); (3) number of infested nuts (light grey line); (4) number of infested nuts after treatments at packing house (dark yellow line); (5) number of infested nuts after shipping to the EU (light blue line); (6) number of infested nuts transported to climatically suitable areas in EU at a time of the year suitable for establishment (green line); (7) number of *A. transitella* transferring to hosts in climatically suitable areas at a suitable time of the year (dark blue line); (8) number of *A. transitella* mating on hosts in climatically suitable areas at a suitable time of the year (brown line); (9) founder populations surviving and establishing (dark grey line)

Nine stages in the pathway model are shown as descending cumulative curves in Figure 4. The rightmost, blue, curve represents the number of imported nuts (walnuts plus almonds, both shelled and unshelled) per year, calculated as the sum of V/w over four pathways (walnuts inshell, walnuts shelled, almonds inshell, almonds shelled). This is the steepest curve among the nine, indicating it has the lowest relative uncertainty, having all plausible values within a relatively narrow range. The number of imported nuts is in the order of 10^{11} (100 billion nuts) per year. The majority of the nuts is traded in the year of production, so the effect of the parameter p_1 is small such that the dark orange line and the blue line almost overlap. In the order of one to a few in a thousand nuts are infested with *A. transitella* at harvest in the country of origin (Appendices B and D), hence the number of infested nuts that are harvested (light grey line in Figure 4) is in the order of a billion per year. Measures in the packing house result in a major reduction (approximately five orders of magnitude reduction) in the number of infested nuts being destined for international transport. This number is still in the range of a few hundreds to a number in the order of 100,000 (dark yellow curve in Figure 4). Survival during transport to the EU is high; hence, there is almost no further reduction during oversea transport, such that the curves for infested nuts pretransport (dark yellow line in Figure 4) and post-transport (light blue line in Figure 4) are close to each other. Only a portion of the nuts are marketed during the warmer months of the year in areas that are suitable for *A. transitella*. Hence, the green curve (infested nuts to the southern EU during the warmer months of the year) is approximately a factor 10 lower than all nuts to the EU (light blue curve). Still, in the hundreds to thousands of infested nuts would make it to the southern EU each year during the warmer months of the year. Three further steps are accounted for by the pathway model: (1) transfer to hosts (p_6), (2) sufficient adults present at hosts to start a viable population (p_7) and (3) newly founded populations persist under existing biological and chemical controls under practical conditions (p_8). The latter three processes are uncertain, but the associated probabilities were assessed to be low, indicating that there are severe bottlenecks for establishment, even if live insects entered into the EU. Hence, the number of new founder populations (dark grey in Figure 4) line is well below one per year, resulting in an expected long waiting time (tens to thousands of years) before at founder population of *A. transitella* would be expected to occur. In Figure 4, from right to left, as more processes are accounted for, the distributions become shallower, indicating greater relative uncertainty. This is due to the accumulation of uncertainties as more factors are considered.

The median and certainty range of the nine variables quantified are quantitatively presented in Table 5.

Table 5 summarises the medians and 90% certainty ranges of nine outcome variables of the pathway model for introduction of *A. transitella*. These outputs comprise the final output, i.e. the number of established founder populations per year, as well as all intermediate variables calculated to arrive at this final estimate. These values summarise the 5, 50 and 95% points of the curves shown in Figure 4. The model comprised introduction via four pathways: shelled walnuts, inshell walnuts, shelled almonds and inshell almonds. Calculated outputs are (1) the total number of nuts imported, (2) the number of nuts marketed in the year of production, (3) the number of infested nuts arriving at the packing house in the country of origin, (4) the number of nuts infested with live insects after treatments at the packing house, (5) the number of infested nuts arriving in the EU, (6) the number of infested nuts transported to NUTS-2 regions that are suitable for establishment during a time of the year conducive to establishment, (7) the number of *A. transitella* transferring to hosts, (8) the number of *A. transitella* reproducing on hosts and (9) the number of founder populations establishing each year. To facilitate a better understanding of the small magnitude of the number founder populations establishing each year, the rate of new populations establishing was also presented as the average waiting time until the next successful establishment event. This waiting time is the inverse of the rate. The upper 90% certainty limit of the number of years until establishment (output nr 10) is calculated as the inverse of the lower 90% limit of the number of founder populations establishing each year, while the lower 90% limit of the number of years until establishment is calculated as the inverse of the upper 90% limit of the number of founder populations establishing each year.

Table 5: Medians and 90% certainty limits of one final outcome variable and eight intermediate outcome variables of the overall pathway model. In addition, to put the number of new founder populations per year in perspective, the median and 90% certainty limits are given for the expected number of years until the first establishment event

	Variable	Lower 90% certainty limit	Median	Upper 90% certainty limit
1	Number of nuts imported	155 billion	214 billion	278 billion
2	Number of nuts marketed in year of production	128 billion	177 billion	228 billion
3	Number of infested nuts	250 million	863 million	2,260 million
4	Number of infested nuts after treatments	482	3,750	37,200

	Variable	Lower 90% certainty limit	Median	Upper 90% certainty limit
5	Number of infested nuts after shipment to the EU	338	2,630	26,000
6	Number of infested nuts to suitable NUTS-2 regions in suitable time of the year	54.7	512	5,550
7	Number of *A. transitella* transferring to hosts	0.049	1.04	24.3
8	Number of *A. transitella* reproducing on hosts	0.00127	0.0501	2.01
9	Number of founder populations establishing per year	0.0000126	0.000698	0.0364
10	Expected number of years until establishment	27.5	1,430	79,400

3.1.5. Assessment of entry via individual pathways, Scenario A0 (baseline)

Tables 6–8 present the results of model outputs under Scenario A0. Outputs from the four pathway models (walnuts inshell, walnuts shelled, almonds inshell, almonds shelled) indicate that shelled almonds are the most commonly infested nuts entering the EU. This is mostly due to the high volume of trade of shelled almonds as compared to the other three pathways. There is little difference in infestation level of inshell almonds or walnuts at EU entry (Appendices B and D).

The quantiles for the four pathways are summed in the tables to provide an estimate of the distribution of the total entry under the assumption that uncertainties in different pathways are the same, i.e. the same ranking of random realisations of the pathway model is assumed in this case. Moreover, a joint @Risk model for the four pathways was constructed to account in detail for dependencies and independencies between the uncertainties in different pathways. The differences between these two methods of calculating the total entry across four pathways were small and inconsequential for the conclusions of the PRA.

Table 6: Pathway model[(a)] results showing the estimated mean annual number of nuts infested with *Amyelois transitella* entering the EU via walnuts and almonds (inshell and shelled) from the USA. Calculations with the pathway model were made with the baseline scenario without additional phytosanitary measures (Scenario A0)

Percentile[(b)] **Pathway**	**5th**	**25th**	**Median (50th)**	**75th**	**95th**
Walnuts inshell	13	47	112	269	942
Walnuts shelled	5	21	55	144	570
Almonds inshell	5	20	51	132	503
Almonds shelled	166	771	2,151	5,975	25,481
Sum of the quantiles[(c)]	189	859	2,369	6,520	27,496
Aggregate number of infested nuts entering the EU[(d)]	338	879	2,627	6,587	26,046

(a): Details on the data and parameters that underlie these modelling results are given in Appendices A–D, together with detailed breakdown of pathway model results.
(b): Descending cumulative probability, numbers rounded to indicate whole nuts.
(c): The sum of the quantiles for the four pathways provides an estimate for the quantiles of the overall entry if there is full rank correlation in the @Risk model realisations for different pathways.
(d): A more detailed accounting for dependencies and independencies results in changed estimates and a narrower certainty range for the output, but the effect is minor and does not affect conclusions.

Table 7: Pathway model[(a)] results showing the estimated mean annual number of *Amyelois transitella* adults transferring to hosts in suitable regions of the EU at an appropriate time of year via walnuts and almonds (inshell and shelled) from USA. Calculations with the pathway model were made without additional phytosanitary measures in place (Scenario A0)

Percentile[(b)] **Pathway**	**5th**	**25th**	**Median (50th)**	**75th**	**95th**
Walnuts inshell	0.000542	0.00314	0.0106	0.0352	0.209
Walnuts shelled	0.000969	0.00607	0.0218	0.0787	0.506

Percentile[(b)] Pathway	5th	25th	Median (50th)	75th	95th
Almonds inshell	0.00809	0.00516	0.0186	0.0660	0.409
Almonds shelled	0.0352	0.244	0.924	3.46	23.2
Sum of the quantiles[(c)]	0.0448	0.258	0.975	3.64	24.3
Aggregate number of adults transferring[(d)]	0.0493	0.292	1.04	3.77	24.3

(a): Details on the data and parameters that underlie these modelling results are given in Appendices A–D, together with detailed breakdown of pathway results.
(b): Descending cumulative probability, numbers are given with three significant digits.
(c): The sum of the quantiles for the four pathways provides an estimate for the quantiles of the overall entry if there is full rank correlation in the @Risk model realisations for different pathways.
(d): A more detailed accounting for dependencies and independencies results in changed estimates, but the effect is minor and does not affect conclusions.

Table 8: Pathway model[(a)] results showing the estimated mean annual number of *Amyelois transitella* founder populations establishing in the EU via walnuts and almonds (inshell and shelled) from USA. Calculations within the pathway model were made without additional phytosanitary measures (Scenario A0)

Percentile[(b)] Pathway	5th	25th	Median (50th)	75th	95th
Walnuts inshell	0.000000137	0.00000140	0.00000706	0.0000348	0.000321
Walnuts shelled	0.000000263	0.00000279	0.0000146	0.0000751	0.000779
Almonds inshell	0.000000216	0.00000235	0.0000124	0.0000636	0.000615
Almonds shelled	0.00000957	0.000113	0.000613	0.00328	0.0354
Sum of the quantiles[(c)]	0.0000102	0.000120	0.000647	0.00345	0.0371
Aggregate number of founder populations establishing per year[(d)]	0.0000126	0.000136	0.000698	0.00363	0.0364
Number of years until first founder population	27.5	275	1,430	7,370	79,400

(a): Details on the data and parameters that underlie these modelling results are given in Appendices A–D, together with detailed breakdown of pathway results.
(b): Descending cumulative probability, numbers are given with three significant digits.
(c): The sum of the quantiles for the four pathways provides an estimate for the quantiles of the overall entry if there is full rank correlation in the @Risk model realisations for different pathways.
(d): A more detailed accounting for dependencies and independencies results in changed estimates, but the effect is minor and does not affect conclusions.

3.1.6. Aggregate assessment of introduction via walnuts and almonds: Scenario A1 (regulation)

Table 9 presents the results of model outputs under Scenario A1 in which all nuts are shipped in refrigerated containers (reefers) where temperatures are −3 to 0°C as recommended by CargoHandbook.com (2022) and TIS (2022b). Requiring walnuts and almonds to be transported in reefers reduces the likelihood of founder populations establishing by a factor of more than 100,000. Hence, what is already a very small likelihood becomes vanishingly small. Noting that Johnson (2007) studied the survival of *A. transitella* eggs and larvae at 0°C and found that it took from 1.1 to 2.9 days to kill 95% of eggs (95% confidence limit 0.8–3.5 days) and that 95% of larvae were killed within 4.3 days at 0°C (95% CL 2.7–9.8 days), it is not surprising that being transported whilst chilled for between 15 and 30 days has a major impact on survival. See also Appendix J. Figure 5 illustrates the large effect of this extra measure.

Table 9: Pathway model[(a)] results showing the estimated mean annual number of *Amyelois transitella* founder populations surviving to establish in the EU via walnuts and almonds (inshell and shelled) from USA. Calculations within the pathway model were made assuming all nuts were transported in chilled conditions (–3 to 0°C); an additional phytosanitary measure (Scenario A1)

Percentile[(b)] Pathway	5th	25th	Median (50th)	75th	95th
Walnuts inshell	6.07E-13	6.37E-12	3.29E-11	1.66E-10	1.59E-09
Walnuts shelled	1.95E-12	2.14E-11	1.14E-10	6.02E-10	6.46E-09
Almonds inshell	9.51E-13	1.08E-11	5.79E-11	3.03E-10	3.11E-09
Almonds shelled	9.57E-06	1.13E-04	6.13E-04	3.28E-03	3.54E-02
Sum of quantiles	1.60E-10	1.88E-09	1.03E-08	5.52E-08	5.91E-07
Aggregate number of founder populations establishing per year[(d)]	8.62E-11	9.92E-10	5.29E-09	2.84E-08	2.96E-07
Number of years until first founder population	3.38E+06	3.52E+07	1.89E+08	1.01E+09	1.16E+10

(a): Details on the data and parameters that underlie these modelling results are given in Appendices A–D, together with detailed breakdown of pathway results.
(b): Descending cumulative probability, numbers are given in scientific notation to capture the very small and large number sizes. For example, the suffix E-9 means times 10–9 (i.e. parts per billion) and E+9 means times 109 (i.e. billions).
(c): The sum of the quantiles for the four pathways provides an estimate for the quantiles of the overall entry if there is full rank correlation in the @Risk model realisations for different pathways.
(d): A more detailed accounting for dependencies and independencies results in changed estimates, but the effect is minor and does not affect conclusions.

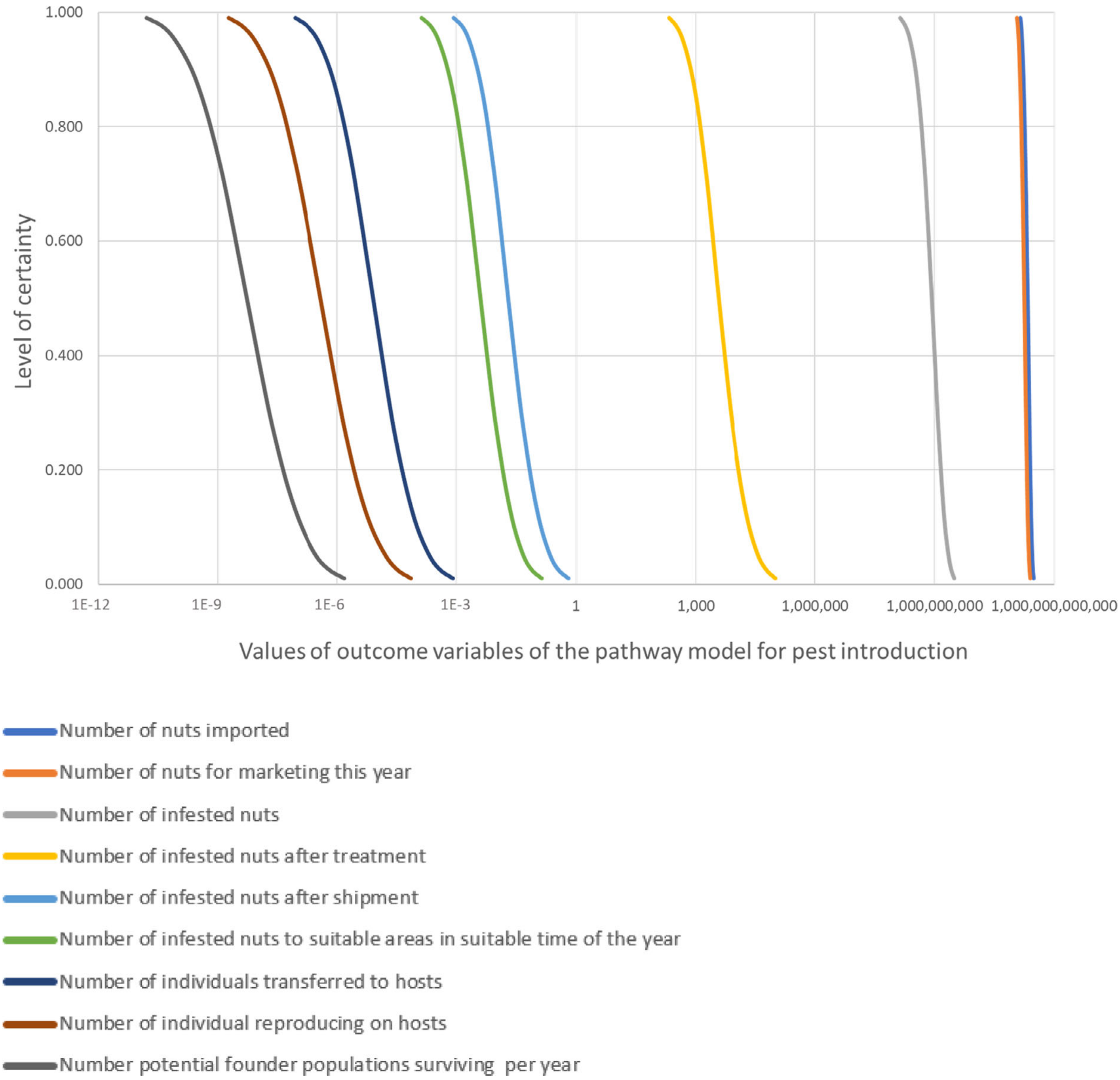

Figure 5: Descending cumulative probability distributions of nine output variables of the pathway model for pest introduction under a scenario (A1: regulation) in which all shipments to the EU are cooled. From right to left: (1) Number of imported nuts per year (walnuts plus almonds, both shelled and unshelled) (blue line); (2) number of infested nuts marketed in the year of harvest (dark orange line); (3) number of infested nuts (light grey line); (4) number of infested nuts after treatments at packing house (dark yellow line); (5) number of infested nuts after shipping to the EU (light blue line); (6) number of infested nuts transported to climatically suitable areas in EU at a time of the year suitable for establishment (green line); (7) number of *A. transitella* transferring to hosts in climatically suitable areas at a suitable time of the year (dark blue line); (8) number of *A. transitella* mating on hosts in climatically suitable areas at a suitable time of the year (brown line); (9) founder populations surviving and establishing (dark grey line). In this case, there is a big reduction from number of infested nuts after treatments at the packing house (dark yellow line) and the number of infested nuts after shipping to the EU (light blue line), due to the effect on survival of cooling during shipment to EU. Note that the x-axis runs from 10^{-12} on the left to 10^{12} on the right while the x-axis of Figure 4 (Scenario A0) runs from 10^{-6} to 10^{12}

3.1.7. Pathways not quantified

Figs

The pest categorisation identified figs as a potential pathway for *A. transitella* (EFSA PLH Panel et al., 2021) based on publications from California (Burks and Brandl, 2004, 2005), with specific reference to dried figs (Wilson et al., 2020). The EU imports fresh figs from countries where *A. transitella* is present (Figure 6), while significant importations of dried figs are only from countries where the species is not reported and rather limited from the USA where the species is present (Figure 7).

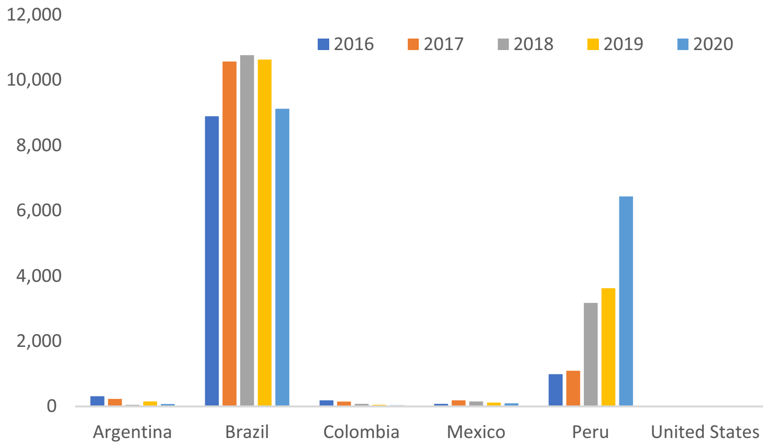

Figure 6: EU imports of fresh figs, 2016–2020, from countries where *Amyelois transitella* is reported (100 kg) (Source: Eurostat)

Figure 7: EU imports of dried figs, 2016–2020, from countries where *Amyelois transitella* is reported (100 kg) (Source: Eurostat)

The USA and Brazil have significant fig production (Ferraz et al., 2020). Depending on the variety of fig, there can be a spring (June) harvest and a later summer harvest (August–September) (Ferguson et al. 1990; Burks and Brandl, 2004). *A. transitella* populations are low in June. It is the late summer harvest, when the third or fourth generation of *A. transitella* are in flight, which may be susceptible to infestation. However, Bagchi et al. (2016) note that *A. transitella* does not cause extensive crop loss in figs and no chemical control guidelines have been developed for *A. transitella* in figs (Coviello, 2006). Nevertheless, fresh fig fruit harvested for local consumption can be contaminated by *A. transitella* resulting in complaints from local consumers (Fergusson et al., 1990). Fresh ripe figs do not transport and keep well so figs for export are in dried and processed forms (TIS, 2022c). The quantity of figs imported into the EU from countries where *A. transitella* is present was obtained for fresh figs (Figure 6) and dried figs (Figure 7) from Eurostat for the years 2016–2020. Although dried figs can in theory be a pathway for *A. transitella*, the traded volumes are so much smaller than those for walnuts and almonds from the USA that the contribution to total entry was deemed to be negligible and the panel decided not to quantify the fig pathway. Instead, the likelihood of entry via dried figs was considered within the uncertainty of overall entry via all trade combined (Section 3.1.7).

Pecans (Carya illinoensis)

Pecans are grown commercially in 15 states in the southern USA, specifically in Alabama, Arizona, Arkansas, California, Florida, Georgia, Kansas, Louisiana, Missouri, Mississippi, New Mexico, North Carolina, Oklahoma, South Carolina and Texas (USA Pecan Growers Council, 2022). *A. transitella* is reported in all these states except for Kansas and New Mexico.

In describing the biology of *A. transitella*, and how it is a pest of walnuts and almonds, Wade (1961) provided a list of 25 hosts including pecans. Other than being in the list of hosts, no supporting evidence or reference is provided; no context or additional information is provided regarding pecans as a host. During meetings with hearing experts from the USA, pecans were not considered as a viable pathway given that *A. transitella* was not considered a pest of pecans (C. Burks pers. comm. March 2022). In support of this position, pecan is not listed as a host to *A. transitella* in a checklist of North American nut-infesting insects by Williams (1989). *A. transitella* is not included in a list of 75 insect pests of pecan by Thopmson and Conner (2012). Nor is *A. transitella* listed as a pest of pecans by Knutson and Ree (2019) who report on insect and mite pests of pecan in Texas; *A. transitella* is not mentioned in a review of key pecan insect pests by Lacey and Shapiro-Ilan (2003). The datasheet in the CABI Crop Protection Compendium lists 45 insect pests of pecan and *A. transitella* is not included (CABI, 2019). Reporting on *A. transitella* in Mexico, Lara-Villalón et al. (2017) state that there is no report of damage on pecans in Mexico.

Taking into account the views of US hearing experts and the lack of evidence in the literature, the import of pecans was excluded from consideration as a pathway for the introduction of *A. transitella* into the EU.

Pistachios inshell

The EU imports the vast majority of pistachios from USA (Figure 8). Whilst *A. transitella* can infest the nuts, pistachios are heated during processing to remove moisture from around 40% to 5% (Hodges and Farrell, 2004).

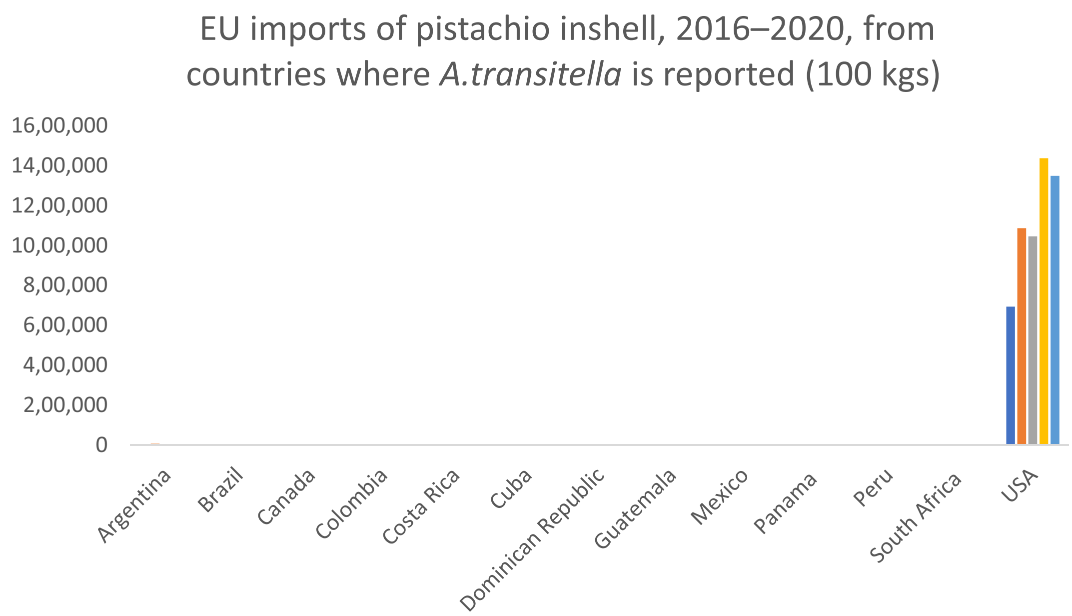

Figure 8: EU imports of pistachio inshell, 2016–2020, from countries where *Amyelois transitella* is reported (100 kg) (Source: Eurostat)

Venkitasamy et al. (2017) report that most pistachios processors in the USA use a two-stage process to dry pistachios nuts; the first stage reduces moisture to 12–13% in a column using forced hot air at 82°C, the second stage uses air no hotter than 49°C over 24–48 h. Such temperatures will certainly kill any *A. transitella* larvae within pistachios. Johnson et al. (1996) studied the potential survival of *A. transitella* in pistachios after commercial processing (dehydration). During the study, 1,980 kg of pistachios (approx. 880,000 nuts) was sampled and no live *A. transitella* were found following dehydration and only one dead adult was observed.

Pistachios as a pathway can be eliminated, assuming that dehydration continues to be used, because larvae do not survive processing.

Plants for planting

The pest categorisation identified plants for planting as a potential pathway for *A. transitella* (EFSA PLH Panel, 2021) based on publications from Australia (AQIS, 1999; NSW, 2012).

The HS/CN customs code system for classifying commodities traded internationally does not sufficiently discriminate plants for planting to provide import or export data on individual plant species. To overcome this problem, enquiries were made to the Netherlands, the major EU member state that imports plants for planting. Specifically, the EFSA PLH Panel sought data about imports of the following hosts of *A. transitella*: *Juglans regia* (walnut), *Prunus armeniaca* (apricot), *P. dulcis* (almond), *P. domestica* (common plum), *Pyrus communis* (European pear), *Malus domestica* (*syn. pumila*) (apple) and *Cydonia oblonga* (quince) from the USA. The EU has prohibited the import of plants for planting of plants in the genera *Citrus* and *Vitis* for many years under previous legislation (the plant health directive, 2000/29/EC) and the prohibition continues in the current plant health implementing regulation (EU 2019/2072). In addition, since 2018, plants in the genera *Juglans*, *Malus* and *Prunus* have been listed as high risk whose import is prohibited as plants for planting unless a risk assessment is conducted and a derogation has been provided (EU/2018/2019). *Pyrus* and *Cydonia* can only be imported as dormant plants without leaves, flowers and fruit.

Information provided from the Netherlands indicated that there were no imports of *Juglans, Prunus, Pyrus, Malus* or *Cydonia* plants for planting from the USA in 2020.

A search of NL import data indicated five consignments of *Cydonia, Malus, Prunus* and *Pyrus* during an 8-year time period, 2010–2017. All imports occurred in 2014 or 2015. In total, 34 plants for planting were imported (Table 10).

Table 10: *Amyelois transitella* host plants for planting imported into the Netherlands from USA, 2010–2017

Year	Genus	Consignments	Pieces in consignment
2010	–	–	–
2011	–	–	–
2012	–	–	–
2013	–	–	–
2014	*Prunus* *Malus* *Pyrus* *Cydonia*	1 1 1 1	7 11 13 1
2015	*Prunus*	1	2
2016	–	–	–
2017	–	–	–

The import of *Juglans*, *Malus* and *Prunus* has been prohibited and there is no evidence of imports of other major hosts since 2015 in the Netherlands. It is assumed that imports to other EU MS have followed the same pattern, i.e. very low numbers, if any, imported in the past decade, with no imports in recent years.

Based on the available information, plants for planting were excluded as a pathway for *A. transitella*.

Fruit as a potential pathway

Although *A. transitella* was given the common name of navel orangeworm after it was found infesting oranges in Arizona in the 1920s, it is a secondary pest of citrus, i.e. it can only feed and develop on oranges whose rind has already been damaged by another pest or other causes, because *A. transitella* larvae cannot chew through the rind of oranges and need to access the inner fruit through cracks or where the surface has been weakened by another pest (Wade, 1961). A previous pest categorisation on *A. transitella* (EFSA PLH Panel, 2021) identified fruit such as oranges, some pome fruit and stone fruit as having potential to provide pathways for *A. transitella*. However, although the EU does import fruit from countries where *A. transitella* is present, larvae of *A. transitella* infest damaged and fallen fruit and fruit that remain in orchards after harvest, and are therefore not exported. Such 'trash feeding' is typical of Pyralidae whose larvae often eat dried and decaying plant matter. In the USA, *A. transitella* is primarily a pest of walnuts and almonds and is not recognised as a pest of commercial oranges. During consultations with USDA hearing experts, it was clear that nuts (almonds and walnuts) should be the primary focus for an analysis of entry pathways. The only known interception on oranges was reported by Hong et al. (2012). This paper shows photographic documentation on oranges, but the description of the insect and its biology is based on nuts described in the literature. EFSA sent a request for the information on this finding to the Animal and Plant Quarantine Agency in Republic of Korea in April 2022, which confirmed that the only interception of *A. transitella* was in 2012 in the Republic of Korea and the identification was made by morphological methods.

3.1.8. Interceptions around the world and occurrence in the EU

Literature searching revealed interceptions in Japan (Sonda, 1962) and South Korea (Hong et al., 2012). Hong et al. (2012) mention other interceptions with reference to original papers by Yoshida et al. (1989) [in Japanese] and Choi et al. (1996) [in Korean]; both papers mention interceptions on walnuts. A report in the Fauna Europaea portal by de Jong et al. (2014) describing *A. transitella* in Germany cites (Roweck and Savenkov (2002)). Roweck and Savenkov (2002) list 244 species of Lepidoptera captured in Hof Ritzerau, Lübeck's city forest. The list was checked and *A. transitella* or synonyms of *A. transitella* were not present in this list. Therefore, the record in Fauna Europaea appears to be mistaken.

There is no evidence of interceptions of *A. transitella* in Europhyt or TRACES. Notifications of EU interceptions of harmful organisms were recorded in Europhyt between May 1994 and June 2020. TRACES began recording interceptions in May 2020 and is the system in place today. Both databases were consulted during the pest categorisation (EFSA Plant Health Panel, 2021) and no records of interceptions of *A. transitella* were found in either database. However, nuts of almonds, walnuts and pistachios only became regulated in December 2019 since when they have required a phytosanitary certificate if they are to be introduced into the EU (Implementing Regulation 2019/2072, Annex XI, part B). 1% of consignments are required to be inspected.

Although no interceptions of *A. transitella* are recorded in Europhyt or TRACES – findings of *A. transitella* would not necessarily be notified even if they were made because *A. transitella* is not an EU quarantine pest, so there has been no legal obligation for NPPOs to notify interceptions in either Europhyt or TRACES. Nevertheless, some NPPOs (competent authorities) have alerted the Commission and other Member States when a harmful plant pest has been intercepted despite it not being a regulated quarantine pest, by entering interception information into Europhyt in the past or more recently into TRACES. No such entries were found for *A. transitella*. There is therefore variation in the information and consistency of reporting findings of plant pests by MS. In conclusion, the panel found no evidence on entry of *A. transitella* with imported fruit and nuts into the EU using Europhyt and TRACES, but this lack of evidence is no proof of the absence of the insect in imported product because of the difficulty of detection in large imports and the absence of a requirement to notify.

Previous findings of *A. transitella* in the EU have been reported in the scientific literature, e.g. in Italy (Trematerra, 1988) and Austria (Essl and Rabitsch, 2002). Trematerra (1988) identified *A. transitella* in walnuts imported from the USA after nuts were sent to him for identification by the inspection service at the port of Ravenna. Infested nuts were found on multiple occasions (around 10; Trematerra, personal communication). Essl and Rabitsch (2002) and Burmann (1995) report on two moths flying on a balcony in Innsbruck in 17 January 1984. The moths were identified by an expert taxonomist, but this finding is unlikely to reflect an established population, given that the Innsbruck climate is considered unsuitable to the insect. This finding could not be linked to a specific commodity or pathway.

Unconfirmed records

According to Fauna Europaea *A. transitella* is present in Germany (de Jong et al., 2014) although it likely refers to a finding rather than an established population. More details regarding this doubtful record are described in Section 2.1 Entry, page 10. In addition, *A. transitella* was also reported on pistachios in South Africa in a Master's degree (Grobler, 2010). However, this work was not published in any peer-reviewed publication and Burks (personal communication; 1 November 2022) suggested that it might be a possible misidentification. As the presence is neither officially confirmed nor refuted, the status of this pest in South Africa remains uncertain.

3.1.9. Entry into the EU where establishment is possible (NUTS2 resolution)

Appendix F details the NUTS-2 regions where climate is suitable for *A. transitella* establishment according to CLIMEX together with human population (Eurostat 2019 data) and NUTS-2 area.

3.1.10. Uncertainties affecting the assessment of entry

The quantitative assessment of entry focused on almonds and walnuts from California in the USA. California dominates production in the US and information was gathered on nut production, pest control and nut processing in California. It is possible that different systems are applied in other nut producing and exporting states in the USA. In addition, small numbers of almonds can be imported to the EU from other countries where *A. transitella* is present, such as Argentina, Brazil, Colombia and Mexico (Appendix A). From 2016 to 2020, imports of almonds from sources other than the US accounted for 0.25% of all EU almond imports and for 3.2% of walnut imports. Given the domination of nut imports from California, information collection focused on California for almonds (Appendix A) and walnuts (Appendix B). It is recognised that different conditions and industry practices could apply in non-US third countries which affect the likelihood of nuts being infested and surviving to enter the EU from such sources. Figs and other possible host fruit were excluded from quantitative analysis due to the relatively small amounts being imported and the low likelihood of infested fruit being exported to the EU.

The panel analysed which parameters in the pathway model had the greatest influence on the results. This analysis was carried out for the four separate pathways. Results per pathway are given in Tables 11–14. Each table lists parameters in the order of their influence on the variation in the calculated number of established populations resulting from the pathway per year. The rank order of the most influential variables was similar between the pathways. The likelihood of pest transfer (p_7) was the most influential parameter explaining variation in the calculated number of established founder populations in three of the four pathways and it was the second most influential parameter in the other pathway (walnuts shelled). The survival of treatments at the packing house (p_3) was the second most influential parameter explaining variation in the number of established founder populations in three of the pathways and the most influential parameter in the other (walnuts shelled). Likelihood of mating after transfer (p_8), likelihood of survival of founder populations (p_9) and proportion of infested nuts in the country of origin were the third, fourth and fifth most important variable explaining variation in the calculated number of established founder populations, respectively. This analysis underscores the comparatively large uncertainty in processes responsible for pest transfer following its entry, but preceding its establishment. Another important uncertainty concerns the effectiveness of treatments at the packing house. Uncertainty in other parameters such as trade flow, proportion of infested nuts and nut weight had small to negligible effects on the uncertainty in the calculated results (Tables 11–14).

Table 11: Uncertainty analysis of parameter in the model for walnuts inshell

Rank	Parameter	Meaning	Partial R^2	%
#1	p_7	Likelihood of pest transfer from infested nuts	0.078	55
#2	p_3	Survival of treatments at packing house	0.033	23
#3	p_8	Likelihood of mating following transfer	0.017	12
#4	p_9	Likelihood of survival and establishment of founder populations following mating	0.012	9
#5	p_2	Proportion infested nuts in country of origin	0.002	1
#6	V	Import volume [kg]	0.000	0
#7	w	Nut weight [kg]	0.000	0
		TOTAL	0.142	100

Table 12: Uncertainty analysis of parameters in the model for walnuts shelled

Rank	Parameter	Meaning	Partial R^2	%
#1	p_3	Survival of treatments at packing house	0.052	62%
#2	p_7	Likelihood of pest transfer from infested nuts	0.016	19%
#3	p_8	Likelihood of mating following transfer	0.008	7%
#4	p_9	Likelihood of survival and establishment of founder populations following mating	0.006	2%
#5	p_2	Proportion infested nuts in country of origin	0.002	0
#6	V	Import volume [kg]	0	0
#7	w	Nut weight [kg]	0	0
		TOTAL	0.142	100%

Table 13: Uncertainty analysis of parameters in the model for almonds inshell

Rank	Parameter	Meaning	Partial R^2	%
#1	p_7	Likelihood of pest transfer from infested nuts	0.040	46
#2	p_3	Survival of treatments at packing house	0.025	29
#3	p_8	Likelihood of mating following transfer	0.013	14
#4	p_9	Likelihood of survival and establishment of founder populations following mating	0.007	8
#5	p_2	Proportion infested nuts in country of origin	0.003	3
		TOTAL	0.087	100

Table 14: Uncertainty analysis of parameters in the model for almonds inshell

Rank	Parameter	Meaning	Partial R^2	%
#1	p_7	Likelihood of pest transfer from infested nuts	0.078	55
#2	p_3	Survival of treatments at packing house	0.033	23
#3	p_8	Likelihood of mating following transfer	0.017	12
#4	p_9	Likelihood of survival and establishment of founder populations following mating	0.012	9
#5	p_2	Proportion infested nuts in country of origin	0.002	1
#6	V	Import volume [kg]	0.000	0
#7	w	Nut weight [kg]	0.000	0
		TOTAL	0.142	100

3.1.11. Conclusion on the assessment of entry

Walnuts and almonds, both inshell and shelled, provide a pathway to enable *A. transitella* to enter the EU. In the order of a few hundred to a few thousand infested nuts are expected to enter each year. This represents a very small proportion of all nuts arriving in the EU. The likelihood of infested nuts entering and the insects contained therein successfully transferring to a host and initiating a founder population is very small, although there is considerable uncertainty around the estimate, as shown by the time span over which a founder population may be expected (between 27 and 100,000 years, as shown in Table 8).

3.2. Assessment of climatic factors and host distribution affecting establishment

Climatic mapping is the principal method for identifying areas that could provide suitable conditions for the establishment of a pest taking key abiotic factors into account (Baker, 2002). Climatic factors are considered in Section 3.2; availability of hosts is considered in Section 3.3.

3.2.1. Köppen–Geiger climate classification approach

Figure 9 shows the results of Köppen–Geiger climate classification. Figure 9A and B show climate types that are present in the EU and have also been associated with detections of *A. transitella* in the Americas (red dots in Figure 9A and C). Climate type Cfb (temperate oceanic) is rare in the USA but common across EU. This climate is represented by 2.2% of five arcmin grid cells in the USA, and by 45.8% of grid cells in the EU (MacLeod and Korycinska, 2019), but there is uncertainty on the suitability of climate type Cfb for establishment of *A. transitella*. Panels C and D in Figure 9 show maps of the Americas and the EU without the Cfb climate type to highlight those regions in which the climate suitability for establishment of *A. transitella* is more certain. These more restricted maps are in better agreement with the results of CLIMEX (Figure 10A and B) and more consistent with the temperature requirements of *A. transitella* taking cold stress into account (see Appendix G).

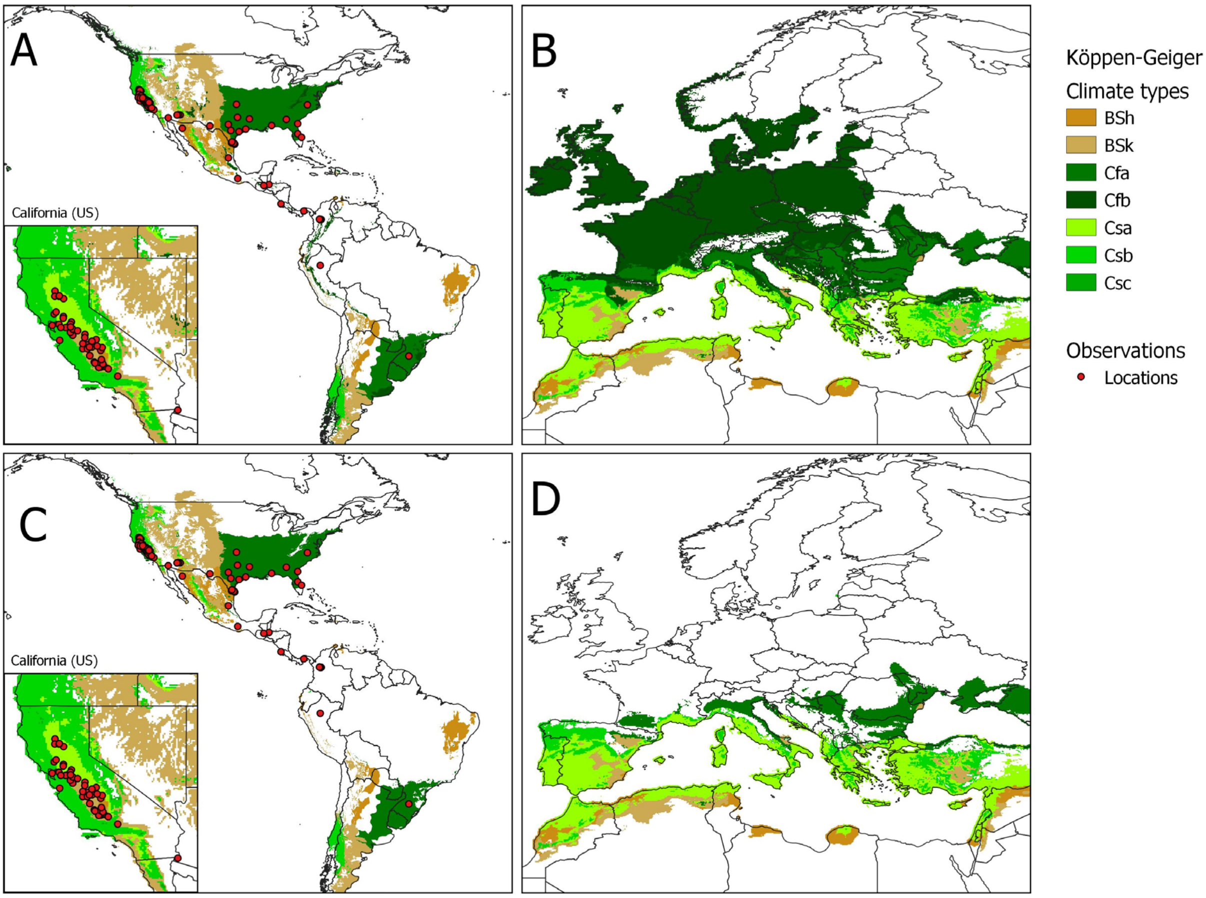

Figure 9: (A–D) Climate suitability analysis for *Amyelois transitella* based on Köppen–Geiger climate classification. The maps show climate types that are present in EU and have presence locations of *A. transitella* in the Americas. In panels c and d, climate Cfb was removed as considered less relevant for *A. transitella*. B-ARID: BSh-Hot semi-arid climate, BSk-Cold semi-arid climate, C-warm temperate: Cfa-Humid subtropical climate, Cfb-Temperate oceanic climate, Csa-Hot-summer Mediterranean climate, Csb-Warm-summer Mediterranean climate, Csc-Cold-summer Mediterranean climate (Kottek et al., 2006)

3.2.2. CLIMEX modelling

CLIMEX is a fundamental niche model that combines information on a species response to climatic factors (bottom-up approach) and information on worldwide presence of the organism in different climates (top-down approach) to derive maps of an organism's potential geographic distribution and relative abundance (Sutherest and Maywald, 1985). CLIMEX analysis (Kriticos et al., 2015) requires parameterisation of relationships between survival and stresses resulting from high or low temperature or high or low humidity. Observation points were used to calibrate CLIMEX. Here, we map the Ecoclimatic Index (EI). This index characterises the climatic suitability of areas to support a persistent population of the species on a scale from 0 to 100 where 0 means unsuitable and 100 means highly suitable for the long-term survival of the species. Details of the parametrisations of CLIMEX are given in Campese et al. (2022).

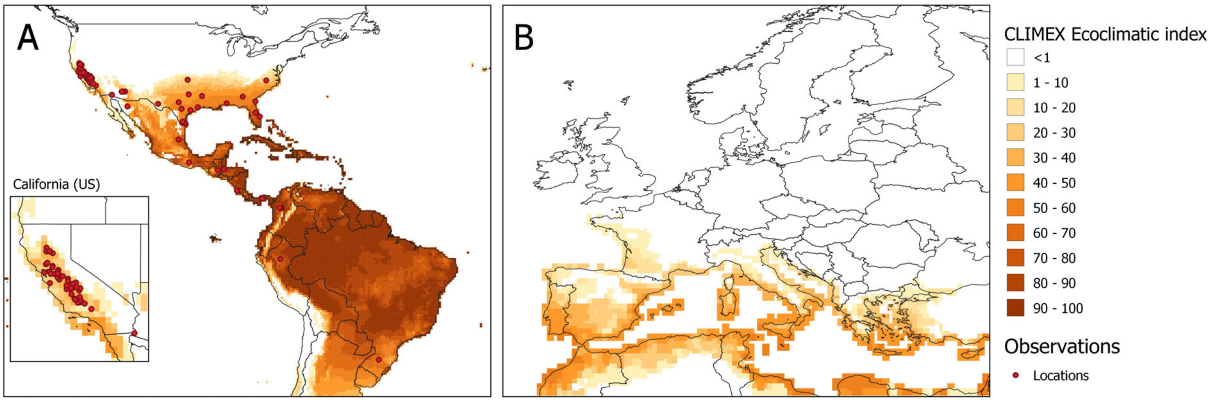

Figure 10: (A–B) Maps of CLIMEX Ecoclimatic Index (EI) for *Amyelois transitella* interpolated across the Americas (A) and in the EU and northern Africa (B) based on parameters given in Campese et al. (2022). Darker colours suggest more favourable conditions for establishment

Several elements are considered in the calculation of the Ecoclimatic Index. One of those is the CLIMEX Cold Stress Index (CSI), which is a factor for cold stress (Appendix G, Figure G.3). An index equal to 0 indicates no stress, while 100 indicates conditions that are detrimental to the organism and do not allow establishment. The CSI is based on two parameters, the cold stress temperature threshold (TTCS) and the cold stress temperature rate (THCS). The TTCS defines a temperature below which cold stress begins to accumulate. The rate at which this stress accumulates is determined by the THCS. The stress is accumulated weekly based on the average weekly minimum temperature (Kriticos et al., 2015). In CLIMEX, weekly climate data are derived from monthly data through interpolation (Kriticos et al., 2015). Based on the literature on *A. transitella* (Johnson, 2007; Tebbets et al., 1978), TTCS was set to 0°C (Campese et al., 2022) (Appendix G).

Figures 8 and 9 can be interpreted as the areas where climate is most suitable for establishment of *A. transitella*. Additional maps are provided in Appendix G and in Campese et al. (2022).

Based on climate matching and CLIMEX modelling, the majority of Croatia, Cyprus, Greece, Italy, Malta, Portugal and Spain are suitable for *A. transitella* establishment. The crop area for key hosts such as almonds, apples, citrus, grapes, pears, plums and walnuts in these countries is shown in Table 10. In France, the NUTS 2 regions of Aquitaine, Corsica, Languedoc-Roussillon, Midi-Pyrénées, Pays de la Loire, Poitou-Charentes and Provence-Alpes-Côte d'Azur are considered climatically suitable for establishment. Overall, approximately 3.0% of the area of NUTS 2 regions in the EU which is climatically suitable for *A. transitella* is used to grow the hosts detailed in Table 15. Although quince and pistachios are also potential hosts, no data was found to enable the estimation of the area of these crops in climatically suitable NUTS 2 regions.

3.2.3. Potential number of generations and risk of transient populations

The panel used a degree day model to calculate the potential number of generations during the growing season. Calculating the number of generations informs the potential impact of the pest as the number of moths and larvae can potentially increase with each generation. This approach is not suited for assessing the potential for establishment as it does not consider the ability of larvae to overwinter. The model used a base temperature for development of 12.8°C and a heat-sum of 615 accumulated degree days above this threshold for the development of one generation in mummy almonds, and 417.5 degree days in new crop almonds (Seaman and Barnes, 1984; Sanderson et al., 1989a; http://ipm.ucanr.edu/PHENOLOGY/ma-navel_orangeworm.html).

In the Mediterranean areas of Spain, France, Italy, Greece, up to four generations were simulated.

Most of the European territory is suitable for the development of one generation, but this includes areas with unfavourable winter temperatures hence allowing a single generation but making persistent populations impossible due to cold stress (Appendix G). *A. transitella* has not been found established in regions of the Americas where according to this model one generation would be possible (Figure 11).

Such areas, however, may still be at risk of transient populations during the growing season. Particularly, in areas in the Eastern EU (Romania, Hungary, Bulgaria, Croatia) where the expected number of generations could be equal or higher than two. The maps illustrate a large effect of the quality of the host plant material (mummy vs. new crop almonds) on the size of the predicted area suitable for the development of transient generations.

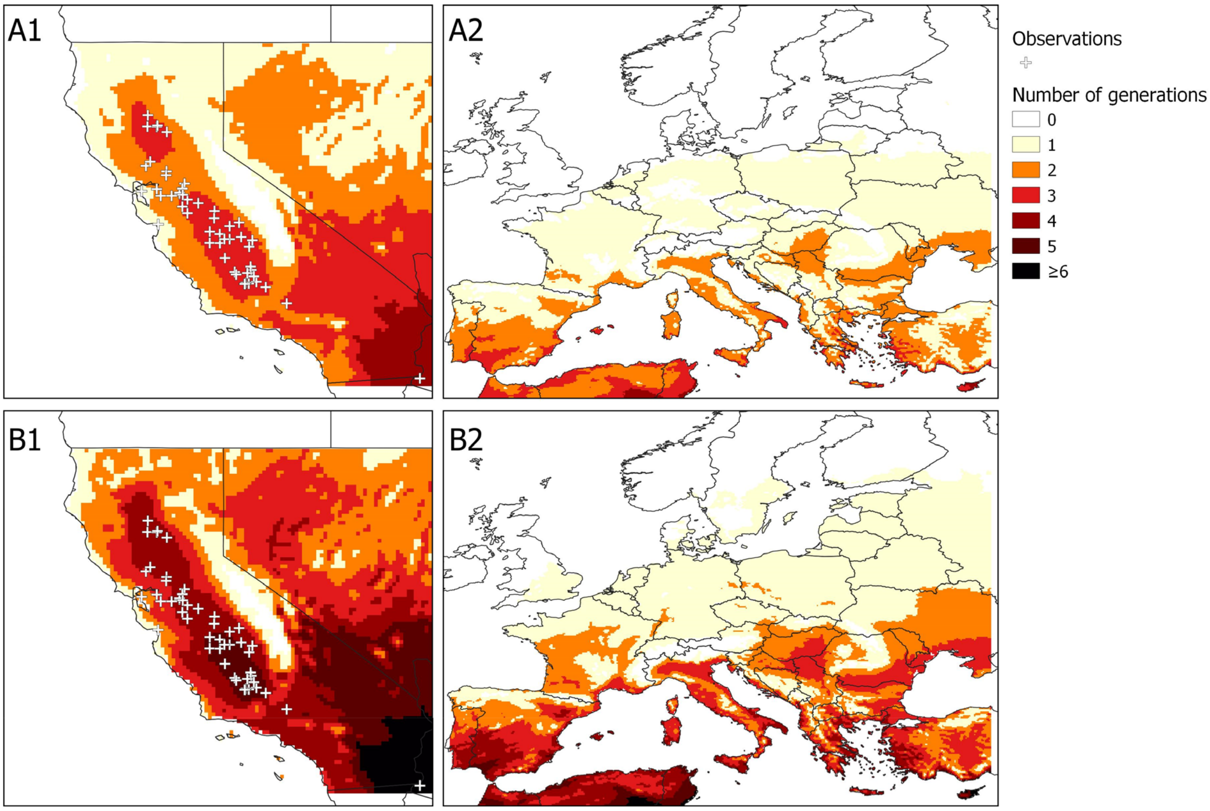

Figure 11: (A1–B2) Number of generations of *Amyelois transitella* in California (A1, B1) and the EU (A2, B2). The legend shows the number of generations (the darker the colour, the higher the potential number of generations). The observed distribution in California is represented using white plusses in panels A1 and B1. Panels A1 and A2 use a heat-sum of 615 degree days for completion of one generation of the insect while in panels B1 and B2 use a temperature sum of 417.5 degree days. These temperature sums are averages of the values reported by Seaman and Barnes (1984) and Sanderson et al. (1989b). Weather data are from the Copernicus Climate Change Service information. Degree-day calculation was based on hourly temperature data from the ERA5-Land data set (Muñoz Sabater, 2019). For each pixel of the ERA5-Land 0.08° regular grid, degree days were calculated for each year from 1991 to 2020 and then averaged

3.2.4. Availability of hosts where climate is suitable for establishment

Table 15: Area of potential host crops in climatically suitable crop NUTS 2 regions of EU member states (km^2)

EU MS	Almonds	Apples	Citrus	Grapes	Pears	Plums	Walnuts	Sum crop area	Area of NUTS 2 regions	% of NUTS area cropped
Spain	6,561.5	301.0	2,963.3	9,363.3	213.2	148.8	109.5	19,660.5	498,511	3.9
Italy	555.4	524.0	1,344.4	6,843.0	299.6	117.6	46.0	9,730.0	302,071	3.2

EU MS	Almonds	Apples	Citrus	Grapes	Pears	Plums	Walnuts	Sum crop area	Area of NUTS 2 regions	% of NUTS area cropped
France[(1)]	12.1	502.0	44.4	3,767.1	35.2	98.3	153.2	4,612.3	212,003	2.2
Greece	139.0	99.3	448.6	1,007.8	42.5	22.4	140.3	1,899.8	131,957	1.4
Portugal	384.3	147.0	208.2	1,788.5	125.4	18.0	36.8	2,708.1	89,089	3.0
Croatia	5.5	49.6	20.9	212.5	8.0	43.9	66.1	406.5	56,594	0.7
Cyprus	24.7	4.0	31.2	64.3	0.6	3.9	2.0	130.8	9,251	1.4
Malta	0.0	0.0	0.0	5.2	0.0	0.0	0.0	5.2	316	1.7
Sum	7,682.6	1,626.9	5,061.0	23,051.6	724.6	452.9	553.8	39,153.3	1,299,792	3.0

(1): In France, the NUTS 2 regions of Aquitaine, Corsica, Languedoc-Roussillon, Midi-Pyrénées, Pays de la Loire, Poitou-Charentes and Provence-Alpes-Côte d'Azur are considered suitable climatically for establishment.
Final column is the percentage of the considered areas that are used for growing the crops in the 2nd–10th column.

3.2.5. Uncertainties affecting the assessment of climatic suitability and presence of hosts in the risk assessment area

A number of caveats should be considered for the analyses on climate suitability:

- The three climate suitability products (namely the Köppen–Geiger classification, the CLIMEX outputs, and the maps showing the potential number of generations) are based on three different climate data sets and different periods:
  - The Köppen–Geiger classification used in this work is the one from the Institute for Veterinary Public Health of the University of Vienna based on Kottek et al. (2006), rescaled after Rubel et al. (2017). This classification is based on the 25-year period 1986–2010 and on a 0.08° grid. Temperatures are from the Climate Research Unit (CRU, Norwich, UK) TS data set, precipitations from the Global Precipitation Climatology Centre (GPCC).
  - The CLIMEX model was run using the data set CM30_1995H_V2_WO available in CLIMEX v.4.1. This data set is based on the 0.5° world grid of historical meteorological data (period 1981–2010), from the Climate Research Unit (CRU, Norwich, UK), transformed using the methods of Kriticos et al. (2012).
  - The map showing the potential number of generations is based on the ERA5-Land data set (Muñoz Sabater, 2019, Copernicus Climate Change Service information), period 1991–2020 and on a 0.08° regular grid.
- The Köppen–Geiger approach is based on matching European climates with those in areas of known presence of a pest. This is a rather coarse approach that does not consider in detail the influences of biotic and abiotic factors on pest distribution.
- Other representations of the Köppen–Geiger classification exist, based on different climate data, period, spatial resolution, slight differences in the criteria for climate classifications (e.g. Beck et al., 2018; Kriticos et al., 2012). Different climate classification products result in differences in the area covered by the climates relevant for the organism.
- Using different climate data sets, at different spatial resolution, in CLIMEX simulations could cause differences in the border of the area simulated as suitable. In addition, considering the current climate warming, more recent climate data would most probably result in an increased area of climate suitability in the EU. See, for instance, also the difference in CLIMEX results when station weather data or spatially interpolated weather data were used (EFSA PLH Panel et al., 2018b).
- Climate suitability assessment is based on the known global pest distribution. In the case of *A. transitella*, a high number of observations were found from the USA, especially California. Information was found also from Central and South America. The resulting climate suitability maps are consistent with what is known about the pest ecophysiology. However, it must be considered that the regions immediately outside of the area of observed distribution might be underrepresented due to limited impact of the pest.
- Whilst climatic factors (Section 3.2.1 and 3.2.2) and the presence of hosts (Section 3.2.4) are major constraints on an organisms' ability to establish in a new region, factors such as

competition from other species, cultural practices and control measures applied in a new region can also play a role (IPPC, 2017) but due to lack of information, these were not considered in detail in this assessment, thereby adding to the uncertainty of establishment.
- The Panel only collected the data on the cultivation areas of major host crops. Data on host crops that are not widely grown, such as quince and pistachios, were not found. The Panel did not explore the distribution of wild hosts e.g. *Prunus* spp.

3.2.6. Conclusions on establishment

- *A. transitella* is known to occur in the Americas, from the southern states of the USA to the Northern regions of Argentina
- The Köppen–Geiger climate matching and CLIMEX modelling indicate that conditions are most suitable for establishment in the southern EU, especially around the Mediterranean, but conditions for pest persistence exist also along the western Atlantic coasts of the EU (Spain, Portugal, France).
- The number of simulated potential generations in areas suitable for persistence is up to four. Most of the European territory shows a climate suitable for the development of at least one generation which implies a risk of potential transient populations during the season favourable for growth.

3.3. Spread

3.3.1. Assessment of spread

Based on the scenario defined for this assessment, the duration of the lag period in the area where *A. transitella* can potentially establish is around 3 years (with a 95% uncertainty range of 1.5–7 years) with a subsequent rate of range expansion of 5.6 km/year (with a 95% uncertainty range of 0.6–23.2 km/year). More details are available in Appendix H.

A. transitella is expected to have an initial slow increase of population size and a limited dispersal. This can be due to (a) genetic factors related to the lack of fitness of the species in a new environment, (b) suboptimal environmental conditions limiting the biological performance of the individuals (impacting on life-history traits), (c) limited availability of hosts and their patchiness. In this phase, defined as 'lag period', the spread is limited and not homogeneous (it can change in the different directions). At the end of this phase, the species reaches a level of adaptation to local conditions to allow it to survive, reproduce and spread effectively.

3.3.2. Uncertainties affecting the assessment of spread

- The duration of the lag period is mainly driven by the effect of EU agricultural practices and by the presence of natural enemies and other competing species (e.g. *Cydia pomonella, Ectomyelois ceratoniae*). These factors were not evaluated, but are sources of uncertainty.
- The expansion rate is mainly driven by the effect of the host species communities in terms of species composition, patchiness and distance among suitable patches and availability in the EU environments compared to the observations collected from the area of origin. Information is lacking to assess this in detail; hence, the rate of range expansion was assessed using EKE.

More details are available in Appendix H.

3.3.3. Conclusions on spread

- Spread by natural means was assessed to be a few km per year (0.8–19.3 km/year; 90% CR) with a median rate of 5.6 km/year, after an initial lag period of a few years (1.7–6.2 years; 90% CR) following the establishment of a founder population.

3.4. Impact

The impact of *A. transitella* is due to the feeding activity of the larvae, resulting in rasped and tunnelled fruits and nut kernels. The most important losses are observed on nut crops (e.g. almonds, pistachios, walnut) and figs (Wilson et al., 2020). They are caused (i) directly by the damage and the contamination of frass and webbing by larvae, and (ii) indirectly by secondary fungal infections and aflatoxins contamination (Higbee and Siegel, 2009; Palumbo et al., 2014; Ampt et al., 2016; EFSA PLH Panel, 2021).

A. transitella can feed and complete its life cycle on a potentially large number of plant species. For the selection of the main hosts on which to carry out a quantitative assessment of the impact, the following aspects were considered.

- Host preference by the pest
- Productive areas in the MSs of the hosts
- Observed damages in the current area of distribution of the pest.

The hosts on which the main damages are observed are almonds, walnuts and pistachios. In the past, *A. transitella* damage has been observed in the US on figs; it is still unclear how *A. transitella* develops on this host and if the apparent preference is only due to the proximity of the infested figs to almond and pistachios orchards. A similar situation is true for pomegranate.

For these reasons, the quantitative assessment focuses on losses on.

- Almonds
  - Grown under intensive agricultural practices
  - Grown under traditional agricultural practices
- Pistachios
- Walnuts

Yield losses are assessed as the overall expected production losses for the whole EU productive area where *A. transitella* is able to establish and spread.

Quality losses have not been included in the assessment because damaged fruits and nut kernels are no longer marketable. Thus, infested fruits and nuts are completely lost whereas the market value of uninfested fruit is not affected by the insect. A potential effect of the proportion of infested fruit on the value of the harvest, due to willingness to pay of processors and packing houses, was not considered.

The secondary effect of *A. transitella* attacks, such as the creation of a suitable environment for aflatoxins to accumulate in the stored products (in particular nuts and dried figs), is not explicitly quantified in this opinion. However, the low acceptable level of damage by *A. transitella* on almonds and pistachios for trade as defined in the international standards is actually related to the health-related risk of aflatoxins (UNECE, 2014).

3.4.1. Assessment of impact via expert knowledge elicitation

Based on the scenario defined for this assessment, the mean percentage of yield loss (i.e. the proportion of marketable product lost due to larval feeding on nuts) within different nut crops in the EU is shown in Table 16.

Table 16: Estimated mean yield losses by *A. transitella* in nut crops grown in EU

Crop	Median yield loss	90% certainty range
Almonds grown under intensive agricultural practices	2.0%	0.2–35.7%
Almonds grown under traditional agricultural practices	0.9%	0.17–2.9%
Pistachios	1.3%	0.13–4.0%
Walnuts	1.1%	0.08–3.3%

More details are available in Appendix K.

3.4.2. Uncertainties affecting the assessment of impact

The main uncertainties affecting the impact assessment are related to the transferability of the US (mainly Californian) experience on impacts of *A. transitella* to the EU situation, in particular in the presence of differences in:

- predominant crop varieties (with predominant European varieties having considerably thicker shells than those in California)
- sanitation and phytosanitary measures

- production areas (e.g. more heterogeneous production in the EU, with a smaller plot size and higher availability of alternative hosts)
- climate (which would be expected to influence the pest cycle).

3.4.3. Conclusions on impact

If the insect did establish, yield losses in infested areas are expected to be 0.23–5.7% (90% CR) in almonds under intensive production (median: 2.0%) or 0.17–2.9% under traditional production (median: 0.9%); 0.13–4% in pistachios (median: 1.3%) and 0.08–3.3% in walnuts (median: 1.1%).

4. Overall uncertainty

The components of the assessment have different degrees of uncertainty. Entry was assessed for four pathways, focusing on almonds and walnuts, both shelled and inshell, from the USA, as the insect is prevalent in the main growing area of these nuts in the USA, and the insect is known to be able to survive in these nuts and move intercontinentally. Other pathways were not quantitatively assessed because they represented much smaller trades, often at least a factor of 100 times less than the pathways that were assessed. Within the pathways that were quantitatively assessed, several factors were highly uncertain, e.g. the effectiveness of control at the packing house and the factors mediating the establishment of founder populations, following entry of the insect. These processes are insects reaching hosts, sufficient insects congregating at hosts to allow mating and building a local population and survival over multiple generations at a site under the influence of biological and chemical controls. As a result, the certainty ranges for the entry process are wide, but there is nevertheless little uncertainty that live insects do enter the EU, and there is also little uncertainty that despite the almost inevitable entry, the establishment of founder populations is a rare event. Although *A. transitella* has been intercepted in areas where it is not native, it has never established outside of the Americas. There are reports that *A. transitella* spread from Mexico to the southern USA and California (Trematerra 1988). However, this historic spread can also be interpreted as an increase in population levels in areas in which *A. transitella* was already present previously, but only at low densities, after areas of cultivation of major hosts such as walnuts, almonds and pistachios, were increased. As it stands, it is not clear whether the organism really spread from Mexico to California, or was already present. There are no records of establishment of *A. transitella* in areas that are spatially disjunct of the native range in the Americas.

A comprehensive analysis of the literature was made to collect all the known locations of the presence of *A. transitella* in the Americas. The literature showed a high density of records from the USA, particularly from California, but few records from Southern America. The high number of records in California is related to the importance of the insect in the cultivation of nut and fruit crops, particularly walnuts, almonds and pistachio. The intensive cultivation of multiple hosts of the insects in California is a factor driving the ecological success of the species in this area. The low number of records from Southern America could indicate the insect is not widely distributed in Southern America, but there is uncertainty on this due to the absence of specific confirmation of absence from large parts of the continent, while climatic factors enable establishment in large parts of Southern America. Three analyses were conducted to depict the potential of establishment in the EU: (1) climate matching using Köppen–Geiger maps, (2) CLIMEX modelling and (3) a degree model to calculate the potential number of generations per year. The three models all strongly support that the insect can establish in the Mediterranean areas of the southern EU. This conclusion is drawn with low uncertainty.

The impact of additional uncertainties was considered but not further quantified. Overall, the certainty ranges used in the different sections of the assessment (Section 3) capture in the panel's assessment the overall uncertainty.

5. Conclusions

Following a request from the European Commission, the EFSA Panel on Plant Health performed a pest risk assessment of *A. transitella* for the EU. The quantitative assessment focused on pathways and likelihood of entry, climatic conditions allowing establishment, presence of major cultivated hosts, spread and impact. Although *A. transitella* is a polyphagous pest, the importation of walnuts and almonds from the USA were the focus of the analysis because they were identified as the most likely pathway of entry of *A. transitella* into the EU. Other commodities are less likely to be infested prior to export (e.g. pistachios) and walnuts and almonds from other countries are imported in much smaller volumes than from the USA. *A. transitella* is a common pest of almonds, pistachios and walnuts in California, which is the main source for these nuts imported into the EU. Using expert knowledge elicitation and pathway modelling, a median estimate of 2,630 infested nuts is expected to enter the EU each year over the next 5 years (90% CR from 338 to 26,000 infested nuts per year). However, due to small likelihoods of transfer, mating upon transfer and survival of new founder populations, the number of newly established founder populations is estimated to be 0.000698 year^{-1} (90% CR 0.0000126–0.0364 year^{-1}). Accordingly, the expected median period between founding events resulting in establishment would be 1,430 years (90% CR 27.5–79,400 year). The likelihood of entry resulting in establishment is therefore considered very small, but the estimate has high uncertainty, mainly due to uncertainties on the processes of transfer of the insect to hosts and the establishment of new founder populations by successfully transferring insects.

Climate matching and CLIMEX modelling indicate that conditions are most suitable for establishment of *A. transitella* in Mediterranean Europe. Spread and impact were assessed using literature and expert knowledge elicitation. There is certainty that the insect can spread by flight, although there is uncertainty on the rate of range expansion (in both the EU and in California). The median rate of natural spread was estimated to be 5.6 km/year (90% CR 0.8–19.3 km/year), after an initial lag period of 3.1 year (mean, 90% CR 1.7–6.2 year) following the establishment of a founder population. If *A. transitella* did establish and spread to reach its expected equilibrium state in the EU, estimated median yield losses in nuts were estimated to be in the order of 1–2% depending on the nut species and production system. This conclusion is drawn by drawing analogies with production systems in California and considering how differences in cultivation systems between California and the EU could affect impacts.

In interpreting the numbers above and based on the results of the assessment, it is the Panel's opinion that some thousands of *A. transitella* are likely to enter the EU each year, but given the very large flow of product, and the low proportion of infested nuts, the likelihood of detection of infested nuts during inspection is small. Climatic conditions, especially in southern Mediterranean EU regions, could support establishment with low uncertainty, but the number of insects that successfully transfer, mate and survive to initiate a founder population is so low that the likelihood of establishment occurring is very low, resulting in expected waiting times until the first established founder population of several tens to thousands of years. If *A. transitella* did establish in the EU, establishment is most likely to occur in the Mediterranean region, where spread could occur at rates of a few up to 20 km/year after an initial lag period in which the insect builds a local population and adapts to local conditions. If establishment and spread occurred, an impact on nut production would be expected, predominantly amongst more intensively cultivated almonds. This might necessitate control efforts comparable to measures taken in the USA if a similar level of control as in the USA is desired.

A scenario requiring imports to be transported under chilled conditions was shown to provide potential to further reduce the likelihood of entry.

Concluding overall, this opinion shows that *A. transitella* could establish in the EU and could cause damage if it established. However, it is unlikely to be introduced because of limitations to transfer and establishment, even though with current trade and industry practices, we estimate that in the order of thousands of infested nuts enter the EU each year.

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Abbreviations

CN	Combined nomenclature (8-digit code building on HS codes to provide greater resolution)
CR	certainty range
DD	degree days
EI	ecoclimatic index (an index of climatic suitability used by CLIMEX)
EKE	Expert Knowledge Elicitation
EPPO	European and Mediterranean Plant Protection Organization
HS	Harmonized System (6-digit World Customs Organization system to categorise goods)
IPM	Integrated Pest Management
MS	Member state (of the EU)
NUTS	Nomenclature Units for Territorial Statistics
RRO	risk reduction option
ToR	Terms of Reference

Appendix A – Walnut production and processing

The EU imports the vast majority of imported walnuts from USA (Figures A.1 and A.2). California is the major walnut producing state in the USA. *A. transitella* is a key pest of walnuts in California (Wilson et al., 2020 and refs therein). *Juglans* nuts become vulnerable to attack by *A. transitella* just prior to harvest each year.

EU imports of walnuts inshell, 2016–2020, from countries where *A.transitella* is reported (100 kg)

Figure A.1: EU imports of walnuts inshell, 2016–2020, from countries where *Amyelois transitella* is reported (100 kg)

Different colours indicate the years 2016 (dark blue), 2017 (dark orange), 2018 (grey), 2019 (yellow) and 2020 (light blue).

EU imports of walnuts (shelled), 2016–2020, from countries where *A.transitella* is reported (100 kg)

Figure A.2: EU imports of shelled walnuts, 2016–2020, from countries where *Amyelois transitella* is reported (100 kg)

Evidence/information to inform judgments about the number of nuts exported each year.

<u>Nut and kernel weight</u>

Investigating walnut characteristics in Turkey, Yasar and Sen (1994) reported the average nut and kernel weights for a range of walnut varieties. Nut weight varied from 10.4 g to 19.6 g (mean = 13.8 g), whilst kernel weight varied from 5.8 g to 9.4 g (mean 7.3 g).

Investigating the physical properties of walnuts, Altunas and Erkol (2010) studied nuts ranging from 16.6 g to 21.4 g (mean weight approximately 18.4 g).

A cookery and diet website (https://weighschool.com/contact-weigh-school/ undated) indicates an average walnut (inshell) weighs 11 g; whilst a kernel weighs 4.8 g.

Table A.1: Summary of above

Walnut nut weight (g)			Kernel weight (g)			Reference
Min	Mean	Max	Min	mean	Max	
10.4	13.8	19.6	5.8	7.3	9.4	Yasar and Sen (1994)
16.6	18.8	21.4	7.3	7.5	7.8	Altunas and Erkol (2010)
	11.0			4.8		Anon (undated)

Walnut production summary (based on Anon, 2022)

Walnuts are produced in orchards and are suitable for harvest 5–7 years after planting saplings. In California over 85% of production is represented by six walnut varieties, 'Chandler', 'Hartley', 'Howard', 'Tulare', 'Serr' and 'Vina'. Due to differences in phenology, not all cultivars are equally susceptible to becoming infested by *A. transitella*. For example, the older varieties 'Vina' and 'Serr' mature earlier in the season during peak abundance of third generation (3rd flight) adults, these varieties are also susceptible to Lepidoptera larvae such as *Cydia pomonella* L. (Lepidoptera: Tortricidae) which can bore through green walnut hulls providing access holes for *A. transitella* which, as a poor penetrator, relies on naturally occurring fissures or entry holes caused by other insects for access to walnut kernels (Khan et al., 2016). 'Chandler' is a newer cultivar and matures later becoming susceptible in October after peak *A. transitella* abundance, which usually occurs in September, hence there are less females laying eggs on walnuts.

There are three important steps growers follow when managing *A. transitella*, (i) clearing fallen walnuts to prevent overwintering, (ii) monitoring the development of the crop and insect phenology to inform insecticide spray decisions during the growing season and (iii) timely harvest to minimise the exposure of walnuts to late season *A. transitella* populations (Wilson et al., 2020). Sterile Insect Technique and mating disruption with sex pheromones are also used to suppress populations of *A. transitella*.

Harvesting begins when the green walnut hulls start to split (exposing the nuts to *A. transitella*) and generally takes place from late August until late November (depending on cultivar). Mechanical shakers vigorously shake each tree causing walnuts to fall to the ground. The walnuts are then gathered by mechanical harvesters and taken for 'hulling' where the outer green hull (also known as the husk) is removed by a huller machine. The longer the hulls remain on nuts after harvest, the more the nut quality deteriorates (Perry and Sibbett, 1998).

A walnut orchard can take 8–10 years to come into full production, with highest yields when trees are 25–30 years old. Trees produce nuts each year but tend to alternate between years of high and low yields. Highest yields are obtained at tree densities of 160–200 trees per ha (https://www.growingproduce.com/nuts/proper-walnut-spacing-for-light-exposure/) Yields can be approx. 6,725 kg per ha (approx. 33.6 kg per tree to 42.0 kg per tree, depending on density) but does vary. Healthy and mature walnut trees produce from 30 to 160 kg of nuts, but this production cannot be achieved every year. In general a walnut tree will give good yield in 2 or 3 years of a 5-year period https://wikifarmer.com/starting-a-walnut-orchard/.

Box 1: Evidence of walnuts being infested post-harvest

- Prior to the phase out of methyl-bromide, the fumigant was an essential component of post-harvest disinfestation used against *A. transitella* and *C. pomonella* (California Walnut Commission, 1998).
- Johnson et al. (2010) reported that inshell walnuts for export could be infested with *A. transitella* and therefore exports were fumigated with methyl bromide to disinfest consignments.
- *A. transitella* has been intercepted three times in walnuts imported into Japan (Choi et al., 1996).

At harvest the moisture content of nuts is variable (Khir et al., 2013). De-hulled nuts are dried in batch dryers with air temperature not above 43°C (Kader, 2002). Processors aim to dry nuts to 8% moisture before entering storage. A moisture content of 8% does not support fungal growth. Wang et al. (2002) determined the thermal-death kinetics of fifth-instar *A. transitella* by heating larvae at 46, 48, 50, 52 and 54°C for various time periods. Extrapolating back to 43°C the PLH Panel estimate 100% mortality of *A. transitella* larvae would take approximately 16 h and 40 min. Kader (2002) reported drying times of walnuts can vary from 4 h to almost 2 days (assumed to be 48 h) depending on the original moisture content of the walnuts. Walnuts are then stored inshell. CargoHandbook.com (2022) reports dried walnuts can be stored for 1 year at −3 to 0°C. From storage walnuts are graded and either packed inshell or shelled then packed.

Some nuts can be heat pasteurised e.g. almonds (see Appendix C) but walnuts are very sensitive to heat and cannot be heat pasteurised because the fatty acids in walnuts rapidly becomes rancid after exposure to the elevated temperatures required for pasteurisation (Mermelstein, 2013).

Walnuts for shelling can be destined for either the consumer or industrial market. Walnuts inshell are removed from storage as necessary and mechanically cracked; shells and kernels are then air-separated, kernels are screened into a series of sizes, physically inspected and colour graded in accordance with an official walnut colour chart (USDA, 2017; Khir and Pan, 2019).

In the USA shelled walnuts are graded into two quality standards, the premium standard is called 'US no. 1', the other standard in called 'US Commercial' (USDA, 2017). Insect injury is regarded as 'very serious damage'. Insect damage is described in the walnut quality standard and means that an insect, web, frass or other evidence of insects is present on a portion of kernel. US no. 1 grade walnuts should be free from insect injury although there is a 1% tolerance (by weight) for all types of 'very serious damage' combined. Other 'very serious damage' is caused by five other defects: shrivelling, presence of mould, discolouration, rancidity and presence of shell or any foreign material.

The USDA provide detailed instructions to officials conducting inspections of walnuts for grading purposes (USDA, 1974, reprinted 2009). Sampling during packing involves 'in-line' sampling where 25–50 nuts are sampled and graded every 30 min from the packing line. The average of all samples is the overall grade for the lot when packing has been completed. If lots have been packed prior to inspections, the USDA guidance provides sampling rates in relation to the weight of the lot (Table A.2).

Table A.2: USDA sampling regime for grading walnuts when walnuts are already packed (USDA, 1974, reprinted 2009)

Weight of lot (US pounds)	Weight of lot (Kg)	Number of containers to sample from	Walnuts per container	Total walnuts sampled
Less than 20,000	< 9,072	20 (or all if less than 20)	50	Up to 1,000
20,000–80,000	9,072-36,287	40	25	1,000
More than 80,000	> 36,287	60	25	1,500

Following sorting and grading kernels are packed for distribution. To prolong shelf life walnuts are best transported chilled (next section).

Transport to the EU

To prolong shelf life, the ideal temperature for transporting walnuts is within the range of −3 to 0°C, although transport between 5 and 25°C is possible for short journeys (TIS, 2022b).

Exporters shipping walnuts or almonds to the EU seek to minimise pest contamination before consignments are loaded into shipping containers; exports do not rely on, or take into account, any pest mortality that may occur during shipping (S. Walse pers. comm.). Whilst cargo handlers and literature recommend that nuts, including walnuts and almonds, are transported in refrigerated containers (reefers) some exports are shipped in regular containers and consignments experience ambient temperature during transport. The global COVID-19 pandemic resulted in significant disruption to container shipping supply chains (Notteboom et al., 2021) and caused a shortage of containers with an estimated 9% of the global container fleet idle during the pandemic (Yazir et al., 2020). The lack of availability of reefers and their much higher cost means that at the present time (summer 2022) perhaps around 30% of nut exports to the EU are shipped in reefers where nuts are chilled and held in controlled conditions (S. Walse, pers comm), meaning 70% are shipped at ambient temperatures.

Eurostat trade data indicates the mode of transport for imported commodities. Tables A.4 and A.5 below shows the vast majority of walnuts from USA arrive in EU by sea, i.e. via container ships. Transport on a container truck from California to the major east coast containers ports is expected to take at least 5 or 6 days (Table A.3) during which time we assume 30% of walnuts will be transported whilst chilled (between −3 and 0°C) which would cause substantial mortality in larvae inside nuts.

Table A.3: Distance and minimum transport time from San Joaquin Valley, California to major east coast ports in USA (based on average speeds of 66 mph and 8 h travel per day)

Major east coast ports in USA	Distance from San Joaquin Valley, California (miles)	Travel time (days)
Port of New York, New York	3,070	5.8
Port of Virginia, Virginia	2,930	5.5
Charleston, South Carolina	2,760	5.2
Savannah, Georgia	2,700	5.1

Table A.4: Imports of fresh or dried walnuts, inshell (HS 0802 31) by mode of transport into EU from USA 2016–2020 (Quantity in 100 kg)

Mode of transport	2016	2017	2018	2019	2020
Sea	389,337	376,892	313,793	395,602	358,376
Air	6	4	24	1,022	3
Sum	389,343	376,896	313,817	396,624	358,379
% by sea	100.0	100.0	100.0	99.7	100.0

Table A.5: Imports of fresh or dried walnuts, shelled (HS 0802 32) by mode of transport into EU from USA 2016–2020 (Quantity in 100 kg)

Mode of transport	2016	2017	2018	2019	2020
Sea	442,344	433,523	444,072	469,416	454,490
Air	378	817	1,626	428	24
Sum	442,722	434,340	445,698	469,844	454,514
% by sea	99.9	99.8	99.6	99.9	100.0

Figures A.3 and A.4 shows the % of imports of inshell and shelled walnuts arriving by air each year since 2000. Since 2010, the percentage of inshell walnuts imported by air has generally been less than 0.1%, except in 2019. The percentage of imports of shelled walnuts arriving by air is higher, usually less than 0.3%.

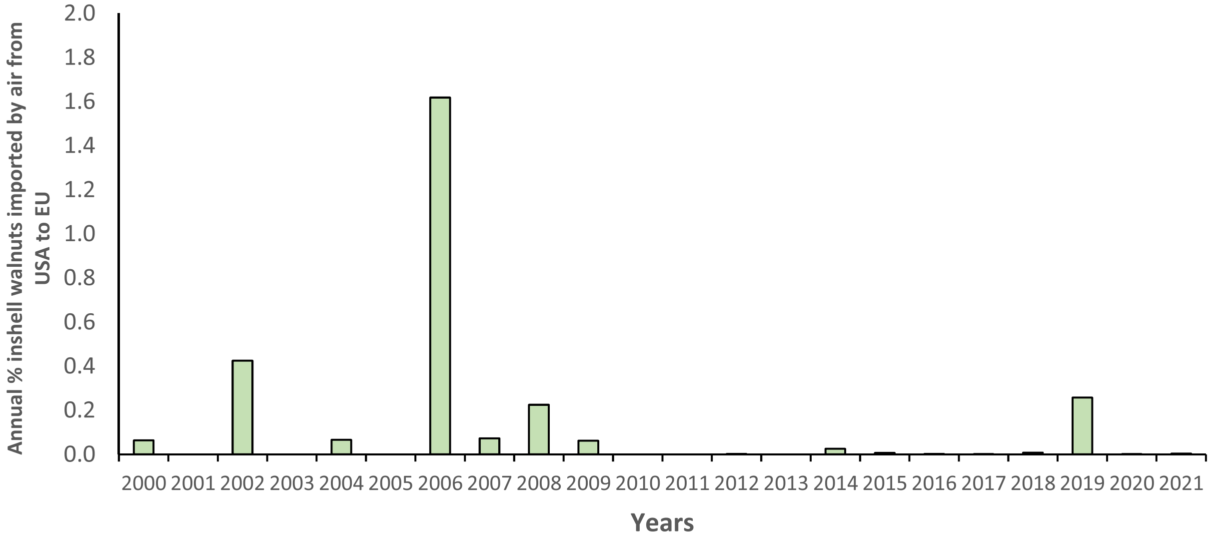


Figure A.3: Annual % inshell walnuts imported by air from USA to EU 2000–2021

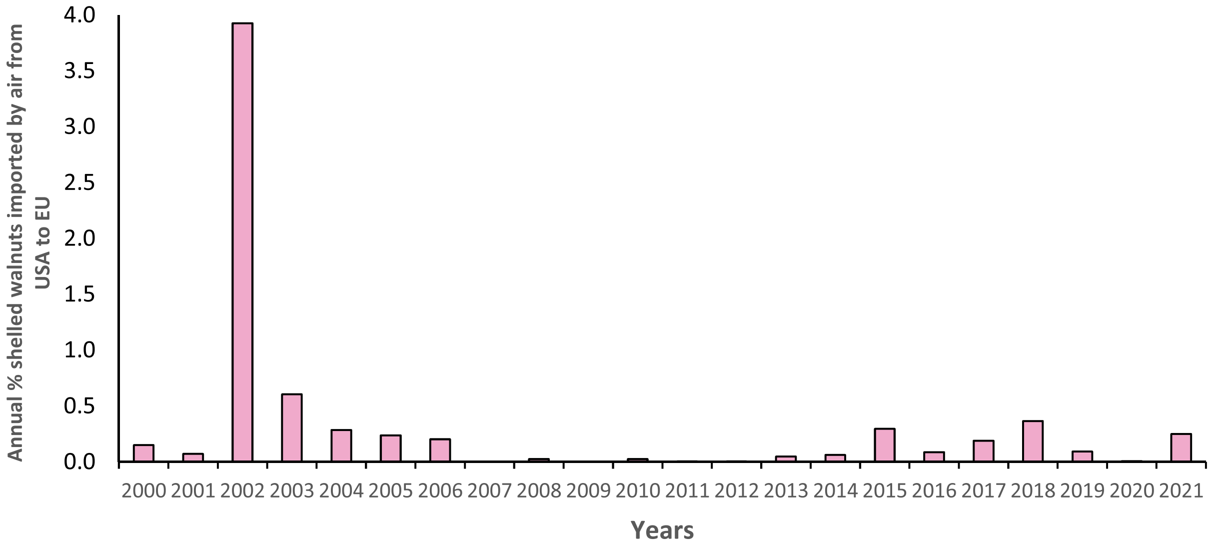


Figure A.4: Annual % shelled walnuts imported by air from USA to EU 2000–2021

Container ships normally take from approximately 8–14 days to cross the Atlantic from North America to the EU depending on the route taken and speed. Although imports occur throughout the year, peak imports occur in November and December ahead of the Christmas season (Figure A.5). Inshell walnuts from USA need to be loaded onto ships by 1st November to reach EU markets in time for St Nicholas Day celebrations (California Walnut Commission, 1998).

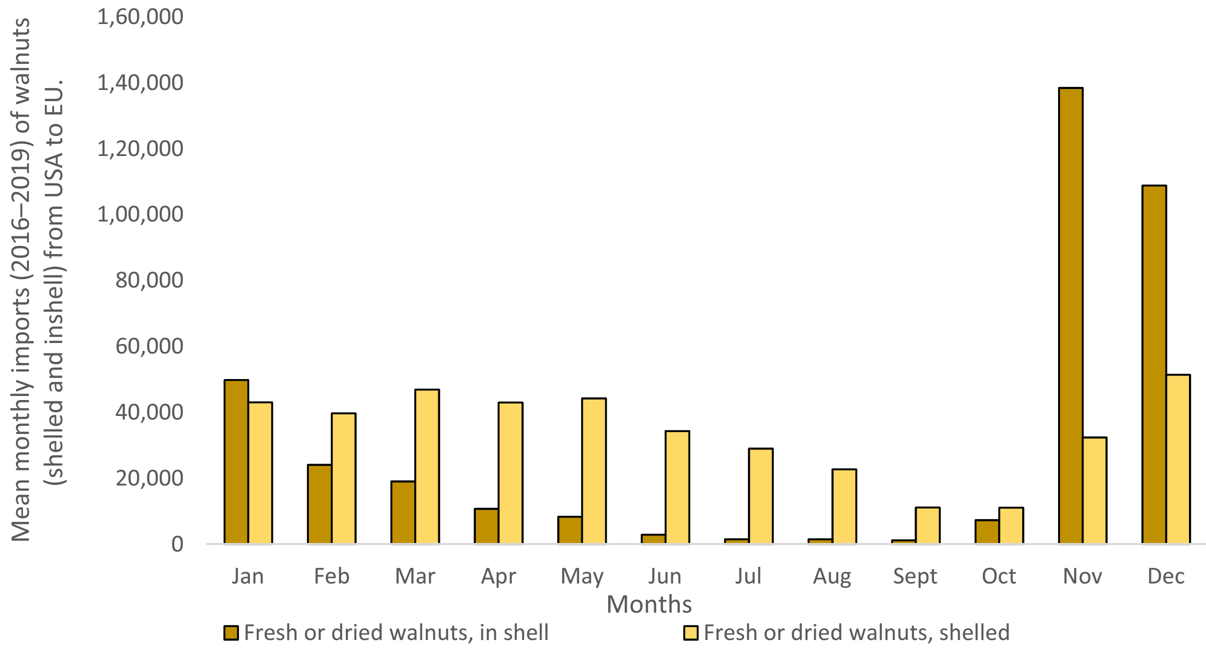


Figure A.5: Mean monthly imports (2016–2019) of walnuts, shelled and inshell from USA (x 100 kg) Source: Eurostat

The EFSA PLH Panel estimate that 30% of walnuts will be in refrigerated containers for a minimum of between 14 and 20 days whilst being transported from California to the EU. Allowing for some dwell time in port, onward distribution and storage within the EU, total transport time whilst chilled could be approximately 15–30 days or longer.

Johnson (2007) investigated the survival of *A. transitella* eggs and larvae at 0°C, 5°C and 10°C. The lower temperatures span the range of temperatures at which walnuts are stored and transported. On testing eggs at 0°C that were 15–63 h old, it took from 1.1 to 2.9 days to kill 95% of eggs (95%

Confidence Limit 0.8–3.5 days). At 5°C, it took from 4.5 to 6.6 days to kill 95% of eggs (95% CL 3.9–7.1 days).

When testing larvae at 0°C, 95% were killed within 4.3 days (95% CL 2.7–9.8 days); and at 5°C, 95% were killed in 10.9 days (95% CL 9.6–12.7).

For marketing purposes in the EU there are no officially defined EU classes or size grades for walnuts, such as Extra Class, Class I or Class II, as there is for many fruits and vegetables. Nevertheless, the United Nations Economic Commission for Europe (UNECE) standard is widely used, and class is based on allowed defects (UNECE, 2014). Regardless of class, the shell and kernel must be free from damage caused by pests and there must be no live pests or dead insects or mites present. There are also a number of other conditions necessary to meet the minimum requirements for marketing purposes e.g. nuts to be free from blemishes (UNECE, 2014).

Sizing: Grading categories for walnuts are not officially defined in the European Union. The most frequently used grading classification is also by UNECE. Sizing is mandatory for Extra Class and Class I, but optional for Class II. For inshell walnuts, the minimum size is 26 mm for Extra Class and Class I. Class II, when sized, has a minimum size of 24 mm.

Appendix B – Expert Knowledge Elicitation: Overview of the assessment of entry via walnuts (inshell and shelled)

The pathway model has 11 steps. For eight of these (with asterisks), parameters were elicited by expert judgement. Three parameters were elicited from data (with hash). The 11 steps are:

1) Trade volume (kg/year)*
2) Individual walnut weight (kg)*
3) Percentage of walnuts held in store till next year (constant calculated from data)#
4) Percentage of walnuts infested with *A. transitella* after harvest entering packing house*
5) Efficacy of operations (proportion surviving insects) to kill *A. transitella* eggs, larvae and pupae inside nuts or remove infested nuts from tradeflow at packing line (numbers surviving out of a million)*
6) Probability of survival of *A. transitella* in/on infested nuts during transport from USA to the EU*
7) Proportion of nuts transported to NUTS-2 regions with suitable climate#
8) Proportion of nuts imported during unsuitable parts of year (winter)#
9) Probability of transfer of *A. transitella* from infested nuts to hosts in EU territory, given its natural behaviour and proximity of a suitable site*
10) Probability of sufficient numbers of adult *A. transitella* being present to lead to mating*
11) Probability that *A. transitella* mortality is sufficiently low to allow population initiation, taking into account that small populations can go extinct easily due to demographic stochasticity*

Note that two of these steps are formulated differently than in the main text of the opinion. For step 3, the main text uses the proportion of nuts marketed in the year of production, while in the expert knowledge elicitation, the panel used the proportion carried over till next year. These two proportions sum to one and can therefore be easily calculated from each other. Similarly, step 5 concerns the efficacy of treatments and other operations at the packing house to kill *A. transitella* or remove infested nuts. The panel assessed the survival. Survival equals one minus efficacy, so one is easily calculated from the other.

The expected number of newly established populations per year due to product import via a given pathway is calculated by simple arithmetic using Monte Carlo simulation to capture uncertainty in elicited parameters.

The eight parameters that were elicited are discussed here for each walnut pathway.

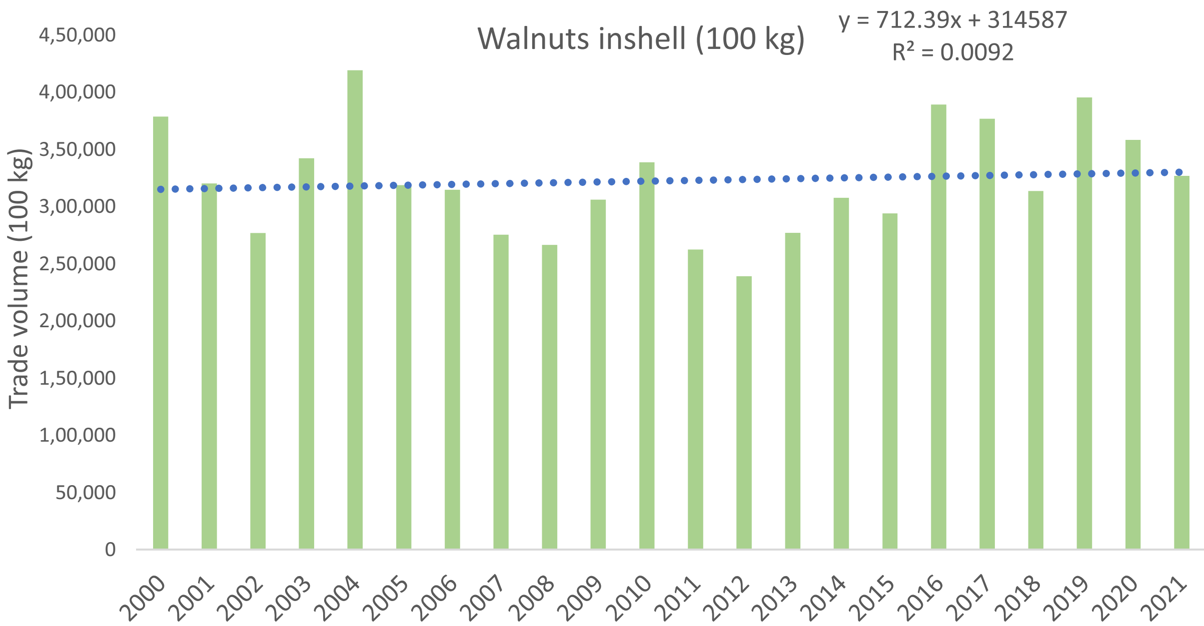
- Walnuts inshell
- Walnuts shelled.

Step 1: Trade volume

The first parameter is trade volume. Data on trade volume were retrieved from Eurostat and are expressed in 100 kg. The panel focused on the trade by sea as the flow by air is a very small fraction of the total. The average percentage of nuts shipped by air from the USA to the EU was 0.15% for walnuts inshell, 0.31% for shelled walnuts from 2000 till 2021 (Eurostat data).

1.1 Walnuts inshell

Trade by sea in walnuts inshell has been fairly steady since 2000. There is no clear trend of increase or decrease. Trade volume over the next 5 years (2022–2026) is therefore expected to be similar to that in the preceding years, with uncertainty on the average due to the rather substantial year-to-year variation in the trade in the past.

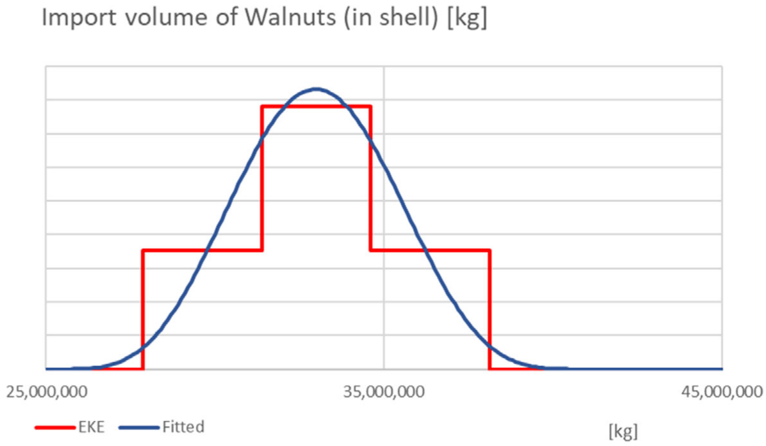


Elicited average yearly trade volume (kg/year) in the upcoming 5 years is given in the table below together with the probability distribution. EKE values are values proposed by experts as consensus estimates. EKE final results are derived from the fitted distribution, shown in the figure below the table.

Results					
Percentiles: %	5%	25%	50%	75%	99%
EKE values	28,000,000	31,400,000	33,000,000	34,600,000	38,000,000
EKE final results	29,298,916	31,400,855	32,997,484	34,602,112	38,018,375

Median (P50%) = 32,997,484

The 90% certainty interval (P5% to P95%) is between 29,298,916 and 36,740,880 kg

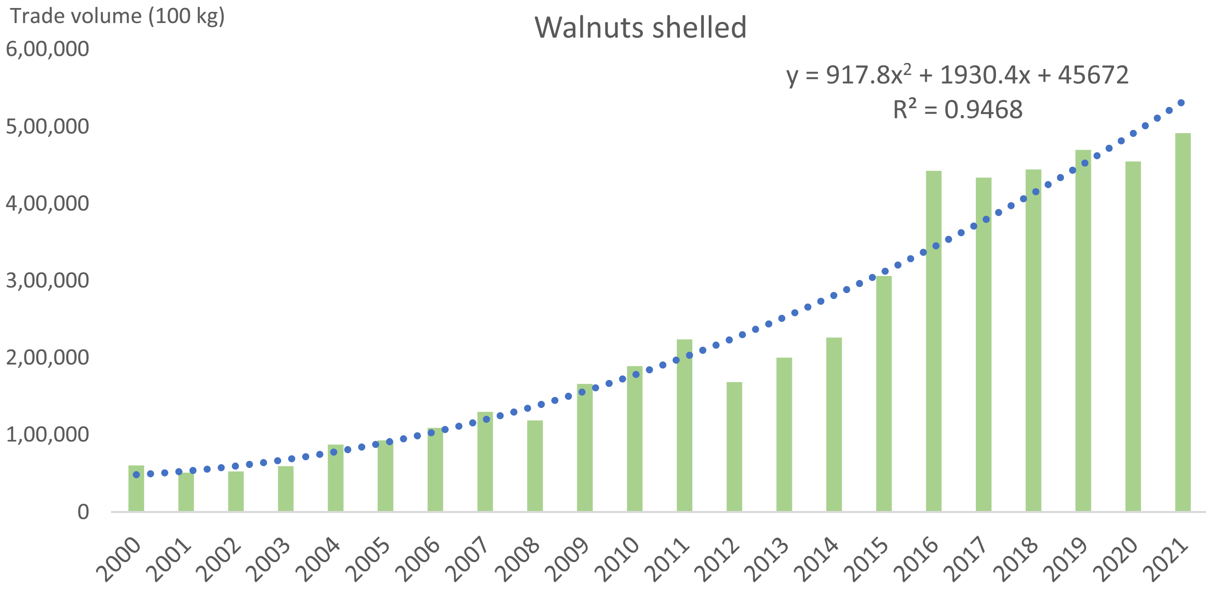


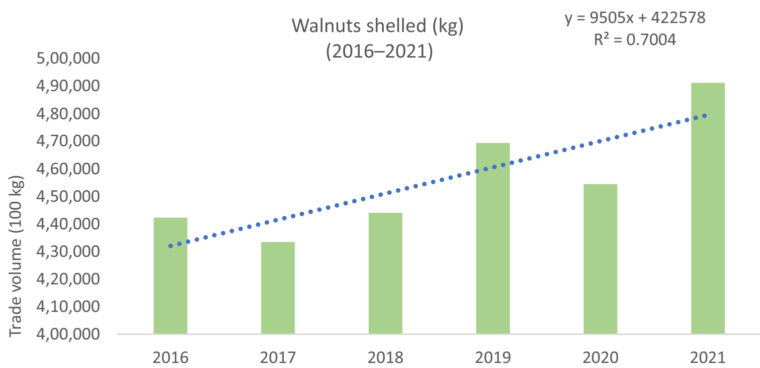
Uncertainties

Future trade may be affected in unexpected ways by costs or sustainability of transport, increased local production, de-globalisation, pandemics or trade restrictions. Growing awareness of the healthiness of eating nuts could affect trade or local production in the future. Advantages of vegetarian diets for health and planet could result in increased demand for nuts from consumers.

1.2 Shelled walnuts

Trade by sea of shelled walnuts shows a consistent increase over time. There is an eight-fold increase from 60,542 * 100 kg/year in 2000 to 491,230 * 100 kg/year in 2021, a 10% increase per year. Over the last 6 years, the trade increased moderately, by 9,500 units of 100 kg on average per year (slope of regression over the years 2015–2021). In its estimate for the next 5 years, the panel assessed a continued tendency towards bigger import of shelled walnuts from the USA. In its estimate for future trade, the panel gave greater weight to the linear trend of increasing trade over the last 6 years than to the curvilinear trend since 2000.





Elicited average yearly trade volume for shelled walnuts (kg/year) over the upcoming 5 years is given in the table below together with the probability distribution.

Results					
Percentiles: %	1%	25%	50%	75%	99%
EKE values	41,000,000	47,500,000	51,000,000	52,500,000	55,000,000
EKE final results	41,001,786	47,782,646	50,592,541	52,777,027	55,001,246

Median (P50%) = 50,592,541
The 90% certainty interval (P5% to P95%) is between 43,514,577 kg and 54,316,625 kg

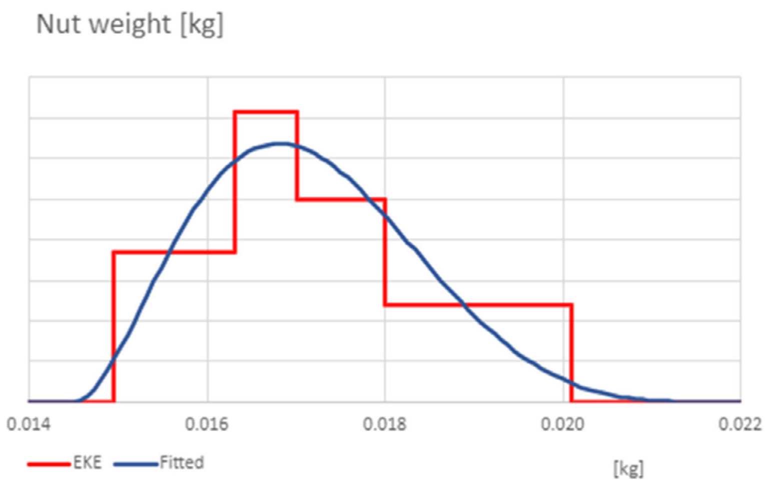
Uncertainties are the same as for unshelled walnuts.

Step 2: Individual nut weight

A small amount of data on the weight of walnuts were collected during the preparation of the walnut evidence dossier (Appendix A). The evidence was reviewed before elicitation.

2.1 Individual walnut weight inshell (kg)

Elicited average weight of walnut inshell over the upcoming 5 years is given in the table below together with the probability distribution.



Results					
Percentiles: %	1%	25%	50%	75%	99%
EKE values	0.0150	0.0163	0.0170	0.0180	0.0200
EKE final results	0.0150	0.0163	0.0171	0.0180	0.0201

Median (P50%) = 0.0171 g
The 90% certainty interval (P5% to P95%) is between 0.0154 and 0.0192 g

Uncertainties:

- There is limited information on nut weights
- Most information was taken from papers from Turkey with Turkish varieties
- The weight of cv. Chandler, the most common variety in USA, was found from industry websites (e.g. https://www.waltreeturkey.com/; https://tsesmelis.gr/en/portfolio/chandler-walnut-variety/) rather than from scientific literature or official information.

2.2 Weight of individual shelled walnuts

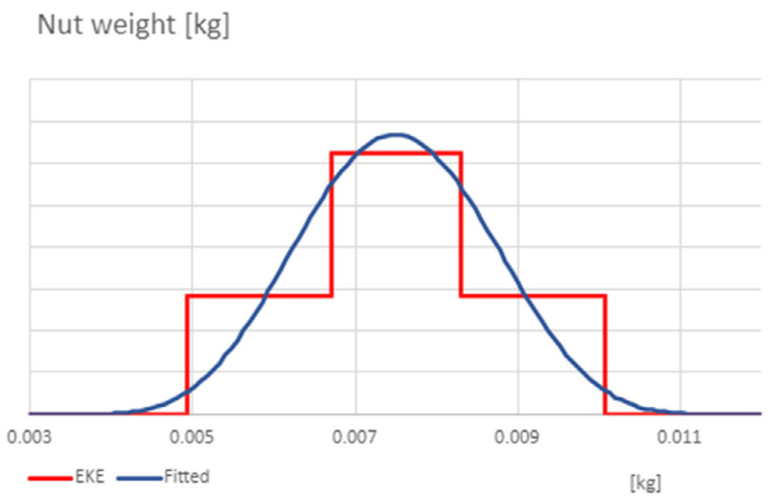
Individual walnut weight without shell (kg)

Based on the Turkish data in the walnut dossier (Appendix A) and keeping in mind the estimates for the walnuts inshell, the panel estimated a plausible range from 5 to 10 g per nut, with 7.5 as mid-point. Due to limited information there is fairly high uncertainty, which is expressed in a broad range (5–10 g).

Elicited mean walnut weight (kg) without shell is given in the table below together with the probability distribution.

Results					
Percentiles: %	1%	25%	50%	75%	99%
EKE values	0.0050	0.0067	0.0075	0.0083	0.0100
EKE final results	0.0050	0.0067	0.0075	0.0083	0.0100

Median (P50%) = 0.0075 g
The 90% certainty interval (P5% to P95%) is between 0.0056 kg and 0.0094 kg



Uncertainties

As above for walnuts inshell.

Step 3: Proportion of walnuts held in store for marketing the following year (Constant, not EKE)

Walnuts do not appear to be held in store for marketing the following year. There is therefore no reduction in any infestation due to long-term cold storage (unlike the situation for almonds). It is presumed that all walnuts harvested are marketed in the same year.

Step 4: Proportion of walnuts infested with *A. transitella* eggs and larvae

4.1 Proportion of walnuts inshell infested with *A. transitella* eggs and larvae, entering packing house after harvest

Initially, an assessment was made of the proportion of nuts infested with larvae at the time of harvest. Afterward, the assumption was made that, in addition to larvae within the nuts, there would be an equal number of eggs on the surface of the nuts. Thus, the infestation level with eggs plus larvae was estimated to be twice as high as the level estimated initially which was only for the larvae.

This assessment largely followed the reasoning and evidence used for the assessment of impact under European conditions (3.4 Impact). However, it was taken into account that in California, there is currently much experience with the pest, and control is based on a judicious combination of measures including variety choice, sanitation, early harvesting, use of pesticides, mating disruption and sterile insect technique. By combining many measures in an integrated approach, levels of infestation of nuts in California orchards have been pushed down to levels well below 1 % on average (personal communication Kent Daane), and pest levels that were common in the 1980s are no longer common. The panel elicited the below distribution taking into account the evidence. The proportion of nuts infested with *A. transitella* larvae, and with eggs on the surface, entering packing house after harvest are shown in the table below.

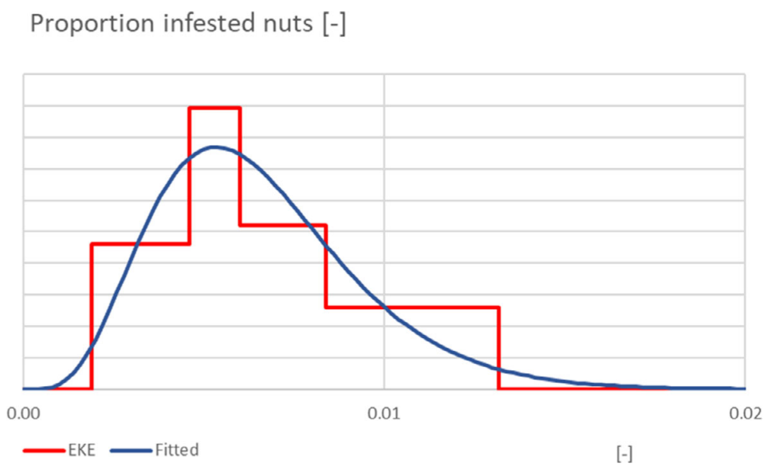
The elicited mean proportion of walnuts inshell infested with eggs and or larvae is given in the table below together with the probability distribution.

Proportion of infested walnuts with eggs and larvae

Results					
Percentiles: %	1%	25%	50%	75%	99%
EKE values	0.0020	0.0046	0.0060	0.0084	0.013
EKE final results	0.0018	0.0045	0.0062	0.0082	0.0148

Median (P50%) = 0.0062

The 90% certainty interval (P5% to P95%) is between 0.0027 and 0.0118



Uncertainties

- We don't know exactly how the level of infestation varies between different individual growers producing for the EU market.
- Control efficacy has improved with the introduction of sterile insect method and mating disruption, but the panel lacks exact data showing the size of the effect
- Due to experience and a broad palette of measures, the panel estimates that the proportion of infested walnuts in USA is below the level that is foreseen when the pest is introduced in the EU, where, for instance, sterile insect technique is not presently available.
- There is pressure in the USA to avoid contamination with aflatoxin; hence, US growers and agencies have a strong incentive to keep the crop pest free and retain this important market for US agriculture industry.
- The panel places trust in the USA field IPM approach but recognises that *A. transitella* is a difficult pest that cannot be controlled completely.
- Information was mostly gathered from experts from California and scientific publications forthcoming from California, but other growing regions in the USA exist and we have less information on them.

4.2 Proportion of shelled walnuts infested with *A. transitella* larvae entering packing house after harvest

These are the same nuts coming into the packing house as those that are exported unshelled. We therefore use the estimate of the proportion of larvae (i.e. excluding eggs, which cannot be laid *inside* the shell unless it was cracked, which would make the nut unmarketable) as above.

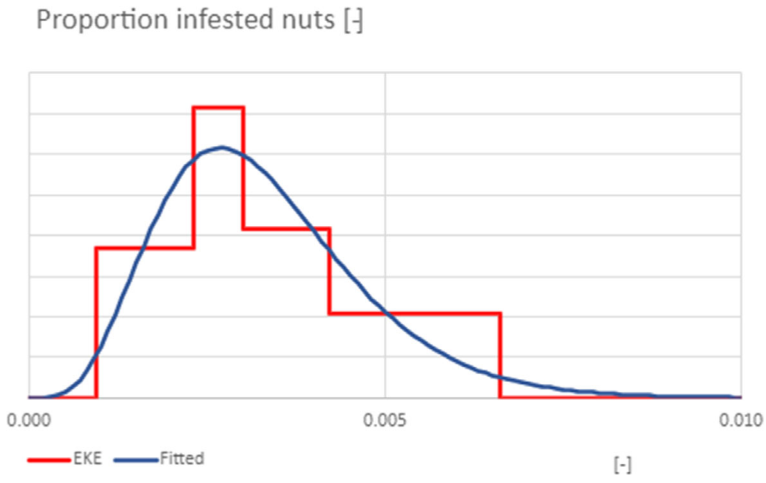
The elicited mean proportion of shelled walnuts infested with larvae is given in the table below together with the probability distribution.

Proportion of infested shelled walnuts with larvae

Results					
Percentiles: %	1%	25%	50%	75%	99%
EKE values	0.0010	0.0023	0.0030	0.0042	0.0065
EKE final results	0.0009	0.0023	0.0031	0.0041	0.0074

Median (P50%) = 0.003

The 90% certainty interval (P5% to P95%) is between 0.0014 and 0.0059



Uncertainties

As for walnuts inshell.

Step 5: Efficacy of operations at treatment/packing house

Here we consider survival of *A. transitella* despite control measures applied at packing houses. Exports seek to achieve probit-9 level of pest freedom (32 alive out of 1,000,000). Chemical fumigants (phosphine and sulfuryl fluoride) can control *A. transitella* well (Appendix E), but sample sizes used in experiments on control efficacy are not enough to demonstrate with certainty that probit-9 is attained.

5.1 Number of infested walnuts inshell after treatments

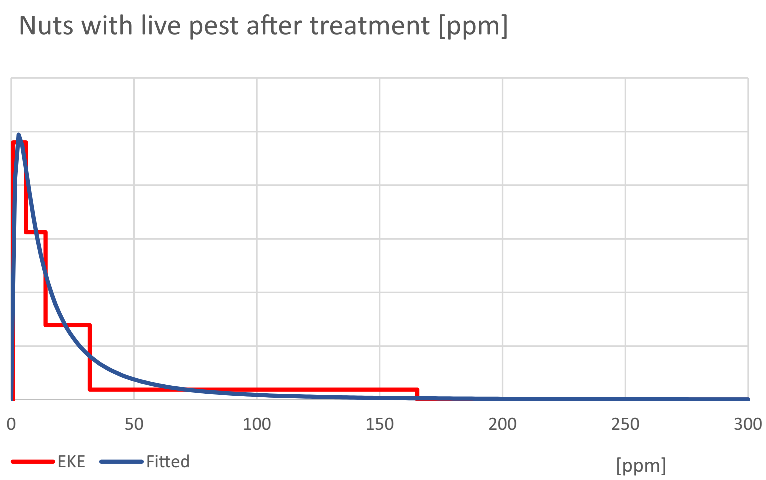
Number of *A. transitella* infested nuts (out of 1,000,000 nuts) that remain infested with live *A. transitella* after treatments, including hulling, shelling, chemicals, pasteurisation (walnuts cannot be heat-pasteurised but propylene oxide is used for pasteurisation) and sorting.

The elicited mean number of infested inshell walnuts (per million nuts) remaining infested after treatments is given in the table below together with the probability distribution.

Results					
Percentiles: %	1%	25%	50%	75%	99%
EKE values	1.0	6.0	14.0	32.0	160.0
EKE final results	0.82	6.11	13.90	31.60	236.16

Median (P50%) = 13.9

The 90% certainty interval (P5% to P95%) is between 1.88 and 102.99 survive per million



The 160 per million survival as the upper extreme means 0.016% survival. That is very low, and we are hard-pressed to believe it could be any more than this, and more likely values are more down to a few 10s per million (similar to the probit-9 standard). The lower extreme is only 1 in a million survival. We hesitated between 0 and 1 but felt that some very small non-zero value is more appropriate. We think the median value is equally far from the lower and upper extremes, on a multiplicative scale. The median survival is lower than the probit-9 norm, which seems reasonable because of the effectiveness of the available options and the interest of producers to comply with the market standards. Quartiles are chosen on a multiplicative scale closer to the median than to the extremes. The upper quartile is similar to the probit-9 standard because we are convinced producers have the means and the intent to reach probit-9 effectiveness. The 25% probability mass above the third quartile of probit-9 survival expresses our uncertainty and lack of knowledge how measures are carried out in practice, e.g. which products are used on which proportion of the flow and what the exposure duration is. Also, the deterrence has been relatively low in the past because *A. transitella* was not a quarantine species and reporting of finds was not required. The lack of recent interceptions last checked 2022-05-23 does therefore not give good information on the actual prevalence of the insect in the tradeflow, though it is considered to be very low and at a level that is not or hardly detectable with normal sample sizes of a few hundred nuts.

Uncertainties

- The combined efficacy of operations (proportion surviving insects) to kill *A. transitella* eggs, larvae and pupae inside nuts, or to remove infested nuts from exports as the nuts pass along the packing line and undergo quality checks, is unknown.
- There is uncertainty over the proportion of exports that undergo fumigation (sulfuryl fluoride or phosphine), heat treatment or other form of pasteurisation.

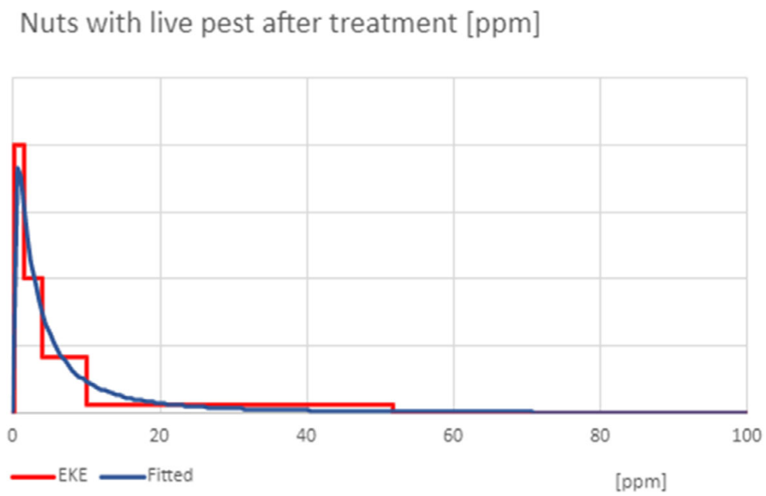
5.2 Walnuts shelled

The elicited mean number of infested shelled walnuts (per million nuts) remaining infested after treatments is given in the table below together with the probability distribution.

Results					
Percentiles: %	1%	25%	50%	75%	99%
EKE values	0.3	1.5	4.0	10.0	50.0
EKE final results	0.17	1.59	3.93	9.71	89.07

Median (P50%) = 4.0

The 90% certainty interval (P5% to P95%) is between 0.43 and 35.7 survive per million



Uncertainties

Same as walnuts inshell.

Step 6: Survival of cold temperatures during storage and transport

Johnson (2007) studied the survival of *A. transitella* eggs and larvae at temperatures from 0 to 10°C. There was 95% egg mortality within 1.1–2.9 days and 95% mortality of larvae within 4.3 days at 0°C. Transport industry sources recommend nuts be transported in reefers between –3 and 0°C. Duration of tranport could be 15–30 days or more.

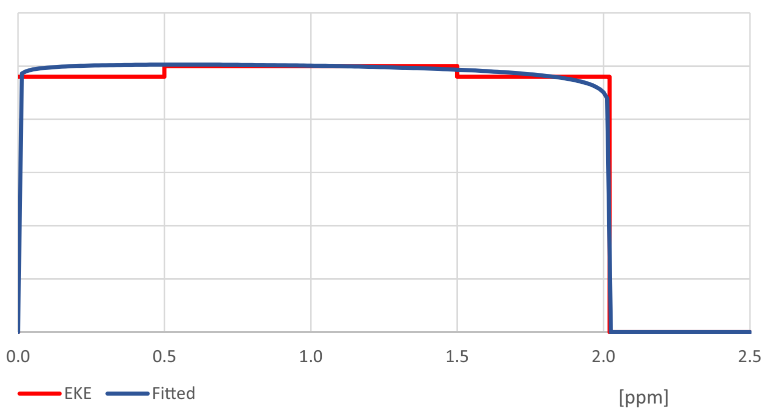
- **Survival of eggs**

The elicited mean number of eggs, per million, that survive 15–30 days of cold transport is given in the table below together with the probability distribution.

Results					
Percentiles: %	1%	25%	50%	75%	99%
EKE values	0.00	0.50	1.00	1.50	2.00
EKE final results	0.02	0.50	1.00	1.50	2.00

Median (P50%) = 1.0
The 90% certainty interval (P5% to P95%) is between 0.1 and 1.91 survive per million

Survival of the cold treatment by eggs [ppm]



Uncertainties

Thirty-two in a million (probit 9) are surviving in reefers at 0°C for 8.9 days, but the temperature in reefers may be lower, and the transport time is longer so survival is expected to be lower, but unknown by how much.

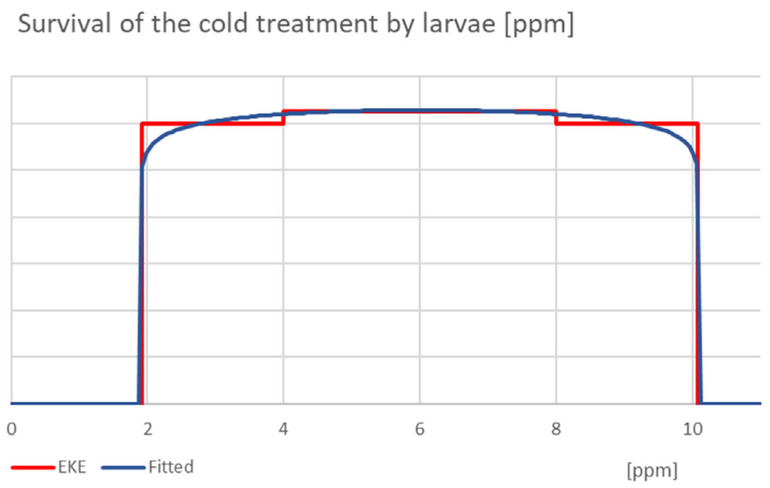
Reefers might not be able to sustain temperatures of 0°C throughout all containers for the entire duration of transport.

- **Survival of larvae during cold store and transport**

The elicited mean number of larvae per million, that survive 15–30 days of cold transport is given in the table below together with the probability distribution.

Results					
Percentiles: %	1%	25%	50%	75%	99%
EKE values	2	4	6	8	10
EKE final results	2.0	4.0	6.0	8.0	10.0

Median (P50%) = 6.0
The 90% certainty interval (P5% to P95%) is between 2.4 and 9.6 survive per million



Step 7: Proportion of nuts transported to NUTS-2 regions with suitable climate (Constant, not EKE)

We assumed walnuts would be distributed within the EU in proportion to human population. In this assessment, imports were spatially distributed by NUTS 2 region. Appendix F details the NUTS 2 regions where climate is suitable for *A. transitella* establishment together with human population (Eurostat 2019 data) and area of these regions. The proportion of imports was held constant in the model (0.337) across all types of imported nuts, meaning 33.7% of walnut imports would be distributed to NUTS 2 regions where climate is suitable for potential establishment.

Step 8: Proportion of nuts imported during unsuitable parts of year (Constant, not EKE)

The monthly imports of walnuts inshell (Appendix A) indicates that 86% of imports arrive in the winter for consumption during the festive period/Christmas season. Initiating a founder population at this time was deemed not possible and a proportion 0.86 was used as a constant in the pathway model for walnuts inshell.

Shelled walnuts do not show a marked seasonality, imports are more evenly spread over the year although 41% are imported during the winter (Appendix A). The proportion 0.41 was used as a constant parameter in the pathway model for shelled walnuts.

Step 9: Probability of pest transfer from infested nuts to hosts in EU territory

Pest transfer is little studied although van der Gaag et al. (2019) did identify key steps to consider and take into account when modelling the likelihood of a pest transferring from plant produce to a site suitable for establishment. Whether or not the pest being assessed can establish outdoors or only in glasshouses should first be considered. In the case of *A. transitella*, establishment outdoors is possible (see 3.2 establishment). In this case the question to consider is where the disposal of contaminated nuts occurs. Options include disposal at wholesale, retail or consumer sites, and most likely as waste. The most plausible scenario would entail a street market with open nut sales (to be scooped up by consumers) where contaminated/bad nuts (inshell predominantly) would be disposed of as regular waste (cf. nuts in pre-weighed sealed plastic bags, where disposal would be by the consumer). The question to consider is, 'of all the imported infested nuts, which proportion would allow an emerging adult to move by its own means to a host if weather and climate zone are suitable?' This is elicited for walnuts and almonds and shelled/unshelled together.

The mean area of key host crops grown in regions of the EU where climate is most suitable was extracted from Eurostat (2016–2020) - Table 15. For Croatia, Cyprus, Greece, Italy, Malta, Portugal and Spain the national area of crops in the table below were deemed as growing in regions climatically suitable for *A. transitella* establishment. All almond, apple and citrus production in France was considered to be within climatically suitable areas whereas 50% of grapes and 66% of pear, plum and walnut production in France were judged to occur in climatically suitable areas. Table 15 below shows that 3% of the NUTS 2 areas where climate is suitable is used to grow *A. transitella* hosts.

Table B.1: Mean area (km^2) of host crops grown in climatically suitable areas in the EU for *Amyelois transitella* establishment (2016–2020) Source: Eurostat

Crop: EU MS	Almonds (F4300)	Apples (F1100)	Citrus (T0000)	Grapes (W1000)	Pears (F1200)	Plums (F1250)	Walnuts (F4100)	Sum	NUTS 2 area	% of area
Croatia	5.5	49.6	20.9	212.5	8.0	43.9	66.1	406.5	56,594	0.7
Cyprus	24.7	4.0	31.2	64.3	0.6	3.9	2.0	130.8	9,251	1.4
Greece	139.0	99.3	448.6	1,007.8	42.5	22.4	140.3	1,899.8	131,957	1.4
Italy	555.4	524.0	1,344.4	6,843.0	299.6	117.6	46.0	9,730.0	302,071	3.2
Malta	0.0	0.0	0.0	5.2	0.0	0.0	0.0	5.2	316	1.7
Portugal	384.3	147.0	208.2	1,788.5	125.4	18.0	36.8	2,708.1	89,089	3.0
Spain	6,561.5	301.0	2,963.3	9,363.3	213.2	148.8	109.5	19,660.5	498,511	3.9
France	12.1	502.0	44.4	3,767.1	35.2	98.3	153.2	4,612.3	212,003	2.2
Sum	7,682.6	1,626.9	5,061.0	23,051.6	724.6	452.9	553.8	39,153.3	1,299,792	3.0

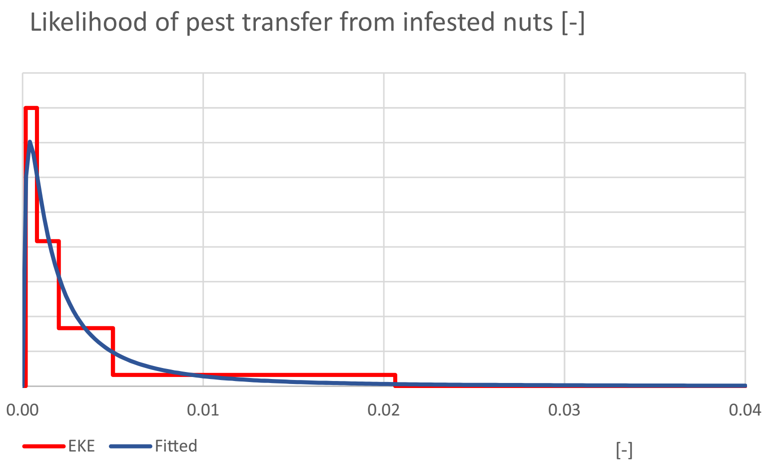
In the USA *A. transitella* can spread between neighbouring orchards to locate hosts. Phelan et al. (1991) reported that mated females, but not males or virgin females could fly more than 2.4 km up an odour plume of almond by-products to locate a host for oviposition. Hence mated females are more likely to find a host than males or virgin females. Success of host finding (transfer) is likely to depend on whether mating has occurred.

Proportion of imported nuts with live eggs/larvae/pupae inside, ending up near host in EU, which leads to the pest transferring to the host

The elicited mean proportion of imported nuts with live *A. transitella* ending up near hosts in the EU, which leads to the pest transferring is shown in the table below together with the probability distribution.

Results					
Percentiles: %	1%	25%	50%	75%	99%
EKE values	0.0002	0.0008	0.0020	0.0050	0.0200
EKE final results	0.00011	0.00085	0.00200	0.00470	0.03806

Median (P50%) = 0.002
The 90% certainty interval (P5% to P95%) is between 0.00025 and 0.01606



Uncertainties

- Where infested nuts are disposed
- Whether juvenile stages in infested nuts will survive and develop into adults Whether adults will locate hosts

Step 10: Likelihood of mating

The next step to consider is how likely are there to be sufficient individuals present that after transferring to a host male and female adults will locate each other and mate.

In estimating this likelihood, we thought that if some individual infested nuts come through, this may be a consequence of some failure in the supply chain, and multiple infested nuts may enter together, and be discarded together. This is unlikely to happen, but if it does happen, then there might be a high likelihood that multiple infested nuts are disposed in in close proximity. The chances of male and female co-occurring in a single nut is in the order of ¼. Such thinking informed the upper estimate of the EKE; setting an upper limit to the likelihood of a male and female ending up close enough to each other in EU territory to mate and lay eggs.

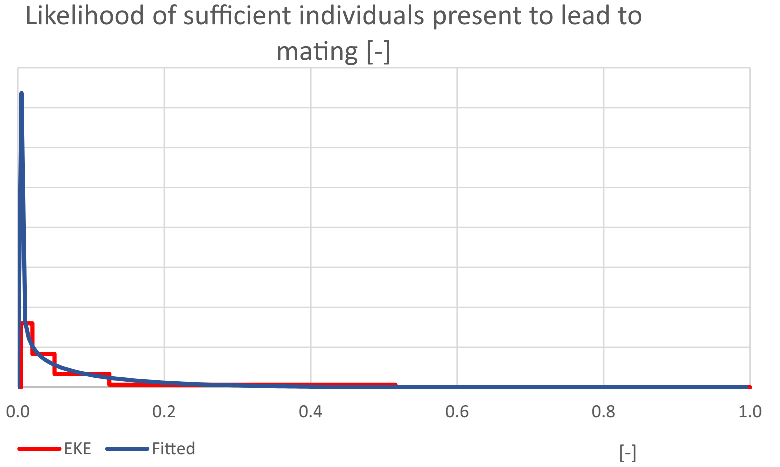
If the supply chain works as it should, i.e. if practically all infested nuts are sorted out, then there should be an extremely low proportion of infested nuts such that the event of an infested nut being discarded in suitable EU territory at the right time would be vanishingly low. Then, these would be single infested nuts, and we need to consider what is the probability that one nut could originate a viable population, or more infested nuts end up together. Responding to this EKE, one considers clustering, and the role of supply chain failures. When the supply chain operates well a male and female would need to come from the same nut. We assume half the infested nuts have one larva, and half the nuts two or more. Of those with two or more larvae, half have both sexes. Recognising that the sex ratio is a little unbalanced (57/43 male/female) (Siegel et al., 2008) the probability is still approximately 0.25. Such thinking informed the lower estimate of the EKE.

The elicited mean likelihood that sufficient numbers of individuals are present after transferring to a host to enable mating is shown in the table below together with the probability distribution.

Results					
Percentiles: %	1%	25%	50%	75%	99%
EKE values	0.005	0.020	0.050	0.125	0.500
EKE final results	0.0050	0.0189	0.0530	0.1215	0.4192

Median (P50%) = 0.05

The 90% certainty interval (P5% to P95%) is between 0.0059 and 0.2808



Uncertainties

- How often there is failure in the supply chain

When there are failures, how often will infested nuts be aggregated and disposed of together.

Step 11: Likelihood of survival and initiation of founder population.

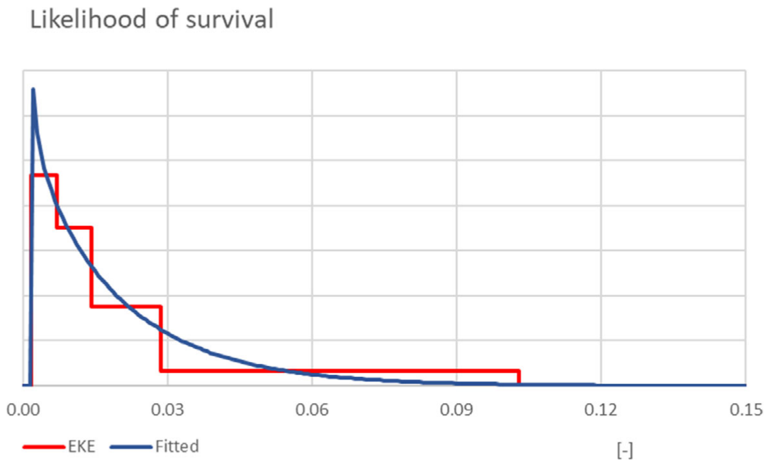
The last step in the entry pathway considered whether pest management regimes and natural mortality factors would allow *A. transitella* population initiation. We considered how likely is it that the pest management regimes used in host crops, and natural mortality factors such as severe weather and predators or other natural enemies, will allow population initiation by an arriving pest, taking into account that small founder populations can go extinct easily due to demographic stochasticity. At this point in the scenario we already have a male and female mating in a suitable area at the right time of year. Eggs have been laid. Then the question is how likely it is that these eggs will hatch and larvae growing from them will develop into adults that mate and lay eggs again in the same year or next. Winter is survived by the pest. Enough individuals survive pest control and natural enemies. A founder population is started.

We considered that a proportion of infested nuts or emerging moths would arrive in proximity to commercial well managed orchards with good pest control in place. Mortality will be high and the chance of initiating a population low. Other infested nuts could reach hosts not in commercial orchards but hosts used as amenity trees that are unmanaged (little managed) across the landscape, or adult *A. transitella* could find a tree in a home garden or organic orchard. Insects emerging from eggs laid in those places probably have a larger chance of survival. Nevertheless, small populations are prone to extinction due to Allee effects (Tobin et al., 2011; Strayer et al., 2006).

The elicited mean likelihood that mating leads to a founder population that survives is shown in the table below together with the probability distribution.

Results					
Percentiles: %	1%	25%	50%	75%	99%
EKE values	0.0020	0.0071	0.0143	0.0286	0.1000
EKE final results	0.00213	0.00697	0.01467	0.02816	0.09019

Median (P50%) = 0.0143
The 90% certainty interval (P5% to P95%) is between 0.00277 and 0.05950



Uncertainties

- The effect that EU pest management regimes will have on small populations of *A. transitella*
- Variation in natural mortality factors (e.g. adverse weather; predators or other natural enemies)

Table B.2: Walnuts inshell: Results of model output

Step	Detail	Unit	How determined	5%	25%	50%	75%	95%
1	Import amount	kg	EKE	29,298,723	31,400,746	32,997,482	34,602,032	36,740,537
2	Nut weight (kg)	kg	EKE	0.0154	0.0163	0.0171	0.0180	0.0192
	Number of nuts imported		Calculation	1,633,986,743	1,801,629,495	1,929,973,512	2,058,867,545	2,247,810,443
3	% nuts held in store till next year	%	Constant	0.00	0.00	0.00	0.00	0.00
	Number of nuts for marketing this year		Calculation	1,633,986,743	1,801,629,495	1,929,973,512	2,058,867,545	2,247,810,443
4	Proportion infested nuts		EKE	0.003	0.005	0.006	0.008	0.012
	Number of infested nuts		Calculation	5,137,626	8,609,993	11,843,777	15,896,892	23,109,896
5	# nuts with live pest after treatment	ppm	EKE	1.9	6.1	13.9	31.6	103.0
	Number of infested nuts after treatment		Calculation	18.8	66.8	160.4	384.9	1,345.0
6	Proportion transported in chilled container		Constant	0.30	0.30	0.30	0.30	0.30
7	Proportion of nuts with eggs		Constant	0.50	0.50	0.50	0.50	0.50
8	Survival of eggs during cold transport	ppm	EKE	0.102	0.501	0.999	1.501	1.913
	Survival of larvae during cold transport	ppm	EKE	2.350	4.001	6.000	7.999	9.649
	Number of infested nuts arriving in EU		Calculation	13.2	46.8	112.3	269.4	941.5
9	Imports to suitable climate (EU population)		Constant	0.337	0.337	0.337	0.337	0.337
10	Imports at unsuitable time of year		Constant	0.86	0.86	0.86	0.86	0.86
	Number of infested nuts to suitable NUTS 2 regions at suitable time of year		Calculation	0.6	2.2	5.3	12.7	44.4
11	Likelihood of pest transfer from infested nut		EKE	0.0002	0.0009	0.0020	0.0047	0.0161
	Number of individuals that transfer		Calculation	0.000542	0.003137	0.010617	0.035219	0.209407
12	Likelihood of mating		EKE	0.006	0.019	0.053	0.122	0.281
13	Likelihood of eggs surviving to reproduce		EKE	0.0028	0.0070	0.0147	0.0282	0.0595
	Number of nuts that result in transfer and population initiation per year		Calculation	0.0000001	0.0000014	0.0000071	0.0000348	0.0003208

Table B.3: Walnuts shelled: Results of model output

Step	Detail	Unit	How determined	5%	25%	50%	75%	95%
1	Import amount	kg	EKE	43,513,891	47,782,453	50,592,484	52,776,960	54,531,520
2	Nut weight (kg)	kg	EKE	0.0056	0.0067	0.0075	0.0083	0.0094
	Number of nuts imported		Calculation	5,146,259,860	5,972,566,207	6,679,675,417	7,524,851,192	9,010,362,837
3	% nuts held in store till next year	%	Constant	0.00	0.00	0.00	0.00	0.00
	Number of nuts for marketing this year		Calculation	5,146,259,860	5,972,566,207	6,679,675,417	7,524,851,192	9,010,362,837
4	Proportion infested nuts		EKE	0.001	0.002	0.0031	0.0041	0.0059
	Number of infested nuts		Calculation	8,717,309	14,860,291	20,596,536	27,997,680	42,065,229
5	# nuts with live pest after treatment	ppm	EKE	0.43	1.59	3.93	9.71	35.70
	Number of infested nuts after treatment		Calculation	7.6	30.3	79.2	205.6	814.9
6	Proportion transported in chilled container		Constant	0.30	0.30	0.30	0.30	0.30
7	Proportion of nuts with eggs		Constant	0.00	0.00	0.00	0.00	0.00
8	Survival of eggs during cold transport	ppm	EKE	0.102	0.501	0.999	1.501	1.913
	Survival of larvae during cold transport	ppm	EKE	2.350	4.001	6.000	7.999	9.649
	Number of infested nuts arriving in EU		Calculation	5.4	21.2	55.4	143.9	570.4
9	Imports to suitable climate (EU population)		Constant	0.337	0.337	0.337	0.337	0.337
10	Imports at unsuitable time of year		Constant	0.410	0.41	0.41	0.41	0.41
	Number of infested nuts to suitable NUTS 2 regions at suitable time of year		Calculation	1.1	4.2	11.0	28.6	113.4
11	Likelihood of pest transfer from infested nut		EKE	0.0002	0.0009	0.0020	0.0047	0.0161
12	Likelihood of mating		EKE	0.006	0.019	0.053	0.122	0.281
13	Likelihood of eggs surviving to reproduce		EKE	0.0028	0.0070	0.0147	0.0282	0.0595
	Number of nuts that result in transfer and population initiation per year		Calculation	0.0000003	0.0000028	0.0000146	0.0000751	0.0007791

Appendix C – Almond production and processing

The EU imports the vast majority of almond nuts from USA (Figures C.1 and C.2 below). California is the major state in the USA for almond production; the soil and climate of the San Joaquin Valley is ideal for almond production, especially when irrigation is used (Almond Board of California, 2021).

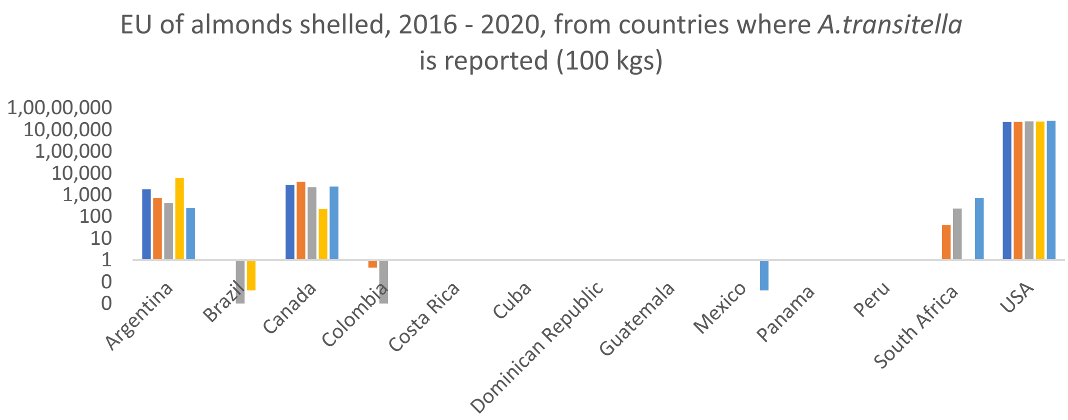


Figure C.1: EU imports of shelled almonds, 2016–2020, from countries where *Amyelois transitella* is reported (100 kg)

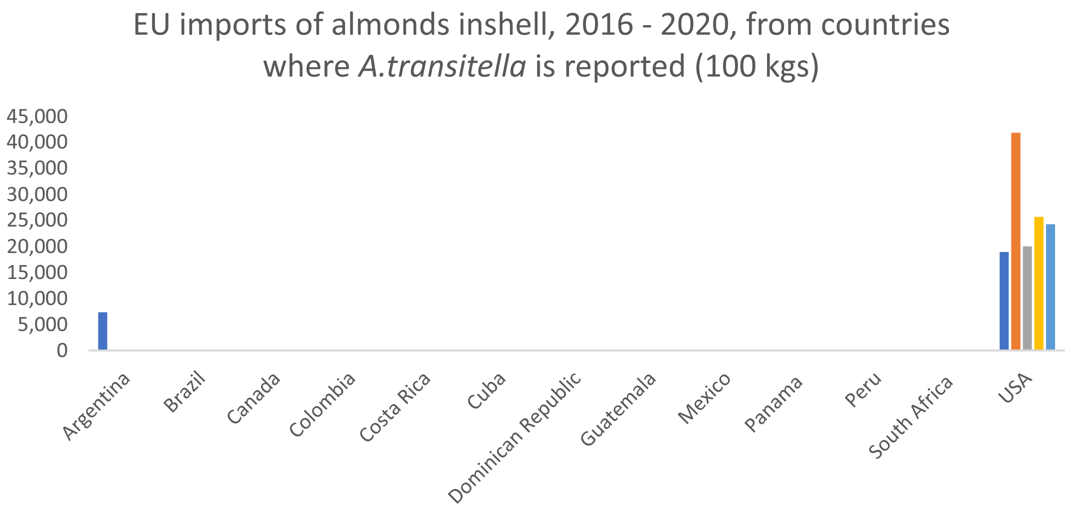


Figure C.2: EU imports of almonds inshell, 2016–2020, from countries where *Amyelois transitella* is reported (100 kg)

Almond trees are deciduous and typically grow to between 3 and 4.5 m tall. Planting densities in California range from 75 to 121 trees/acre; high-density orchards will have 130 trees or more per acre (approx. 320 trees/ha) but will require more intensive pest management. Trees become productive 3years after planting and are most productive from year 6 or 7; commercial orchards are typically replaced after 25 years (Mosz, 2002; Freeman et al., 2008).

Almonds have been grown in California since the 1850s when European cultivars were planted. However, they were replaced with cultivars more suited to Californian conditions (Geisseler and Horwath, 2016). 'Nonpareil', 'Monterey' and 'Butte' and 'Padre' are high yielding varieties widely grown today (Almond Board of California, 2021). Cultivars are classified as early, mid or late blooming. Cultivars are not self-compatible so orchards consist of at least two or more varieties which flower at the same time. Hives of honeybees are rented during flowering to ensure good pollination (Freeman et al., 2008). Flowering occurs during February and March (Mosz, 2002). Harvesting, using mechanised tree shakers, takes place five to seven months after flowering and usually occurs between early August and late October, after the hulls have split open and the kernel (almond 'nut') begins to dry. The fruit is left on the ground to dry for 7–10 days before being swept into rows by a 'sweeper' machine. Nuts are then collected as a mechanical harvester drives over the rows. However, to reduce infestation by *A. transitella* and contamination by aflotaxin producing moulds, alternatives to ground drying are being investigated (Chen et al., 2021). For example almonds can be dried in a hot air column dryer at temperatures between 45 and 60°C over 2.5–6 h (Chen et al., 2020).

After harvest, almonds go to a huller/sheller processor where the kernels pass through a roller to remove the hull, shell and any debris carried from the orchard. They are then graded and sized. The almond industry in California has invested in electronic optical sorting technology to identify and remove damaged almonds, which includes almonds infested by pests (Almond Board of California, 2016). Following sorting and grading almonds are kept in controlled storage conditions until they are either shipped or further processed for a variety of culinary uses (California almonds, 2022).

Almonds can be stored for about 1 year at temperatures between −3 and 0°C at 65–70% r.h. (Perry and Sibbett, 1998; Robins, 2019, TIS, 2022a). During the 10 years up to 2021/22, the percentage of almond crop held in store and carried over to the next year for marketing varied between 14.3% and 22.3%; mean carry over was 18.3% (Table C.1). After 1 year in store, no almonds will be infested with live *A. transitella* given that Johnson (2007) showed that on average 95% of larvae died within 4.3 days at 0°C (95% CL 2.7–9.8 days).

Table C.1: Annual weight of marketable almonds 2012/13 to 2021/22 (millions of lbs) with % of harvested almonds carried over for marketing the following year (Source: Almond Board of California, 2021, p 21, Position Report of California Almonds)

Crop year	Redetermined marketable weight	Carry-in from previous year	Total supply	Carry-over (marketed following year)	% of marketable weight carried over
2012/13	1,848.4	335.2	2,183.6	317.2	17.2
2013/14	1,970.0	317.2	2,287.2	350.6	17.8
2014/15	1,838.6	350.6	2,189.2	376.6	20.5
2015/16	1,846.6	376.6	2,223.2	412.0	22.3
2016/17	2,087.4	412.0	2,499.4	398.7	19.1
2017/18	2,211.9	398.7	2,610.6	359.0	16.2
2018/19	2,223.3	359.0	2,582.3	318.3	14.3
2019/20	2,504.2	318.3	2,822.5	450.1	18.0
2020/21	3,056.1	450.1	3,506.2	608.1	19.9
2021/22*	2,774.0	608.1	3,382.1	500.0	18.0

*: Figures for crop year 2021/22 are estimates.

In experiments Johnson et al. (2002) showed that storing almonds in a controlled atmosphere low oxygen (0.4%) at 25°C for 6 days resulted in 100% mortality of *A. transitella*. However, it is unknown whether this is standard industry practice.

In California there are 7,600 almond farmers growing a combined area of 1.6 million acres (approx. 647,500 ha) of which 1.25 million acres (approx. 505,900 ha) bear almonds. The remaining area (350,000 acres/approx. 141,650 ha) is occupied by young trees not yet mature enough to bear fruit. In year 2020/21, average yield was 2,490 lbs/acre (approx. 2,790 kg/ha); there are 101 almond processors in California (Almond Board of California, 2021).

Phenology of almond in relation to infestation by A. transitella

There are normally four generations of *A. transitella* in the southern San Joaquin valley of California, three further north. Depending on location, the first adults emerge in April or May from 'mummy' nuts, i.e. nuts that remain on the tree, or are not collected from the ground, after harvest. They mate and females oviposit on remaining mummy nuts. The adults of this generation emerge during June or July and can infest the developing almond crop on trees (Hamby et al., 2011). K. Daane (pers comm) suggested the second generation occurred in early August, the third in late August and the fourth in late September. The third generation (late August) is generally the largest population. Almonds are susceptible to *A. transitella* once the hull splits open (July–August). Neonate *A. transitella* larvae are unable to bore through the hull of almond fruit (Wilson et al., 2020), nevertheless, in orchard conditions *A. transitella* begin to oviposit on maturing almond fruit just before the hull splits although many eggs are laid after hull-split; eggs being laid on the inside of the hull or on the exposed shell of the nut (Curtis and Barnes, 1977). Hamby et al. (2011) evaluated the date of hull-split and percentage infestation of nuts by *A. transitella* in 19 varieties of almonds with varying hull-split dates. The hull-split date was negatively correlated with percentage of infestation; later splitting varieties tended to have lower infestation. The rate of infestation varied between 14. 3% (± 15.3) in cv. 'Kapareil' and 0.29% (± 0.76) for cv. 'Padre'. Fifteen of the varieties had infestation rates of over 2.0%, which is above the current industry target of up to 2% (Higbee and Siegel, 2009; Hamby et al., 2011). Table 18 shows the date of hull-split in 3 major almond varieties producing 61.7% of almonds in 2020/21. 'Nonpariel; is an early splitting variety, 'Monterey' and 'Carmel' are late splitting varieties (Hamby et al., 2011).

Table C.2: Production and hull-split date of three major almond varieties (Source: Almond Board of California, 2021; Hamby et al., 2011)

Cultivar	Production (Lbs)	% of production	Mean hull - split date	Date range
Nonpariel	1,296,418,528	41.6	Jul-12	Jul 8–Jul 16
Monterey	487,215,525	15.6	Aug-22	Aug 9–Sept 4
Carmel	136,866,369	4.4	Aug-21	Aug 12–Aug 30
27 others	1,194,394,000	38.3	–	–
Total	3,114,894,422	100.0	–	–

Given there is some tolerance for infestation for almonds marketed within the US, infested almonds in the field can be carried into storage (Johnson et al., 2002) but field pests such as *A. transitella* rarely reproduce or persist under commercial storage conditions. Nevertheless, their presence poses a serious phytosanitary risk for exported nuts and the discovery of live insects result in rejection of shipments (Arthur et al., 2009).

USDA inspection and grading instructions for almonds (USDA, 1998) also note that live insects are seldom present in lots packed under modern methods and the presence of any live insects inside the shell would cause the lot to fail to meet any grade and hence be prevented from being exported.

As noted above, conventional harvesting shakes almonds from the tree which are left on the ground to dry. Curtis et al. (1984) reported that when nuts infested with *A. transitella* fell form the tree to the ground 70–90% of the larvae and pupae were killed by excessive heat from direct sunlight. Other larvae exited the heated almonds and died on the soil surface. However, larvae in nuts in the shade on the ground suffered only 3% mortality. Curtis et al. (1984) also reported that *A. transitella* did not oviposit on cv. 'Nonpareil' on the ground after harvest but did oviposit on nuts still remaining in trees after harvest.

In a recent trial by Chen et al. (2021) the level of insect infestation in almonds harvested conventionally was compared to the level of infestation when shaken from the tree and collected in a catch-frame wrapped around the trunk. The level of infestation in almonds collected directly was approximately half the rate than found in almonds harvested after being left on the ground. However, Chen et al. (2021) did not identify the insect species causing infestation.

In studies by Meals and Caltagirone (1971) 25% of 200 old nuts collected in early April (i.e. mummy nuts from the previous year, in which larvae had overwintered) from an experimental orchard were infested with a mean of 1.3 viable larvae and/or pupae per infested nut. Subsequently 13.7% of the crop from these trees was damaged by *A. transitella* when harvested in early August.

To reduce the level of almond infestation by *A. transitella* winter sanitation is crucial. Higbee and Siegel (2009) recommended a maximum of 0.2 mummy nuts per tree and up to 4 ground mummies per tree in 'Nonpariel' almonds. However, ideally there should be no mummies left in the tree or on the ground. Mummies should be removed before budswell or by 1 February and destroyed by disking or flail by 15 March. Early harvest is also important. This means almonds should be harvested when 95% of nuts between a height of 1.8 and 2.4 m (6–8 ft) in the canopy, exhibit hull-split. This can lower or prevent a third generation of *A. transitella* (Almond Board of California, 2016).

Pasteurisation

Whilst low moisture foods (active water <0.85), such as nuts, are generally less susceptible to microbial spoilage they can be linked to outbreaks of food pathogens (e.g. Sánchez-Maldonado et al., 2018). Such threats can be managed with pasteurisation. Indeed, as a consequence of

Salmonella outbreaks in 2001 and 2004 that were linked to the consumption of unpasteurised raw almonds, it is mandatory for commercially produced US almonds to be pasteurised to reach a minimum 4-log reduction in *Salmonella* bacteria prior to shipment (Siegner, 2015; Luo et al., 2022).

Pasteurisation is primarily aimed at destroying human pathogens contaminating nuts rather than control of insect pests such as *A. transitella*. Nevertheless methods used to control pathogens may impact on contaminating insects. Researchers have tested pasteurisation temperatures for effective reduction in pathogens on nuts; temperature and exposure times can be, for example, 95°C for 25 s (Chang et al., 2010) to 200°C for 15 s which is typical for the almond industry.

Exporting almonds to the EU

The USDA provide detailed instructions to officials conducting inspections of inshell and shelled almonds for grading purposes when almonds are shipped between growers and handlers/packers (USDA, 1998). All grades of inshell almonds have a 5% tolerance for insect damage (i.e. presence of web, frass or evidence of insect feeding) and a 0% tolerance for live insects. The top grade of shelled almonds, termed 'US Fancy', has a 1% tolerance for 'serious damage' which includes decay, rancidity, insect injury and damage by mould. However, the EU regulations on aflatoxins is among the strictest in the world (Wu, 2008) and for almond exports coming into the EU more stringent inspections and checks are required.

In September 2007 the EC adopted Special Measures for almonds imported into the EU due to the risk from aflatoxins (European Commission, 2007[3]). As a consequence, the Almond Board of California established the Voluntary Aflatoxin Sampling Plan (VASP) to control and test for aflatoxin in export shipments particularly to the EU. The VASP program enabled < 5% of almond imports to be inspected on arrival in the EU. Having demonstrated success in reducing the presence of aflatoxin in shipments, California almonds were removed from EU Special Measures and instead enter the EU via the 'Pre-Export Checks' (PEC) program which provides equivalency to official EU testing of incoming shipments. PEC status was granted under EC Regulation (EU) 2015/949, and became effective on August 1, 2015.

Inshell and shelled almonds are included within PEC. To comply with the PEC, aggregate samples are taken from grading lines during processing or from packed lots in compliance with Commission Regulation EC No. 401/206, regarding the sampling protocols for nuts for official mycotoxin control (Table C.3).

Table C.3: Sampling regime for testing almonds exported to EU from California (Almond Board of California, 2016)

Weight of lot (US pounds)	Weight of lot (approx. Kg)	Sample size (kg)
< 220	< 100	2
> 220 < 441	> 100 < 200	3
> 441 < 1,102	> 200 < 500	4
> 1,102 < 2,205	> 500 < 1,000	6
> 2,205 < 2,409	> 1,000 < 1,093	8
> 2,409 < 11,023	> 1,093 < 5,000	12
> 11,023 < 24,046	> 5,000 < 10,900	16
> 24,406	> 10,900	20

Samples are tested for aflatoxin at approved USDA laboratories. The EFSA PLH Panel assume that detecting live insects, including *A. transitella* during aflatoxin testing would result in the lot failing and no export would occur.

Transport to the EU

The EFSA PLH Panel assume the vast majority of almonds will be transported by rail or road from California to ports on the east coast of USA for export to the EU. To preserve quality, transport is assumed to take 5 or 6 days whilst crossing the Atlantic on a container ship may take 8–14 days

[3] European Commission, 2007. Commission Decision of 1 August 2007 amending Decision 2006/504/EC on special conditions governing certain foodstuffs imported from certain third countries due to contamination risks of these products by aflatoxins as regards almonds and derived products originating in or consigned from the United States of America. Notified under document number C(2007) 3613. 2007/563/EC.

(Appendix B). Allowing for some dwell time in port, onward distribution and storage within the EU, total transport time whilst chilled could be approximately 15–30 days or longer.

Exports to the EU occur every month of the year (Figure C.3) with shelled almonds being exported in greater volume, typically more than 100 times more than inshell almonds.

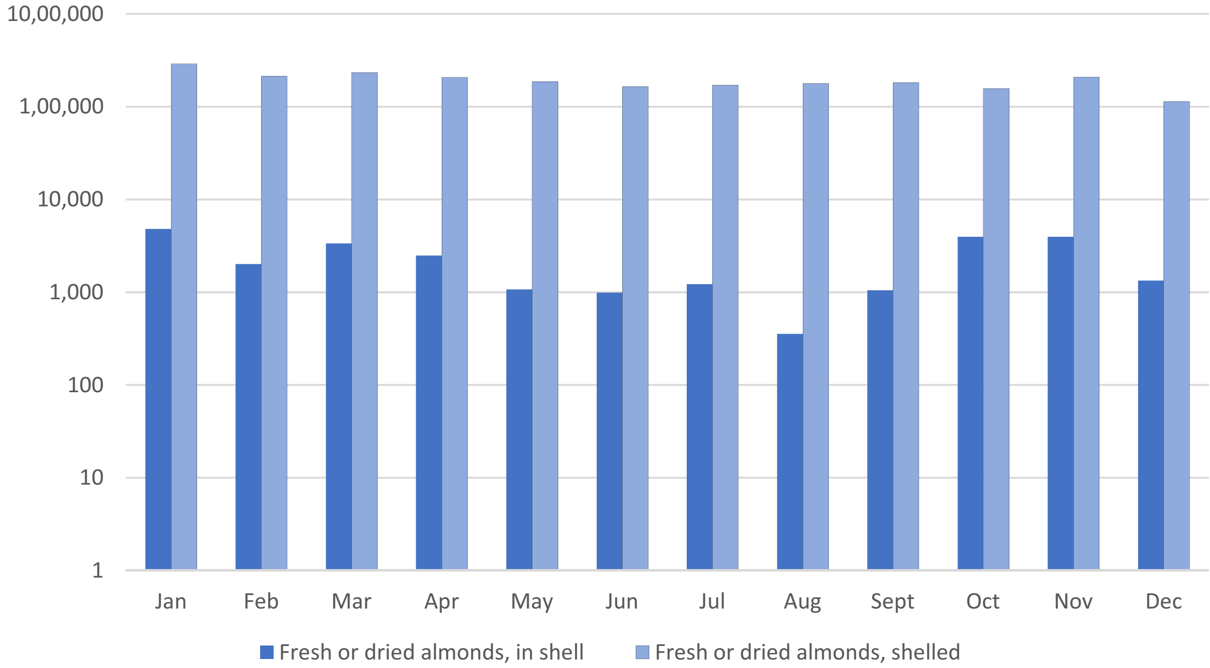


Figure C.3: Mean monthly EU imports (2016–2019) of almonds, shelled and inshell from USA (× 100 kg) Source: Eurostat (note log 10 scale)

Appendix D – Expert Knowledge Elicitation: Overview of the assessment of entry via almonds (inshell and shelled)

As for walnuts the pathway model has 11 steps. The same approach was used for almonds as for walnuts, i.e. eight steps used parameters that were elicited by expert judgement. Three parameters were elicited from data. The expected number of newly established populations per year due to product import via a given pathway is calculated by simple arithmetic using Monte Carlo simulation to take into account uncertainty in elicited parameters.

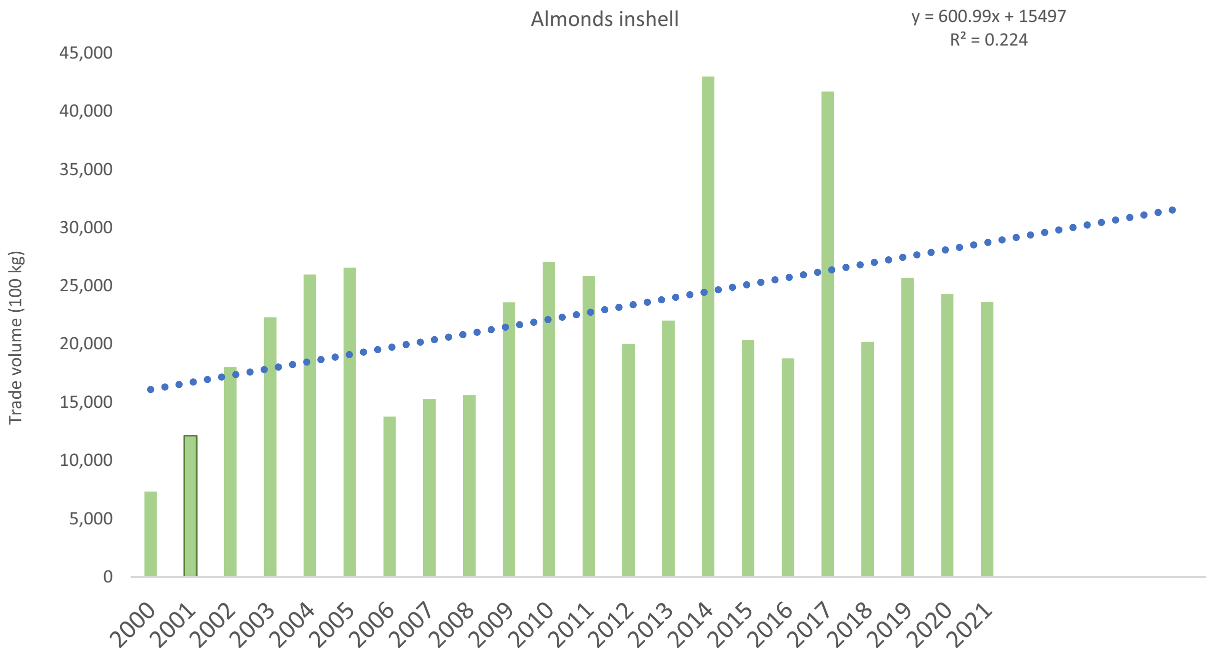
The eight parameters that were elicited are discussed per pathway. The pathways are:

- Almonds inshell
- Shelled almonds

Step 1. Trade volume

The first parameter is trade volume. Data on trade volume were retrieved from Eurostat and are expressed in 100 kg. The panel focused on the trade by sea as the flow by air is a very small fraction of the total. The average percentage of nuts shipped by air from the USA to the EU was 0.07% for almonds inshell, and 0.10% for shelled almonds, on average from 2000 till 2021 (Eurostat data).

1.1 Almonds inshell



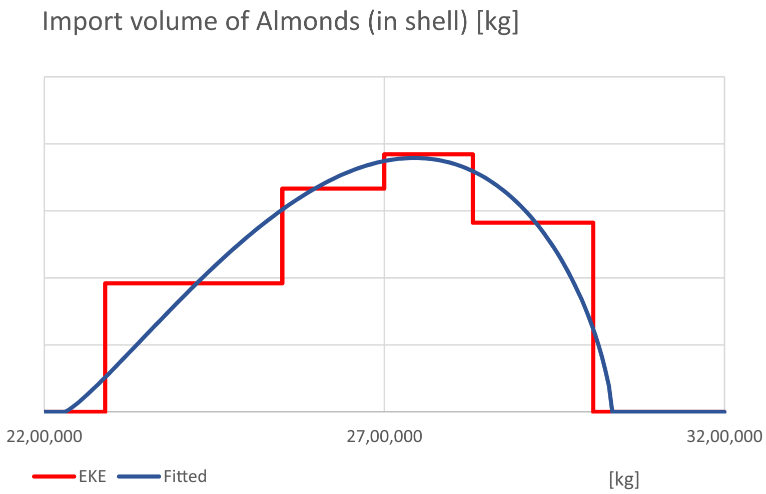
Trade volume for almonds, inshell

The panel evaluated the history and trends including or excluding the first few years. There is a weak tendency to increasing trade, but the increase is not strong, particularly not if the first 2 years are excluded from regression. Two years (2014 and 2017) are outliers. Data series could also be interpreted as stationary. The panel converged on 18–32 * 100,000 kg nuts per year as a plausible interval for average yearly flow in the next 5 years. The mean is somewhere between 18 and 32, but it is difficult to decide where, so we come up with a rather flat (almost uniform) distribution.

Results					
Percentiles: %	1%	25%	50%	75%	99%
EKE values	2,300,000	2,550,000	2,700,000	2,830,000	3,000,000
EKE final results	2,299,989	2,552,371	2,697,363	2,831,033	3,007,659

Median (P50%) = 2,697,363 kg

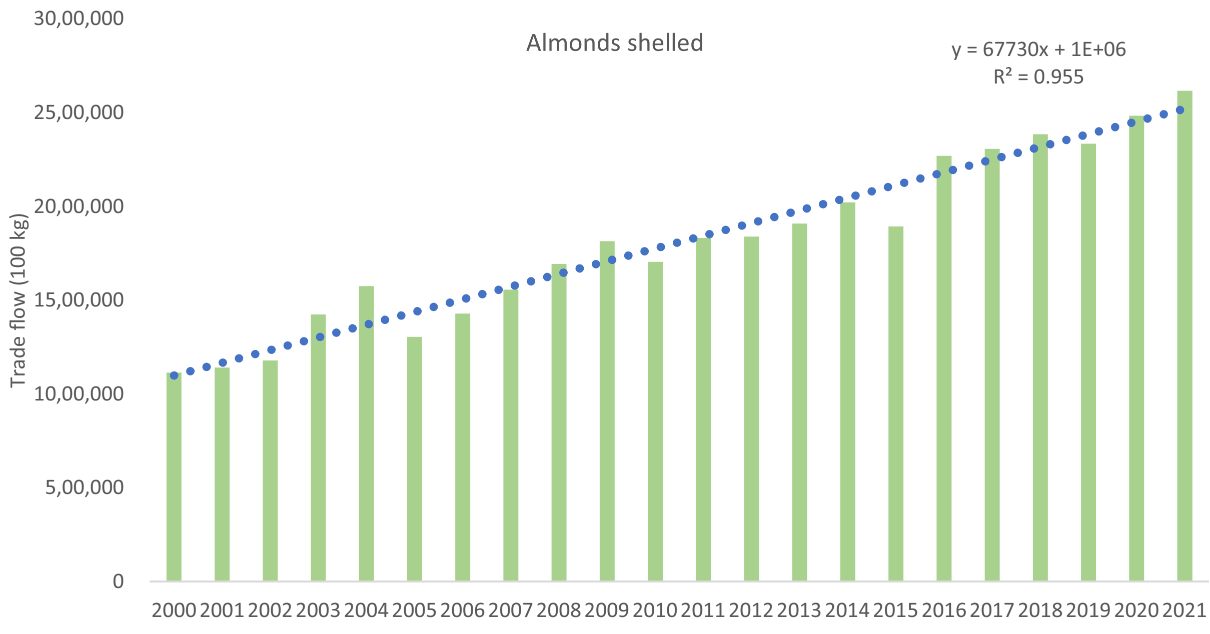
The 90% certainty interval (P5% to P95%) is between 2,377,502 and 2,962,400 kg



Uncertainties are the same as those mentioned for trade in walnuts inshell and shelled.

1.2 Shelled almonds

Among the trade flows of walnuts and almonds inshell and shell, the trade inshelled almonds is by far the greatest. The trade is increasing in an approximately linear fashion by 66,730 * 100 kg/year (i.e. 6.8 million kg/year). Trade in the last 3 years was reported in Eurostat as 2,333,817 * 100 kg/year (2019), 2,483,561 * 100 kg/year (2020) and 2,616,055 * 100 kg/year. Expressed in SI units, the trade was 233 million kg in 2019, 248 million kg in 2020 and 262 million kg in 2021.

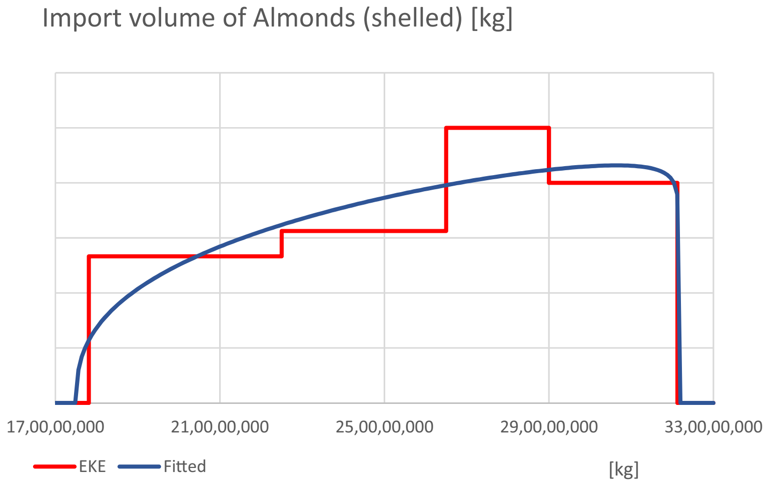


Trade volume for almonds, shelled.

The panel fitted a linear regression with very good fit (R^2 = 0.96) and assessed that the average yearly import of shelled almonds would be from 230 to 300 million kg nuts per year, with a median value of 270 million kg.

Results					
Percentiles: %	1%	25%	50%	75%	99%
EKE values	180,000,000	225,000,000	265,000,000	290,000,000	320,000,000
EKE final results	180,043,258	227,130,374	261,650,487	292,143,546	320,206,865

Median (P50%) = 261,650,487 kg
The 90% certainty interval (P5% to P95%) is between 191,182,418 and 315,418,030 kg



Uncertainties

- Continuation of the increasing trend towards increased trade, under external influences including possible de-globalisation or trade disruptions under pandemics and possible changes in demand for nuts as health food are causes for uncertainty.

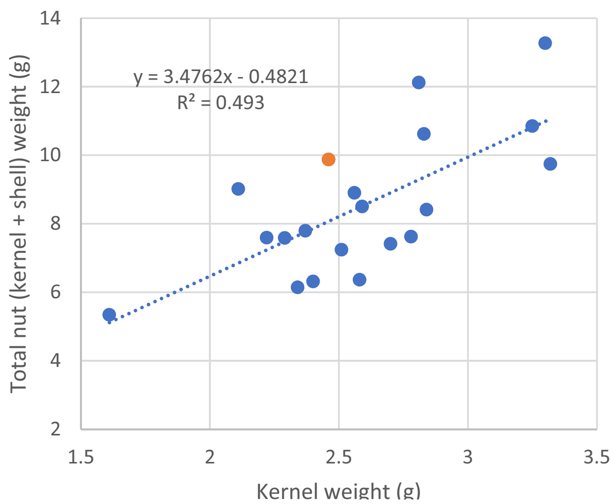
Step 2. Individual nut weight

1.3 Weight of individual almonds inshell

The panel estimated the almond weight with shell on the basis of the elicited values of the almond weight without shell after drying (see below). The panel converted the quantiles elicited for nuts without shell (see below) to quantiles for nuts with shell using the regression equation

$$y = 3.48x - 0.48$$

where x is the kernel weight (g) and y is the total nut weight (kernel + shell; g). This regression equation was fitted on data presented in a study by Godini (1984) on almond kernel weights and total nut weights for a broad set of varieties grown in Bari (Italy).



Relationship between kernel weight and total weight of walnuts including shell, based on data from Godini (1984). The orange point is for the variety Nonpareil which is the most widely grown variety in the USA.

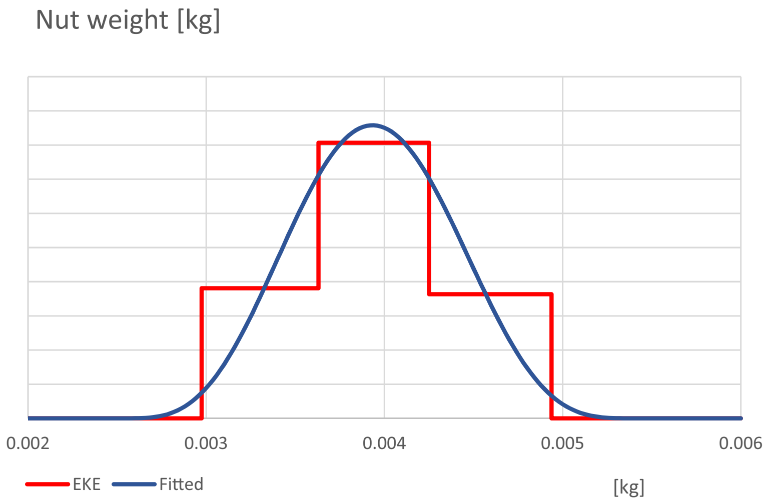
From this study, the panel only used the relationship between total nut weight and kernel weight. The absolute kernel and shell weights from this study were not used in elicitation as they are substantially higher than those in other trials.

Estimates for almond weight (inshell) (kg) are shown below.

Results					
Percentiles: %	1%	25%	50%	75%	99%
EKE values	0.00300	0.00363	0.00394	0.00425	0.00491
EKE final results	0.00300	0.00363	0.00394	0.00425	0.00490

Median (P50%) = 3.94 g (0.00394 kg)

The 90% certainty interval (P5% to P95%) is between 3.23 and 4.66 g



1.4 Weight of individual shelled almonds

Bagged almonds bought in a supermarket in the Netherlands weighed 0.96 g with low variability. California almonds from the market were 1 g (https://weighschool.com/almond-weights-including-calculator-charts/website). This website consulted on 2022-06-14, states 'The average weight of one unshelled blanched almond is around 1.2 g per nut, and the average weight of a raw almond weighs 1.3 g per nut. Smaller unshelled almonds weigh around 1 g, and larger almonds can weigh up to 1.5 g.'

California marketing board provides extensive information on almond weights (https://www.nass.usda.gov/Statistics_by_State/California/Publications/Specialty_and_Other_Releases/Almond/Objective-Measurement/201606almom.pdf). These data are summarised in the table below.

Table D.1: Weight of individual almonds (g). Data from https://www.nass.usda.gov/Statistics_by_State/California/Publications/Specialty_and_Other_Releases/Almond/Objective-Measurement/201606almom.pdf

Variety	Year						Average
	2011	2012	2013	2014	2015	2016	
Butte	1.24	1.20	1.11	1.20	1.14	1.20	1.18
California types 5	1.55	1.53	1.41	1.45	1.46	1.51	1.49
Carmel 6	1.50	1.51	1.38	1.48	1.45	1.51	1.47
Monterey 6	1.76	1.71	1.56	1.54	1.59	1.69	1.64
Nonpareil	1.60	1.64	1.48	1.60	1.61	1.65	1.60
Padre	1.25	1.20	1.10	1.22	1.07	1.14	1.16
Average	1.48	1.47	1.34	1.42	1.39	1.45	1.42
Sacramento Valley 3	1.60	1.54	1.44	1.60	1.51	1.51	1.53
Sacramento Valley 4	1.48	1.48	1.34	1.43	1.41	1.48	1.44
All districts	1.49	1.48	1.36	1.45	1.43	1.48	1.45

cv. Texas almonds, grown in Greece, with and without irrigation have similar kernel weights and moisture content as those from California (Table below) from Nanos et al. (2002).

	Early harvest		Late harvest	
	Kernel weight (fresh; g)	Moisture content (%)	Kernel weight (fresh; g)	Moisture content (%)
Ferragnes variety				
Irrigated	1.32	29.60	1.30	6.30
Non-irrigated	1.30	27.30	1.38	5.60
Texas variety				
Irrigated	1.08	32.50	1.10	6.50
Non-irrigated	0.99	26.50	1.00	5.70

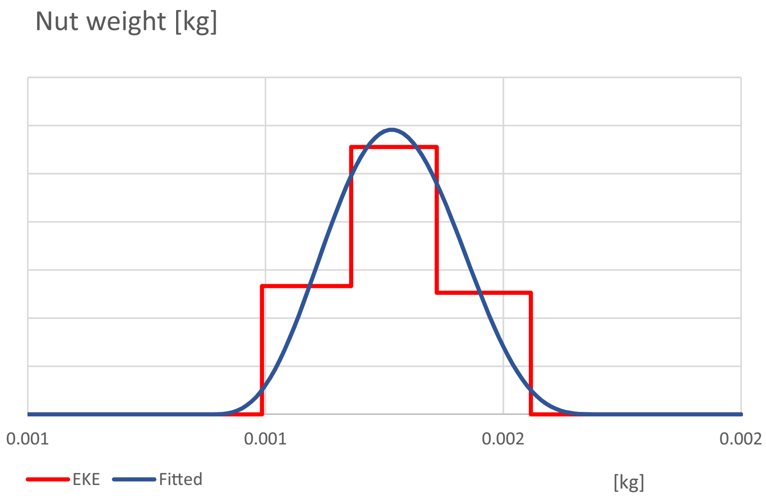
Results from Godoni (1983) in Bari suggest higher weight than those reported in above sources, but these weights appeared fundamentally different from those in the USA and were therefore disregarded. Nonpareil is somewhat heavier than other varieties but represents only 40% of total production so the panel combined data on Nonpareil and other varieties.

Synthesising and discussing the evidence, and giving most weight to data from California, the panel estimated the following distribution for almond nut weight without shell.

Results					
Percentiles: %	1%	25%	50%	75%	99%
EKE values	0.00100	0.00118	0.00127	0.00136	0.00155
EKE final results	0.00100	0.00118	0.00127	0.00136	0.00155

Median (P50%) = 1.27 g (0.00127 kg)

The 90% certainty interval (P5% to P95%) is between 1.07 and 1.48 g



Uncertainties exist with respect to differences between origins of the nuts and differences between varieties as well as effect of growing conditions (year effects).

Step 3: Proportion of almonds held in store for marketing the following year (Constant, not EKE)

During the 10 years up to 2021/22, approximately 18.3% of the Californian almond crop was held in long-term cold store each year for marketing the following year (Appendix C). In the almond pathway models, 0.183 was used as a constant to indicate the proportion of crop held in store and marketed the next year. Given its long-term cold storage, no *A. transitella* were assumed to survive in stored almonds.

Step 4: Proportion of almonds inshell infested with *A. transitella* eggs + larvae, entering packing house after harvest

The reasoning applied was identical to that used for walnuts, hence the same text is provided.

Initially, an assessment was made of the proportion of nuts infested with larvae at the time of harvest. Afterward, the assumption was made that, in addition to larvae within the nuts, there would be an equal number of eggs on the surface of the nuts. Thus, the infestation level with eggs plus larvae was estimated to be twice as high as the level initially estimated.

Proportion of nuts infested with *A. transitella* larvae entering packing house after harvest.

This assessment largely followed the reasonings and evidence used for the assessment of impact under European conditions (3.4 Impact). However, it was taken into account that in California, there is currently much experience with the pest, and control is based on a judicious combination of measures including variety choice, sanitation, early harvesting, use of pesticides, mating disruption and sterile insect technique. By combining many measures in an integrated approach, pest levels in California orchards have been pushed down to levels well below 1 % on average (presentation by Kent Daane), and pest levels that were common in the 1980s are no longer common. The panel elicited the below distribution taking into account the evidence.

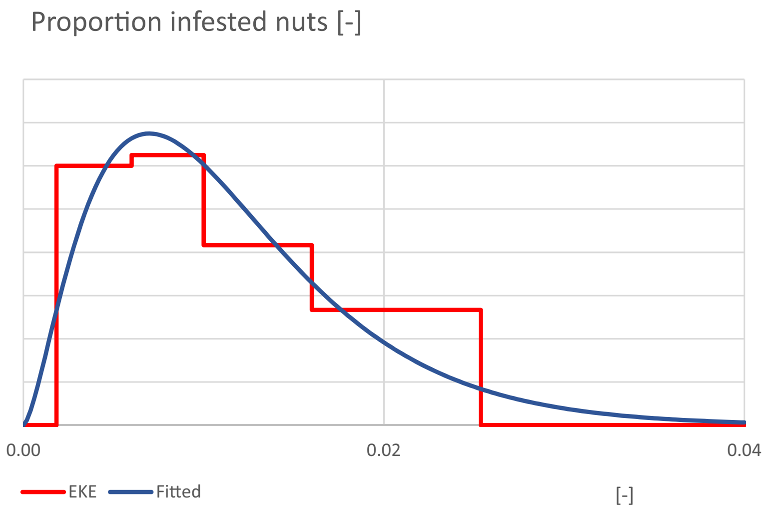
In the elicitation on impacts (involving both European and US experts) a higher level of infestation was found in almonds than for walnuts. The below estimations follow the underlying reasoning.

- We are estimating the overall average.
- Even though 0.01% can be attained in individual orchards, it is impossible to attain this on average across all orchards.
- Zero infestation is not realistically achieved.
- Industry standard is aiming for 1%. The panel does not expect an average level of infestation bigger than 1%, the information is lacking to be certain.
- The panel did not have access to information to make estimates precise, hence the elicited distribution is made fairly flat, with no strong concentration of probability mass towards the median value.

4.1 Proportion of almonds inshell infested with larvae

Results					
Percentiles: %	1%	25%	50%	75%	99%
EKE values	0.002	0.006	0.010	0.016	0.025
EKE final results	0.0013	0.0062	0.0100	0.0152	0.0344

Median (P50%) proportion infested = 0.01 (= 1%)
The 90% certainty interval (P5% to P95%) is between 0.0027 (0.27%) and 0.0253 (= 2.53%)



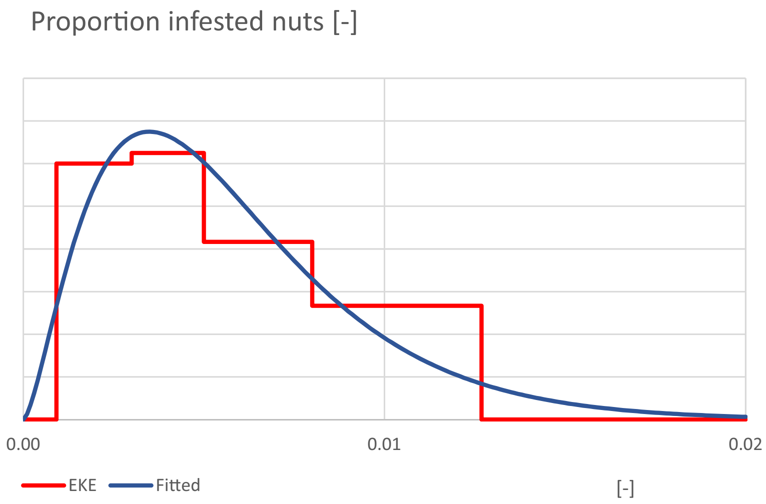
4.2 Proportion of shelled almonds infested with *A. transitella* larvae, entering packing house after harvest

Proportion of shelled almonds infested with larvae

It is assumed to be the same for the almonds inshell as they are identical up to the point that they are shelled. However, the percentiles for shelled almonds are for larvae only and do not account for eggs as the eggs are not inside the shell.

Results					
Percentiles: %	1%	25%	50%	75%	99%
EKE values	0.001	0.003	0.005	0.008	0.013
EKE final results	0.0007	0.0031	0.0050	0.0076	0.0172

Median (P50%) proportion infested = 0.005 (0.5%)
The 90% certainty interval (P5% to P95%) is between 0.0013 (0.13%) and 0.0126 (= 1.26%)



Step 5: Efficacy of operations at treatment/packing house

Here we consider survival of *A. transitella* despite control measures applied at packing house. Exports seek to achieve probit-9 level of pest freedom (32 alive out of 1,000,000). Chemical fumigants (phosphine and sulfuryl fluoride) can control *A. transitella* well (Appendix E), but sample sizes are not enough to demonstrate with certainty that probit-9 is attained.

Because of *Salmonella* outbreaks, it is now mandatory for all almonds marketed in US to attain minimum of 4 log reduction in *Salmonella*, i.e. a reduction by a factor 10,000 We have been told that insects are easier to kill than the pathogens. There is a lack of evidence to conclude that the effectiveness of measures would be different for almonds than for walnuts (Appendix B) therefore, we used the same values for almonds as for walnuts but differentiate between nuts inshell and shelled nuts. The effectiveness of measures in the packing house on almonds inshell is assumed to be the same as for walnuts inshell (see Appendix B), and the idem ditto for shelled walnuts, for which the effect of measures is the same as for shelled almonds.

5.1 Number of infested almonds inshell after treatments

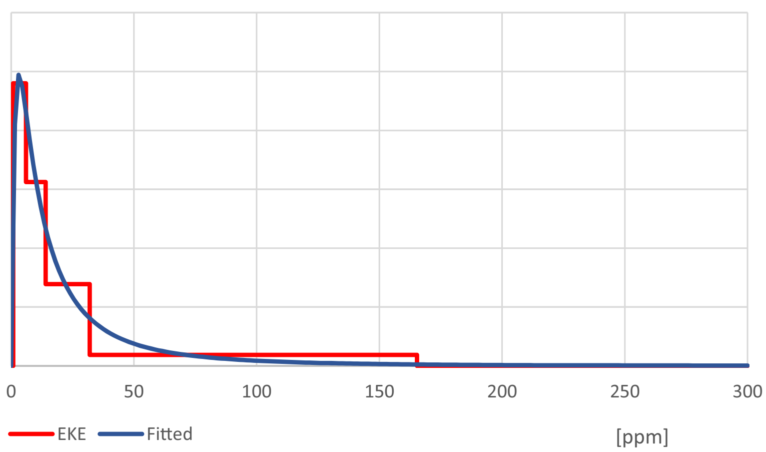
Recall that 18% of almonds are held over for a year and held in cold storage. We assume they are free from *A. transitella* when marketed. What we elicit here is the survival of the measures taken in the packing house upon arrival of the nuts at the packing house. The 18% that are held over for a year are pest free (apply as a multiplier).

Results					
Percentiles: %	1%	25%	50%	75%	99%
EKE values	1.0	6.0	14.0	32.0	160.0
EKE final results	0.82	6.11	13.90	31.60	236.16

Median (P50%) 13.9 survive per million

The 90% certainty interval (P5% to P95%) is between 1.88 and 102.99 survive per million

Nuts with live pest after treatment [ppm]



5.2 Number of infested shelled almonds after treatments

Shelled almonds should be substantially easier to sort. We do not know whether fumigation is more effective with shelled almonds as we lack information on the order of measures, and it is possible to fumigate awaiting hulling and shelling (http://www.freeworld-trading.co.uk/wp-content/uploads/2016/04/Harvesting-and-Processing.pdf). Fumigation can also be carried out while the nuts are waiting to be hulled and shelled. (Probably this is when it *is* carried out, in general.)

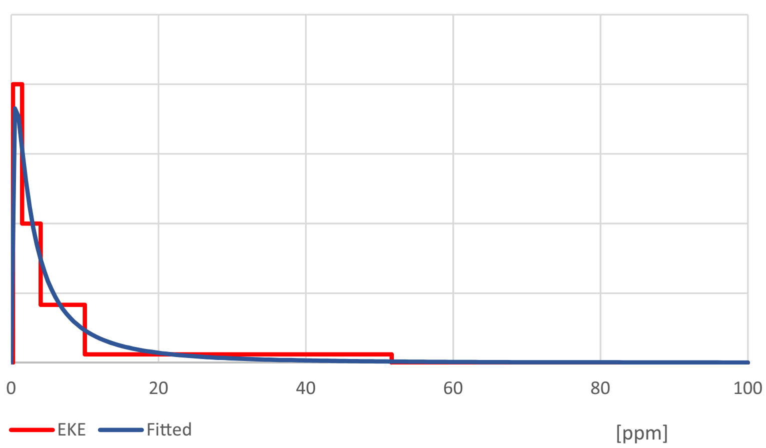
Phosphine is the fumigant that is currently used. There might be dependencies with processors avoiding over-compliance because of the cost and the availability of facilities for fumigation, so if one measure is very effective, there could be less incentive to try as hard with another measure. Again, this is reasoning, not knowledge. We went down a factor 3, approximately, compared to almonds inshell, mainly because the sorting is expected to be more effective because any frass or damage is more readily observed. The distribution is elicited to reflect 'multiplicative' scale, with the upper and low limits differing from the median by a factor of 12–13 approximately.

Results					
Percentiles: %	1%	25%	50%	75%	99%
EKE values	0.3	1.5	4.0	10.0	50.0
EKE final results	0.17	1.59	3.93	9.71	89.07

Median (P50%) 4 survive per million

The 90% certainty interval (P5% to P95%) is between 0.43 and 35.7 survive per million

Nuts with live pest after treatment [ppm]



Step 6: Survival of cold temperatures during storage and transport

Survival in almonds is assumed to be the same as survival in walnuts, see Appendix B

Step 7: Proportion of nuts transported to NUTS-2 regions with suitable climate (Constant, not EKE)

Distribution of almonds is assumed to be based on human population, as with walnuts (see Appendices B and F).

Step 8: Proportion of nuts imported during unsuitable parts of year (Constant, not EKE)

The monthly imports of almonds inshell (Appendix C) indicates that 46% of imports arrive in the winter for consumption during the festive period/Christmas season. Initiating a founder population at this time was deemed not possible and the proportion 0.46 was constant for the pathway almonds inshell.

Shelled almonds imports are evenly spread over the year with 36% imported during the winter (Appendix C). The proportion 0.36 was constant for the pathway shelled almonds.

Steps 9–11

The EKE values used in step 9 (Probability of pest transfer), step 10 (Likelihood of mating) and step 11 (Likelihood of survival and initiation of founder population) are features of the biology of the pest and are independent of the pathways which are nuts for consumption, hence input values based on EKE shown in Appendix B for the walnut pathways are also used for the almond pathways.

Table D.2: Almonds shelled: Results of model output

Step	Detail	Unit	How determined	5%	25%	50%	75%	95%
1	Import amount	kg	EKE	191,181,593	227,129,669	261,648,028	292,141,242	315,415,986
2	Nut weight (kg)	kg	EKE	0.00107	0.00118	0.00127	0.00136	0.00148
	Number of nuts imported		Calculation	145,649,222,800	177,136,881,000	204,923,873,800	231,748,117,900	268,191,425,000
3	% nuts held in store till next year	%	Constant	18.30	18.30	18.30	18.30	18.30
	Number of nuts for marketing this year		Calculation	118,995,415,000	144,720,831,700	167,422,804,900	189,338,212,300	219,112,394,200
4	Proportion infested nuts		EKE	0.00134	0.00310	0.00501	0.00760	0.01263
	Number of infested nuts		Calculation	214,934,285	498,858,066	823,533,078	1,274,030,285	2,211,869,677
5	# nuts with live pest after treatment	ppm	EKE	0.4	1.6	3.9	9.7	35.7
	Number of infested nuts after treatment		Calculation	237.4	1,101.5	3,073.3	8,535.8	36,400.9
6	Proportion transported in chilled container		Constant	0.30	0.30	0.30	0.30	0.30
7	Proportion of nuts with eggs		Constant	0.00	0.00	0.00	0.00	0.00
8	Survival of eggs during cold transport	ppm	EKE	0.102	0.501	0.999	1.501	1.913
	Survival of larvae during cold transport	ppm	EKE	2.351	4.001	6.000	7.999	9.649
	Number of infested nuts arriving in EU		Calculation	166.2	771.0	2,151.3	5,975.1	25,480.6
9	Imports to suitable climate (EU population)		Constant	0.337	0.337	0.337	0.337	0.337
10	Imports at unsuitable time of year		Constant	0.360	0.360	0.360	0.360	0.360
	Number of infested nuts to suitable NUTS 2 regions at suitable time of year		Calculation	35.8	166.3	464.0	1,288.7	5,495.5
11	Likelihood of pest transfer from infested nut		EKE	0.0002	0.0009	0.0020	0.0047	0.0161
12	Likelihood of mating		EKE	0.0059	0.0189	0.0530	0.1215	0.2808
13	Likelihood of eggs surviving to reproduce		EKE	0.0028	0.0070	0.0147	0.0282	0.0595
	Number of nuts that result in transfer and population initiation per year		Calculation	0.00001	0.00011	0.00061	0.00328	0.03540

Proportion infested nuts to potential suitable NUTS2 regions within EU (33.699% of EU population occur in suitable NUTS 2 regions)

Table D.3: Almonds inshell: Results of model output

Step	Detail	Unit	How determined	5%	25%	50%	75%	95%
1	Import amount	kg	EKE	2,377,482	2,552,364	2,697,357	2,831,029	2,962,397
2	Nut weight (kg)	kg	EKE	0.0032	0.0036	0.0039	0.0043	0.0047
	Number of nuts imported		Calculation	555,034,678	624,276,926	682,699,583	748,163,543	852,362,905
3	% nuts held in store till next year	%	Constant	18.30	18.30	18.30	18.30	18.30
	Number of nuts for marketing this year		Calculation	453,463,332	510,034,249	557,765,560	611,249,615	696,380,493
4	Proportion infested nuts		EKE	0.0027	0.0062	0.0100	0.0152	0.0253
	Number of infested nuts		Calculation	1,483,802	3,432,249	5,589,404	8,571,369	14,530,306
5	# nuts with live pest after treatment	ppm	EKE	1.88	6.11	13.90	31.60	102.97
	Number of infested nuts after treatment		Calculation	7.0	28.3	73.2	189.0	718.4
6	Proportion transported in chilled container		Constant	0.30	0.30	0.30	0.30	0.30
7	Proportion of nuts with eggs		Constant	0.50	0.50	0.50	0.50	0.50
8	Survival of eggs during cold transport	ppm	EKE	0.102	0.501	0.999	1.501	1.913
	Survival of larvae during cold transport	ppm	EKE	2.350	4.001	6.0000	7.999	9.649
	Number of infested nuts arriving in EU		Calculation	4.9	19.8	51.2	132.3	502.9
9	Imports to suitable climate (EU population)		Constant	0.337	0.337	0.337	0.337	0.337
10	Imports at unsuitable time of year		Constant	0.46	0.46	0.46	0.46	0.46
	Number of infested nuts to suitable NUTS 2 regions at suitable time of year		Calculation	0.9	3.6	9.3	24.1	91.5
11	Likelihood of pest transfer from infested nut		EKE	0.0002	0.0009	0.0020	0.0047	0.0161
12	Likelihood of mating		EKE	0.0059	0.0189	0.0530	0.1215	0.2808
13	Likelihood of eggs surviving to reproduce		EKE	0.0028	0.0070	0.0147	0.0282	0.0595
	Number of nuts that result in transfer and population initiation per year		Calculation	0.0000002	0.0000023	0.0000124	0.0000636	0.0006148

Appendix E – Review on effectiveness of phosphine and sulfuryl fluoride used against Lepidoptera and other insects

Table E.1: Phosphine summary table review

Insect	Stage	Trial conditions in a nutshell	Mortality	Reference
Amyelois transitella (Lepidoptera)	Eggs and larvae tested	485 and 487 ppm over different time (24 and 36 h experiments) at 26.7°C	73–100%	Hartsell et al. (2005)
Carposina niponensis (Lepidoptera)	Egg and larvae	Gradient of doses in 48 h at 0°C	12–75.3%	Bo et al. (2010)
Carposina sasakii (Lepidoptera)	Larvae	330 ppm (12 h experiment) at 25°C.	77%	Al-Hakkak and Hussain (1985)
		330 ppm (12, 24, 48, 72, 120 h experiment) at 25°C.	20–99%	Liu et al. (2012)
Cydia pomonella (Lepidoptera)	Eggs and larvae	500–3,500 ppm; 48 and 72 h; at 05 and 12°C	Depending on the dose/time/ temperature: 18–99%	Rogers et al. (2013)
Ephestia cautella (Lepidoptera)	Pupae	0–0.042 mg/l over 24 h at 27.5°C	15.7–67%	Al-Hakkak and Hussain (1985)
Epiphyas postvittana (Lepidoptera)	Eggs	250–3,000 ppm over 96 h at in different temperatures 5, 10 and 15°C	75.18–99.44%	Liu et al. (2013)
	Eggs	1,000–2,500 ppm, 40–96 h measured at different hours	82.1–100%	Liu et al. (2014)
Grapholita molesta (Lepidoptera)	Larvae	2,157 ppm, in 95 h, two temperatures 5 and 8°C	100%	Shamilov (2012)
Laphigma spp. *Prodenia* spp./ *Geometridae* (Lepidoptera)	Larvae and adults	500 ppm in 24 h at 4°C	52.1–100%	Finkelman et al. (2012)
Phthorimaea operculella (Lepidoptera)	Eggs, larvae, pupae, adults	3–60 CT product (mg h/l); 24 h at 5 and 20°C	0–100%	Kim et al. (2015)
Plodia interpunctella (Lepidoptera)	Eggs and larvae	4 different temperatures (26.7, 30, 32.5, 35°C); 8 different doses within the range 250–1,000; 24, 36 and 48 h	85.5–100%	Hartsell et al. (2005)
Carpophilus hemipterus (Coleoptera)	Eggs and larvae tested	485 and 487 ppm over different time (24 and 36 h experiments) at 26.7°C	100%	Hartsell et al. (2005)
Lasioderma serricorne (Coleoptera)	Eggs and larvae	485 and 487 ppm, in 24 and 36 h; at 26.7°C	93.1–100%	Hartsell et al. (2005)
Mayetiola destructor (Diptera)	Pupa		75.9–93.3%	Yokoyama et al. (2015)
Orzaephilus surinamensis (Coleoptera)	Eggs and larvae	485 and 487 ppm, in 24 and 36 h; at 26.7°C	99.7–100%	Hartsell et al. (2005)
Tribolium castaneum (Coleoptera)	Eggs and larvae	485 and 487 ppm, in 24 and 36 h; at 26.7°C	98.5–100%	Hartsell et al. (2005)

Table E.2: Sulfuryl fluoride summary table review

Insect	Stage	Trial conditions in a nutshell	Mortality	Reference
Amyelois transitella (Lepidoptera)	Diapausing larvae	2–16 mg/l, 24 h at 15.6°C	0–100%	Leesch and Zettler (1999)
	Eggs	32 and 104 mg/l; 4 and 24 h at 15.6°C	100%	Walse et al. (2014)
	Eggs and larvae	26–1,356 mg/($L * h$); 2 and 4 h at 20 and 25°C	99%	Zettler and Gill (1999)
Ephestia kuehniella (Lepidoptera)	Eggs, larvae, pupae	11.6 and 21.3 mg/m3 in 0, 18, 24, 48 h and 15, 20 and 25°C	3.3–100%	Baltaci et al. (2009)
	Eggs	347–4,800 CT (treatment concentration x time) 24 h, 15°C		Bell and Savvidou (1999)
	All stages	571–1,326 g h/m3; 21 h, 21.8°C	90.25%	Small (2007)
Plodia interpunctella (Lepidoptera)	Eggs	5,10,15,20,25 dose in mg/L in 48 h and temperature 30°C	73.7–100%	Schneider and Hartsell (1998)
Rhyzopertha dominica (Coleoptera)	Adult	1,196–1,467 mg-h/l 5 days of fumigation	100%	Opit et al. (2016)
	Eggs and adults	0.5, 1 and 2 mg/L at 25°C	99–100%	Hwaidi et al. (2017)
Tribolium castaneum (Coleoptera)	Adult and larvae	1,196–1,468 mg-h/l in 7 days	100%	Opit et al. (2016)
	Eggs and larvae	24 h; below 27°C	44–100%	Hartzer et al. (2010)
	Eggs, larvae and adults	Concentrations tested include: 2.0–100 mg L – 1 against eggs, 0.06–1.5 mg L – 1 against the three age groups of larvae, 0.06–3.0 mg L – 1 against pupae and 0.5–1.5 mg L – 1 against adults. Fumigation: 48 h at 25 ∘C	99.9%	Jagadeesan et al. (2015)
Psocoptera	Various species and various life stages	4–72 g/m3	100%	Athanassiou et al. (2012)

The product of concentration and time of exposure may be used to predict mortality. To harmonise data, all concentrations expressed in mg/l were converted to ppm. This was done using the formula:

$$\text{ppm} = \text{mgl} * 24.45 * 1000/34$$

where ppm is the concentration in ppm, mgl is the concentration in mg per L, 24.45 is the volume of a mole of gas at 25°C and 34 is the molecular weight of Phosphine (1 mol of Phosphine weighs 34 g).

The Figure E.1 below shows the relationship between CT (concentration * time) and mortality for a range of Lepidoptera species. The data for *A. transitella* (three red circles in the top left of the graph) indicate that high mortality may be reached at the lower range of values of CT tested across species. This characterises *A. transitella* as an insect that is relatively well suited to control with phosphine. In Figure E.2, the same data are shown with mortality on a probit scale to obtain a better separation of points at high mortality. As the data contained cases of 100% mortality, the mortality was first rescaled using:

$$\text{mortality}_{\text{rescaled}} = \epsilon + (1 - 2\epsilon) * \text{mortality}$$

with $\epsilon = 0.001$

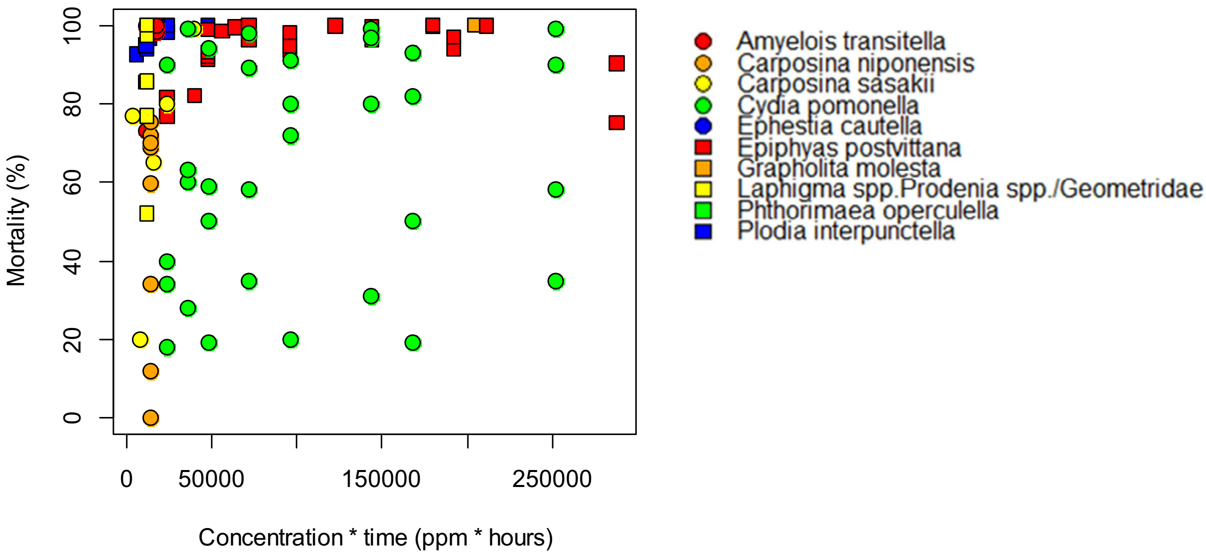


Figure E.1: Relationship between CT (concentration * time of exposure to phosphine) and mortality in a range of Lepidoptera species

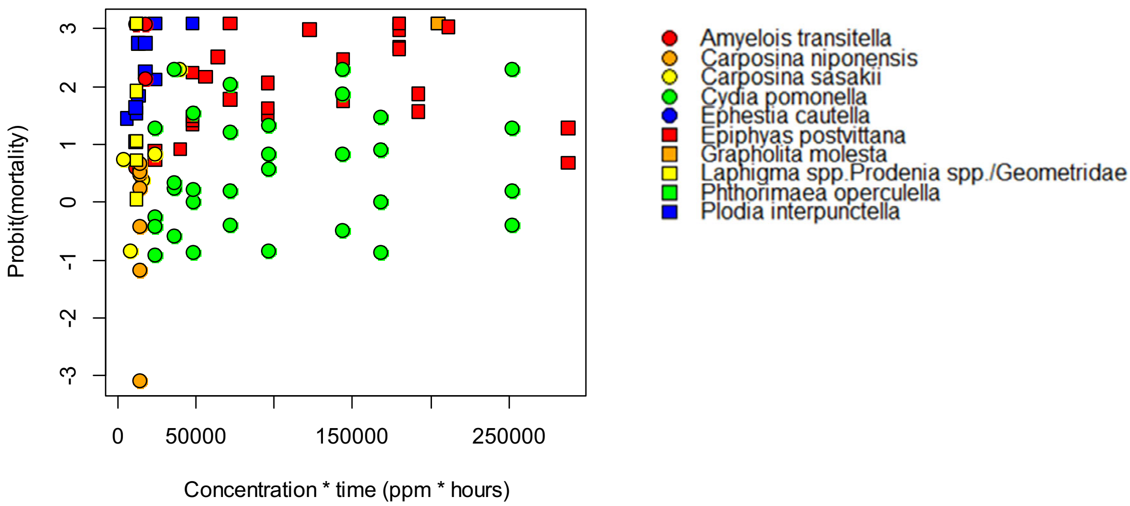


Figure E.2: Relationship between CT (concentration * time of exposure to phosphine) and mortality in a range of Lepidoptera species. The points with probit values of –3.1 and + 3.1 represent 0 and 100% mortality, respectively

Appendix F – NUTS 2 regions where climate is suitable for establishment of *A. transitella*, with their human population and area

Source Eurostat. Population data from 2019.

EU MS	NUTS 2 code	NUTS 2 name	Number of people in NUTS 2 region	Proportion of EU population	NUTS 2 area (km^2)
Croatia	HR03	Jadranska Hrvatska	1,374,071	0.0031	31,889
	HR04	Kontinentalna Hrvatska	2,702,175	0.0061	24,705
Cyprus	CY00	Kypros	875,899	0.0020	9,251
France	FR51	Pays de la Loire	3,800,348	0.0086	32,082
	FR61	Aquitaine	3,458,041	0.0078	41,308
	FR53	Poitou-Charentes	1,812,353	0.0041	25,810
	FR81	Languedoc-Roussillon	2,847,554	0.0064	27,376
	FR62	Midi-Pyrénées	3,071,427	0.0069	45,348
	FR82	Provence-Alpes-Côte d'Azur	5,065,696	0.0115	31,400
	FR83	Corse	342,256	0.0008	8,680
Greece	EL30	Attiki	3,742,235	0.0085	3,808
	EL41	Voreio Aigaio	221,098	0.0005	3,836
	EL42	Notio Aigaio	344,027	0.0008	5,286
	EL43	Kriti	634,930	0.0014	8,336
	EL11	Anatoliki Makedonia, Thraki	599,723	0.0014	14,157
	EL12	Kentriki Makedonia	1,873,777	0.0042	19,147
	EL13	Dytiki Makedonia	267,008	0.0006	9,451
	EL21	Ipeiros	333,696	0.0008	9,203
	EL14	Thessalia	718,640	0.0016	14,037
	EL22	Ionia Nisia	203,869	0.0005	2,307
	EL23	Dytiki Ellada	655,189	0.0015	11,350
	EL24	Sterea Ellada	555,960	0.0013	15,549
	EL25	Peloponnisos	574,447	0.0013	15,490
Italy	ITC1	Piemonte	4,328,565	0.0098	25,387
	ITC2	Valle d'Aosta/Vallée d'Aoste	125,653	0.0003	3,261
	ITC3	Liguria	1,532,980	0.0035	5,416
	ITC4	Lombardia	10,010,833	0.0226	23,864
	ITF1	Abruzzo	1,300,645	0.0029	10,832

EU MS	NUTS 2 code	NUTS 2 name	Number of people in NUTS 2 region	Proportion of EU population	NUTS 2 area (km^2)
	ITF2	Molise	303,790	0.0007	4,461
	ITF3	Campania	5,740,291	0.0130	13,671
	ITF4	Puglia	3,975,528	0.0090	19,541
	ITF5	Basilicata	558,587	0.0013	10,073
	ITF6	Calabria	1,912,021	0.0043	15,222
	ITG1	Sicilia	4,908,548	0.0111	25,832
	ITG2	Sardegna	1,622,257	0.0037	24,100
	ITH1	Provincia Autonoma di Bolzano/Bozen	530,313	0.0012	7,398
	ITH2	Provincia Autonoma di Trento	543,721	0.0012	6,207
	ITH3	Veneto	4,884,590	0.0110	18,407
	ITH4	Friuli-Venezia Giulia	1,210,414	0.0027	7,862
	ITH5	Emilia-Romagna	4,459,453	0.0101	22,453
	ITI1	Toscana	3,701,343	0.0084	22,987
	ITI2	Umbria	873,744	0.0020	8,464
	ITI3	Marche	1,520,321	0.0034	9,401
	ITI4	Lazio	5,773,076	0.0131	17,232
Malta	MT00	Malta	493,559	0.0011	316
Portugal	PT11	Norte	3,572,583	0.0081	21,286
	PT15	Algarve	438,864	0.0010	4,997
	PT16	Centro (PT)	2,216,569	0.0050	28,199
	PT17	Lisboa	2,846,332	0.0064	3,002
	PT18	Alentejo	705,478	0.0016	31,605
Spain	ES11	Galicia	2,700,441	0.0061	29,574
	ES12	Principado de Asturias	1,022,205	0.0023	10,604
	ES13	Cantabria	581,641	0.0013	5,321
	ES21	País Vasco	2,177,880	0.0049	7,235
	ES22	Comunidad Foral de Navarra	649,946	0.0015	10,390
	ES23	La Rioja	313,571	0.0007	5,045
	ES24	Aragón	1,320,586	0.0030	47,720
	ES30	Comunidad de Madrid	6,641,649	0.0150	8,028
	ES41	Castilla y León	2,407,733	0.0054	94,226
	ES42	Castilla-la Mancha	2,034,877	0.0046	79,462

EU MS	NUTS 2 code	NUTS 2 name	Number of people in NUTS 2 region	Proportion of EU population	NUTS 2 area (km^2)
	ES43	Extremadura	1,065,424	0.0024	41,635
	ES51	Cataluña	7,566,431	0.0171	32,113
	ES52	Comunidad Valenciana	4,974,969	0.0113	23,255
	ES53	Illes Balears	1,188,220	0.0027	4,992
	ES61	Andalucía	8,427,405	0.0191	87,598
	ES62	Región de Murcia	1,487,663	0.0034	11,313
		Sum:	150,725,118	0.3410	1,299,792

Appendix G – Establishment supplementary maps

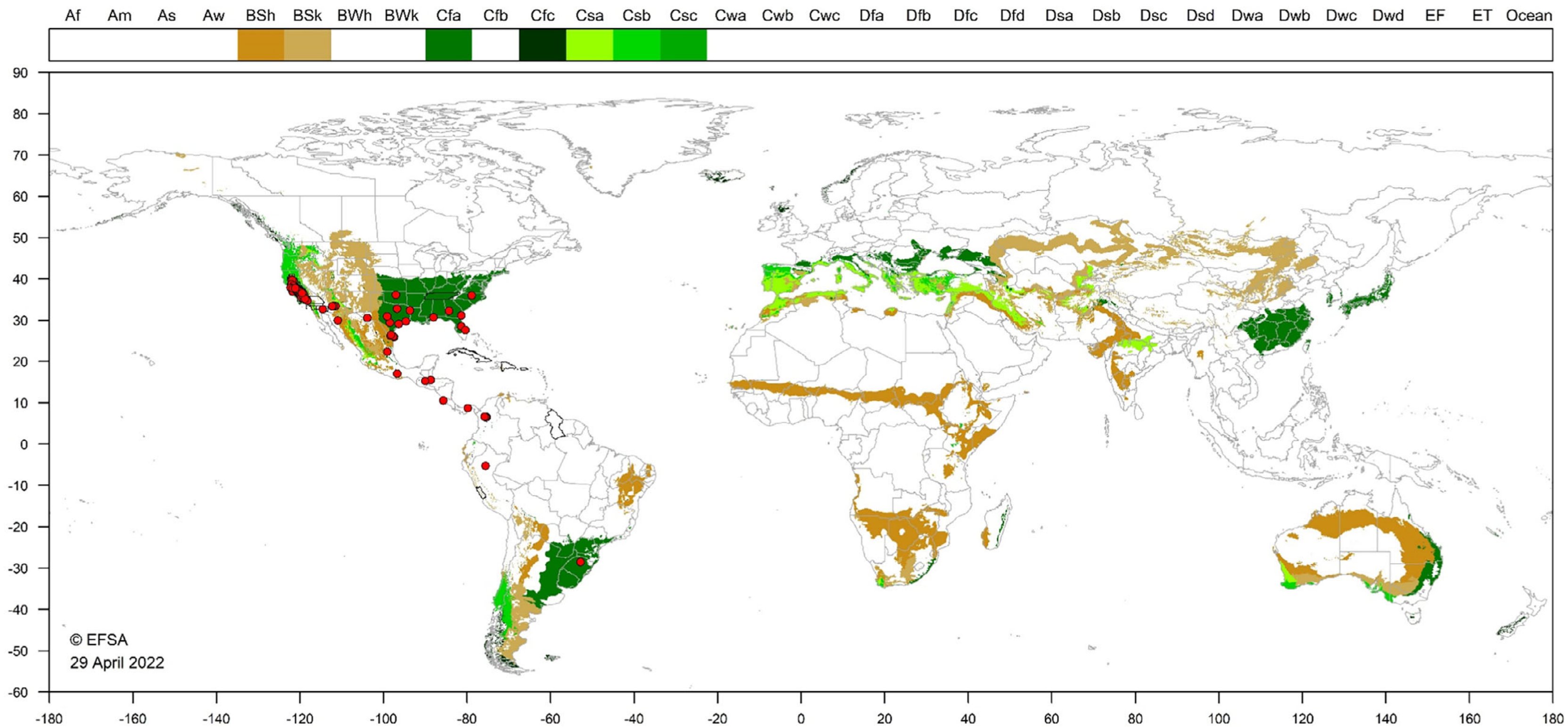


Figure G.1: Global map for *Amyelois transitella* climate suitability analysis based on the Köppen–Geiger climate classification. Regions with black borders indicate countries/regions where the pest was observed. Red dots indicate punctual observations of the pest (centroids, coordinates). Climates not present in EU27 are not mapped, Cfb climate was removed. Legend shows the lists of Köppen-Geiger climate types

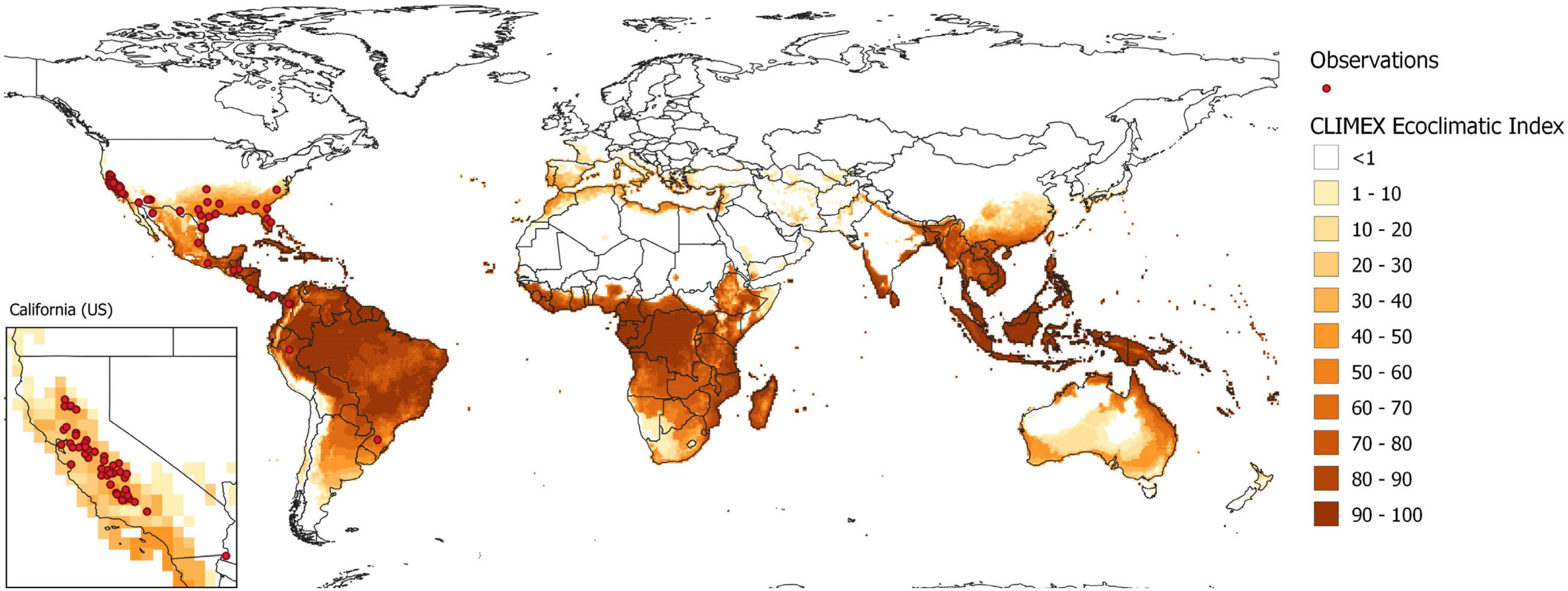


Figure G.2: Global map for *Amyelois transitella* climate suitability analysis modelled using CLIMEX. Red dots indicate punctual observations of the pest. Legend shows the Ecoclimatic Index (EI), representing the potential suitability of the pest: a darker colour corresponds to a more likely potential suitability

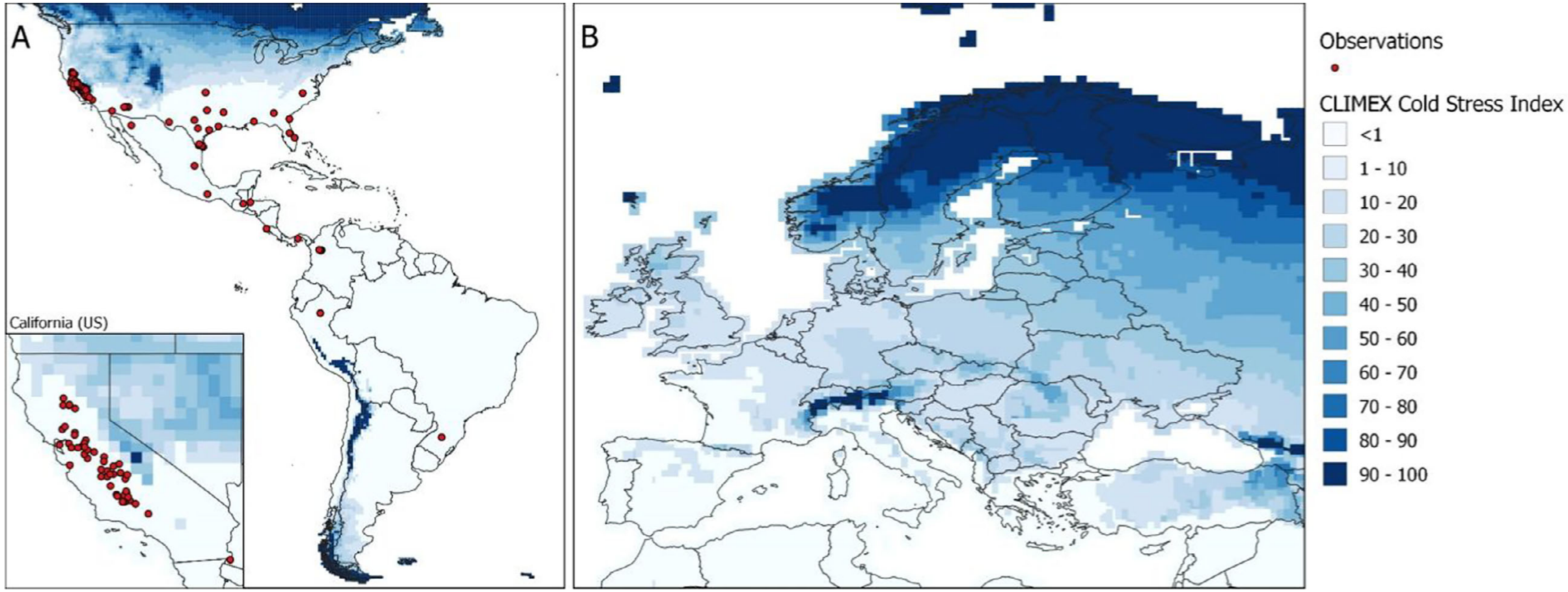


Figure G.3: CLIMEX Cold Stress for *Amyelois transitella* for America (A) and the EU (B). Red dots indicate punctual observations of the pest. Legend shows the Cold Stress Index (EI), a darker colour corresponds to a higher stress condition. Zero degree (Johnson, 2007; Tebbets et al., 1978) was used as cold stress temperature threshold with an accumulation rate of -0.001 week^{-1}

Appendix H – Overview of the evaluation of spread and impact

SPREAD

Table H.1: Lag period

Overview of the results of the Expert Knowledge Elicitation (1st EKE question)															
Parameter	Lag Period (years)														
Stratification															
Question	After the establishment in the area under risk in the EU, how long is the lag period?														
Results	P1%	P2.5%	**P5%**	P10%	P16.7%	P25%	P33.3%	**P50%**	P66.7%	P75%	P83.3%	P90%	**P95%**	P97.5%	P99%
Elicited values	1.50					2.40		3.00		4.50					6.00
EKE results	1.51	1.59	1.70	1.88	2.09	2.34	2.59	3.13	3.78	4.19	4.74	5.38	6.18	6.93	7.86
Fitted distribution	Weibull (1.4265, 2.2063, Risk Shift (1.42))														

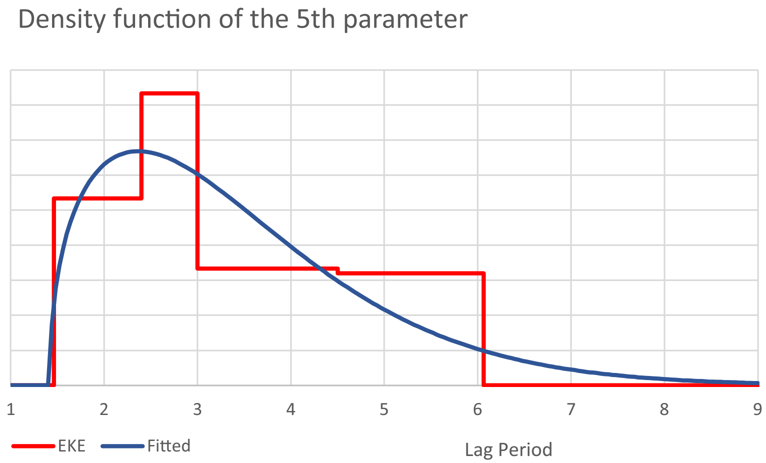


Figure (a): Comparison of elicited and fitted values/density function to describe the remaining uncertainties of the parameter

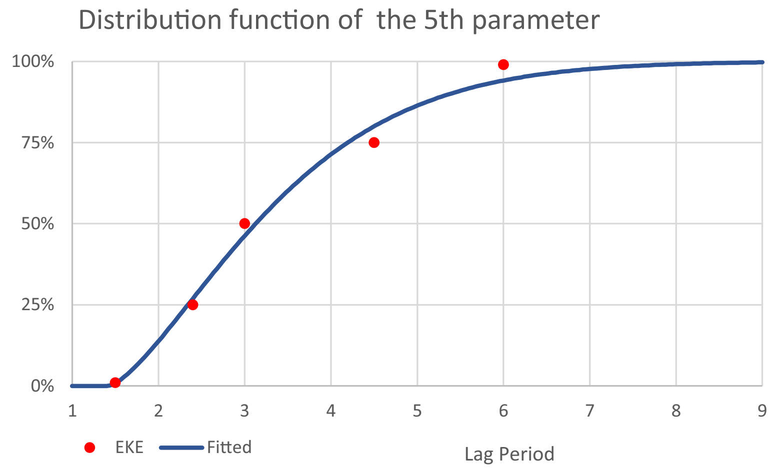


Figure (b): Cumulative distribution function (CDF) of the likelihood of the parameter

Summary of the evidence used for the evaluation

- The experts discussed several factors influencing the presence and the length of a lag phase, in particular: (1) the presence of genetic factors, (2) sub-optimal climatic conditions, (3) limited self-dispersal capacity, (4) limited availability of the hosts, (5) patchiness of the hosts, (6) presence of competitors, (7) influence of agronomic practices and (8) low population sizes in general. The limited availability and patchiness of hosts, presence of natural enemies and less mechanical harvest were seen as main factors for a longer lag phase. It was concluded, that the lag phase is likely to be longer than as one production cycle of nuts, and thus relevant for the assessment.
- No evidence in the literature about the lag phase was found.

Main uncertainties

- The influence of the European agricultural practices (e.g. smaller plot sizes, patchiness of production sites, more natural environment) have contrasting effects on the duration of the lag phase.
- The presence of the codling moth (use of exit holes by *A. transitella*, delayed detections) and natural enemies give contrastive effects on the duration of the lag phase.

Reasoning for a scenario which would lead to a reasonable high proportion	The judgement on the upper limit considers that • The presence of more resistant hosts (e.g. hard shell almonds) leads to lower population sizes • The sub-optimal climatic conditions (e.g. cold winter) reduces the population size • The limited density and patchiness of hosts reduces the population growths at the beginning (until an optimal population size is reached) • Natural enemies will lead to lower population sizes • Non-mechanical harvest/traditional production leads to 'cleaner' trees and orchards and reduces the population growths (overwintering)
Reasoning for a scenario which would lead to a reasonable low proportion	The judgement on the lower limit considers that • The diversity and availability of hosts during the year supports the rapid population growth • The presence of the codling moth promotes population growth • *A. transitella* is a generalist with high fecundity
Fair estimate as judgement on the weighted evidence	The judgement on the median considers that • A relevant lag period will exist in the EU • Although many factors point to a longer lag phase, it is judged that *A. transitella* can cope with the more natural environment and traditional practices and will less likely show long lag phases (right skewed distribution)
Precision of the judgement as description of remaining uncertainties	The judgement on the interquartile range considers that • High uncertainty is judged above the median as the influence of several factors in the EU is unclear • Medium uncertainty is judged below the median as a short lag phase is unlikely
Experts	Vicente DALMAU, Charles S. BURKS, Stefano LA MALFA, Frank ZALOM, Agnès VERHAEGHE, Alexander MASTIN
Facilitator/Reporter	Olaf MOSBACH-SCHULZ/Sara TRAMONTINI
Date and place of the EKE	The EKE (with behavioural aggregation protocol) was done on the 23rd March 2022 in a virtual meeting

Table H.2: Expansion rate

Overview of the results of the Expert Knowledge Elicitation (2nd EKE question)															
Parameter	Expansion rate														
Stratification															
Question	What is the rate of range of expansion?														
Results	P1%	P2.5%	**P5%**	P10%	P16.7%	P25%	P33.3%	**P50%**	P66.7%	P75%	P83.3%	P90%	**P95%**	P97.5%	P99%
Elicited values	0.4					3.0		5.0		11.0					20.0
EKE results	0.40	0.56	0.81	1.29	1.91	2.72	3.58	5.56	8.19	9.98	12.43	15.41	19.34	23.15	28.05
Fitted distribution	Weibull (1.1421, 7.2954, RiskShift (0.27))														

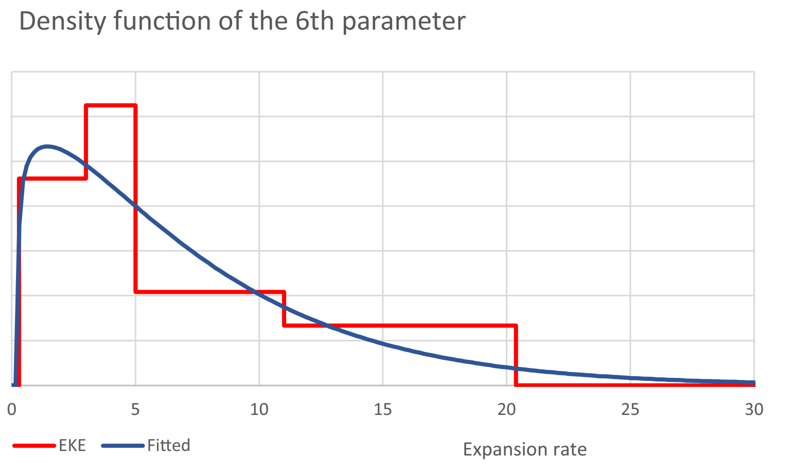


Figure (a): Comparison of elicited and fitted values/density function to describe the remaining uncertainties of the parameter

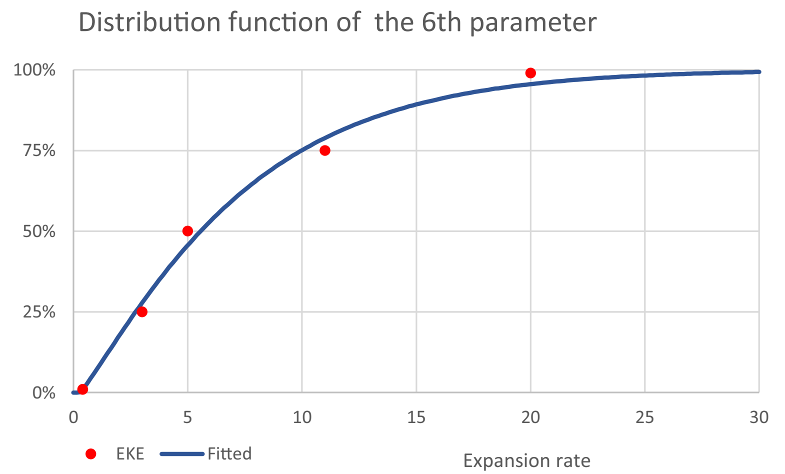


Figure (b): Cumulative distribution function (CDF) of the likelihood of the parameter

Summary of the evidence used for the evaluation	
• Results from flight mill experiments were reviewed (Reger et al. 2021, Rovnyak 2016, Sappington and Burks 2014, Haynes and Baker 1989), as well as release-capture-experiments (Bayes 2014, Andrews et al. 1980). The applicability of experimental results on real spread was discussed. Potentially *A. transitella* could spread on large distances. • Papers from Higbee and Siegel 2009 and Wade 1961 report observations of expansion rates in US. While Higbee and Siegel is on the level of production sites/near environment and reports level of damages, reports Wade introductions into new areas (with unknown means, e.g. human assistance). • Biological spread capacity of *A. transitella* as was discussed and compared with the ones of other moths, e.g. the codling moths. *Amyelois* is seen as a generalist with low invasive capacity. • It is assumed, that after the lag phase *A. transitella* is established in a nuts production site (with European conditions).	
Main uncertainties	
• The spread behaviour of *Amyelois* under the patchy more natural environment of the EU. • The potential of *Amyelois* to build up high population densities under European conditions.	
Reasoning for a scenario which would lead to a reasonable high proportion	The judgement on the upper limit considers that • The large number of alternative hosts in the European environment supports rapid spread • The connectivity of patches in the EU is high and the contribution of barriers is limited • The European population of *Amyelois* will be less synchronised than in California
Reasoning for a scenario which would lead to a reasonable low proportion	The judgement on the lower limit considers that • General low motivation of the pest to invade new environments and search for new hosts • Minimal movement will be done by transportation to the huller, while waste management is effective. • Lower pest pressure (due to smaller plots) will reduce the expansion • Existing measures against the codling moth reduces the population size of *Amyelois* as well.
Fair estimate as judgement on the weighted evidence	The judgement on the median considers that • It is concluded, that *Amyelois* need high populations for expansion of the infested areas, which is less likely in the EU • A minimal expansion will happen due to the plot size (or connectivity between many small traditional sites) and also agricultural practices (e.g. transport)
Precision of the judgement as description of remaining uncertainties	The judgement on the interquartile range considers that • High uncertainties above the median due to the unknown spread behaviour under European conditions, larger expansions were reported in the past in US • Medium uncertainty below the median as some expansion is likely due to agricultural practices.
Experts	Vicente DALMAU, Charles S. BURKS, Stefano LA MALFA, Frank ZALOM, Agnès VERHAEGHE, Alexander MASTIN
Facilitator/Reporter	Olaf MOSBACH-SCHULZ/Sara TRAMONTINI
Date and place of the EKE	The EKE (with behavioural aggregation protocol) was done on the 23rd March 2022 in a virtual meeting

IMPACT

Table H.3: Yield loss on almonds under intensive production conditions

Overview of the results of the Expert Knowledge Elicitation (1st EKE question)															
Parameter	Yield loss on almonds under intensive production conditions														
Stratification	Almonds, intensive production														
Question	What is the percentage yield loss for **almonds** under **intensive production conditions** in the area of the EU under assessment caused by *A. transitella*?														
Results	P1%	P2.5%	**P5%**	P10%	P16.7%	P25%	P33.3%	**P50%**	P66.7%	P75%	P83.3%	P90%	**P95%**	P97.5%	P99%
Elicited values	0.20%					0.70%		2.0%		4.0%					7.0%
EKE results	0.20%	0.21%	0.23%	0.30%	0.44%	0.70%	1.0%	2.0%	3.2%	4.0%	4.9%	5.7%	6.4%	6.7%	7.0%
Fitted distribution	BetaGeneral (0.55692, 1.1305, 0.00199, 0.072)														

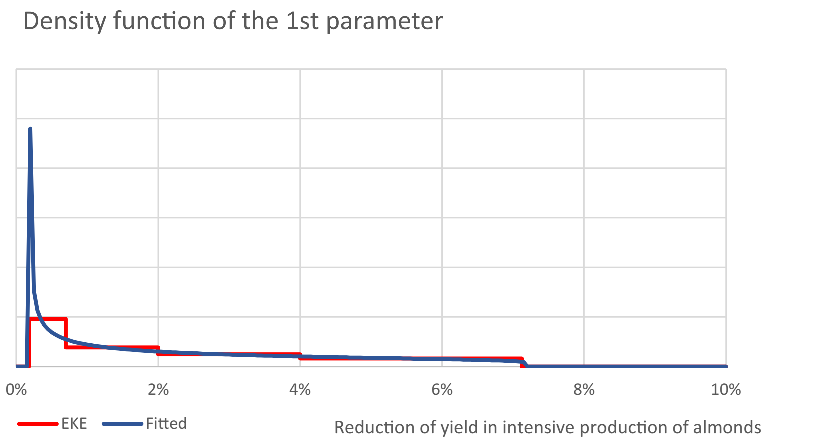


Figure (a): Comparison of elicited and fitted values/density function to describe the remaining uncertainties of the parameter

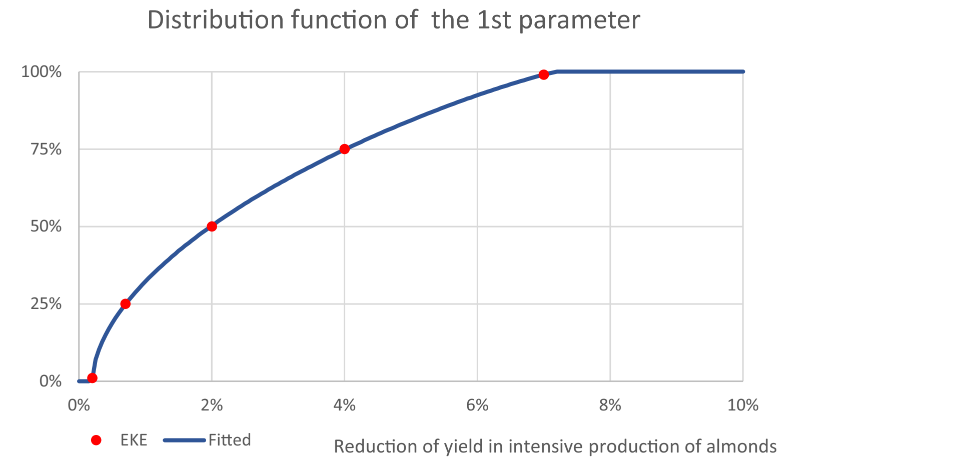


Figure (b): Cumulative distribution function (CDF) of the likelihood of the parameter

Summary of the evidence used for the evaluation	
• Relevant data on yield loss on Nonpareil almonds were extracted from Higbee and Burks (2021), Haviland et al. (2021), Higbee and Siegel (2012), Hamby et al. (2011), Higbee and Burks (2008) and Kellen et al. (1977). Data on infestation of tree mummies were disregarded as not relevant for yield loss estimation. • A meta-analysis resulted in a loss of yield of 3.54% (95% CI 1.88–6.67). Some calculations (in- & exclusion of studies) to estimate the sensitivity of the meta-analysis were made showing relative stable results. • No additional reference were found on pistachios. • Hamby et al. (2011) shows the influence of percentage of shell seal and later hull split on damages by *A. transitella*. Difference between Californian varieties (esp. Nonpareil) and modern European varieties were discussed regarding shelling percentage and harvesting time. • Differences between phytosanitary measures applied in California and the EU were discussed, esp. sanitation/mechanical harvest, mating disruption and (non-targeted) pesticide treatments. • Differences in the existence of alternative hosts for early life cycles, in neighbouring plots, and the surrounding were discussed.	
Main uncertainties	
• The transferability of Californian study results to European varieties is uncertain. • The influence of differences in sanitation and phytosanitary measures between California and the EU are uncertain. • The influence of more heterogenous European production areas (e.g. smaller plot size, more alternative hosts) is uncertain.	
Reasoning for a scenario which would lead to a reasonable high proportion	The judgement on the upper limit considers that • The yield loss on modern EU varieties is unclear • Sanitation and non-targeted phytosanitary measures are less effective in EU • Smaller EU plots lead to uncontrolled pest development in the surrounding, e.g. non-managed hosts
Reasoning for a scenario which would lead to a reasonable low proportion	The judgement on the lower limit considers that • The variety is the most important factor to explain differences in yield loss between California and the EU • The EU varieties have stronger shells • The late harvest in EU not favouring earlier generations of *A. transitella*
Fair estimate as judgement on the weighted evidence	The judgement on the median considers that • Lower values for yield loss are more likely than higher • Reduced yield loss in EU compared to Californian by the varieties with harder shells is partly compensated by the increased availability of alternative hosts in surroundings of European production sites
Precision of the judgement as description of remaining uncertainties	The judgement on the interquartile range considers that • Maximum uncertainty is judged below the median with preference for lower values (L-shaped distribution) • Medium uncertainty is judged above the median, the upper bound is less likely
Experts	Vicente DALMAU, Charles S. BURKS, Stefano LA MALFA, Frank ZALOM, Agnès VERHAEGHE, David MAKOWSKI

Summary of the evidence used for the evaluation	
Facilitator/Reporter	Olaf MOSBACH-SCHULZ/Sara TRAMONTINI
Date and place of the EKE	The EKE (with behavioural aggregation protocol) was done on the 18th and 22nd March 2022 in a virtual meeting

Table H.4: Yield loss on almonds under traditional production conditions

Overview of the results of the Expert Knowledge Elicitation (2nd EKE question)															
Parameter	Yield loss on almonds under traditional production conditions														
Stratification	Almonds, traditional production														
Question	What is the percentage yield loss for **almonds** under **traditional production conditions** in the area of the EU under assessment caused by *Amyelois transitella*?														
Results	P1%	P2.5%	**P5%**	P10%	P16.7%	P25%	P33.3%	**P50%**	P66.7%	P75%	P83.3%	P90%	**P95%**	P97.5%	P99%
Elicited values	0.10%					0.45%		1.0%		1.5%					4.0%
EKE results	0.10%	0.13%	0.17%	0.25%	0.35%	0.48%	0.6%	0.9%	1.3%	1.6%	1.9%	2.4%	2.9%	3.4%	4.0%
Fitted distribution	BetaGeneral (1.2196, 10.052, 0.00075, 0.1)														

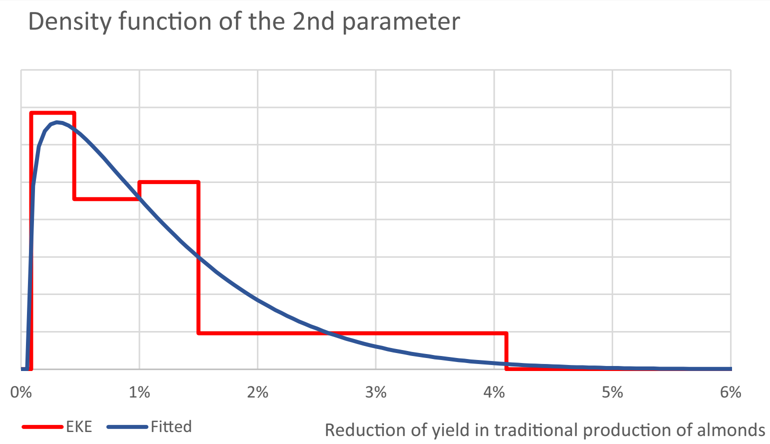


Figure (a): Comparison of elicited and fitted values/density function to describe the remaining uncertainties of the parameter

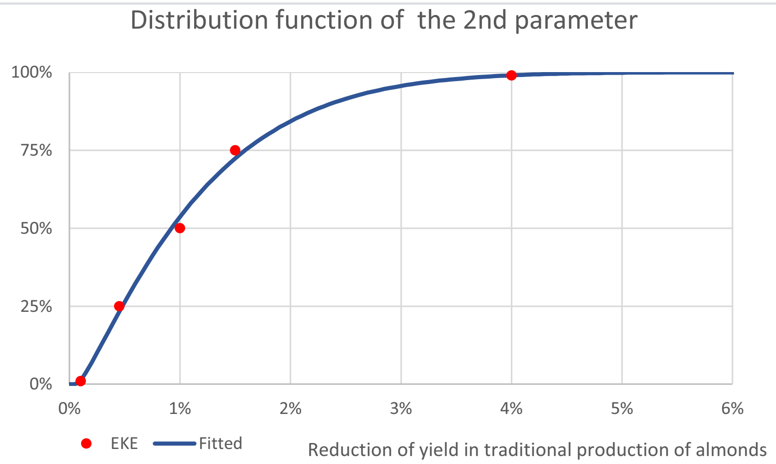


Figure (b): Cumulative distribution function (CDF) of the likelihood of the parameter

Summary of the evidence used for the evaluation	
• The assessment was done in comparison to the yield loss in intensive almond production sites, using the same evidence. • The influences of the differences between intensive and traditional almond production sites on yield loss were discussed esp. the influence of smaller plots, the use of traditional varieties with harder shells, the influence of rainfed plots on hull split, the influence of hand harvest on remaining mummies and finally the influence of heterogeneous surroundings on alternative hosts and enemies for *Amyelois*.	
Main uncertainties	
• The influence of a more heterogeneous/natural surrounding environment of almond plots is unclear.	
Reasoning for a scenario which would lead to a reasonable high proportion	The judgement on the upper limit considers that • Alternative hosts in the surrounding of traditional almond production sites can act as reservoirs for *Amyelois*
Reasoning for a scenario which would lead to a reasonable low proportion	The judgement on the lower limit considers that • The traditional varieties have harder shell and are less vulnerable to infestations with *Amyelois* • The absence of irrigation reduces the level of hull split and following the infestation level • The hand harvesting leads to reduced presence of remaining mummies and reduces the initial population size of *Amyelois* • The more heterogenous surroundings of traditional plots increases the level of natural enemies, predators (incl. vertebrates) to *Amyelois*
Fair estimate as judgement on the weighted evidence	The judgement on the median considers that • The yield loss in traditional production sites is judged to be around 2–3 times less than in intensive production sites
Precision of the judgement as description of remaining uncertainties	The judgement on the interquartile range considers that • Maximum uncertainty is judged below the median • Low uncertainty is judged above the median with clear evidence for lower values
Experts	Vicente DALMAU, Charles S. BURKS, Stefano LA MALFA, Frank ZALOM, Agnès VERHAEGHE, David MAKOWSKI
Facilitator/Reporter	Olaf MOSBACH-SCHULZ/Sara TRAMONTINI
Date and place of the EKE	The EKE (with behavioural aggregation protocol) was done on the 22rd March 2022 in a virtual meeting

Table H.5: Yield loss on pistachios

Overview of the results of the Expert Knowledge Elicitation (2nd EKE question)															
Parameter	Yield loss on pistachios														
Stratification	Pistachios														
Question	What is the percentage yield loss for **pistachios** in the area of the EU under assessment caused by *A. transitella*?														
Results	P1%	P2.5%	**P5%**	P10%	P16.7%	P25%	P33.3%	**P50%**	P66.7%	P75%	P83.3%	P90%	**P95%**	P97.5%	P99%
Elicited values	0.10%					0.50%		1.3%		2.5%					4.5%
EKE results	0.10%	0.11%	0.13%	0.20%	0.31%	0.50%	0.7%	1.3%	2.0%	2.5%	3.0%	3.5%	4.0%	4.3%	4.5%
Fitted distribution	BetaGeneral (0.66236, 1.3904, 0.00096, 0.0475)														

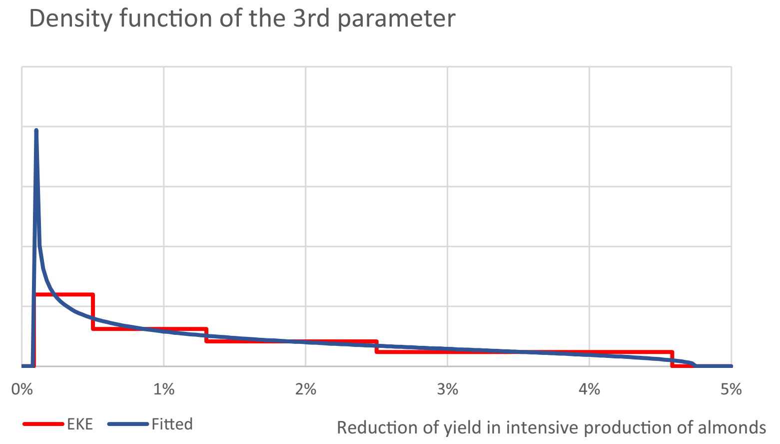


Figure (a): Comparison of elicited and fitted values/density function to describe the remaining uncertainties of the parameter

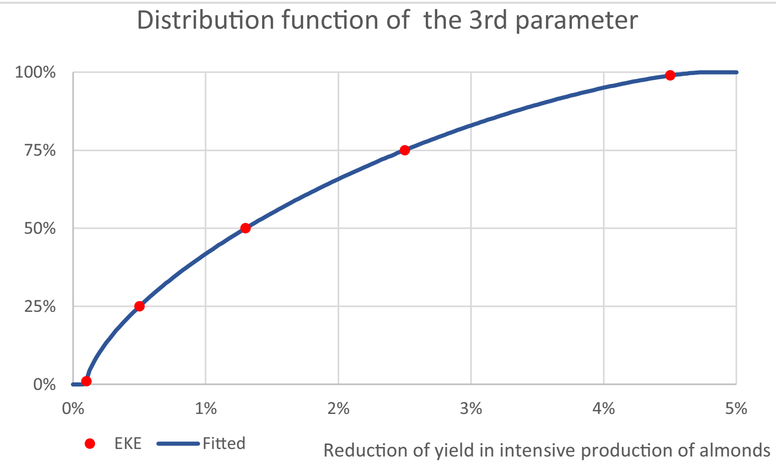


Figure (b): Cumulative distribution function (CDF) of the likelihood of the parameter

Summary of the evidence used for the evaluation

- The assessment was done in comparison to the yield loss in intensive almond production sites, using the same evidence.
- Additional references on yield loss on pistachios were screened.
- The situation of pistachios production in EU27 wasdiscussed. As pistachio production is increasing, many production sites are new established and intensive, esp. in Spain. In Italy and Greece also traditional sites exist and using traditional varieties (not used in Californian).

Main uncertainties

- The transferability of Californian study results to European varieties is uncertain. The influence of differences in sanitation and phytosanitary measures between California (USA) and Europe are uncertain. The influence of more heterogenous European production areas (e.g. smaller plot size, more alternative hosts) is uncertain.

Reasoning for a scenario which would lead to a reasonable high proportion	The judgement on the upper limit considers that • Pistachios varieties in intensive production sites are similar to those in Californian • Very limited studies on yield loss in pistachios leading to a higher upper bound
Reasoning for a scenario which would lead to a reasonable low proportion	The judgement on the lower limit considers that • The traditional European varieties do not show hull split • Very limited studies on yield loss in pistachios leading to decreased lower bound
Fair estimate as judgement on the weighted evidence	The judgement on the median considers that • The yield loss for pistachios (in intensive systems) is generally a factor around 2 lower than for almonds in intensive production systems • The extrapolation to European production conditions may increase the risk of yield loss
Precision of the judgement as description of remaining uncertainties	The judgement on the interquartile range considers that • Maximum uncertainty is judged below the median with preference for lower values (L-shaped distribution) • Medium uncertainty is judged above the median, the upper bound is less likely
Experts	Vicente DALMAU, Charles S. BURKS, Stefano LA MALFA, Frank ZALOM, Agnès VERHAEGHE, Alexander MASTIN
Facilitator/Reporter	Olaf MOSBACH-SCHULZ/Sara TRAMONTINI
Date and place of the EKE	The EKE (with behavioural aggregation protocol) was done on the 22nd March 2022 in a virtual meeting

Table H.6: Yield loss on walnuts

Overview of the results of the Expert Knowledge Elicitation (3rd EKE question)															
Parameter	Yield loss walnut production														
Stratification	Walnuts														
Question	What is the percentage yield loss for **walnuts** in the area of the EU under assessment caused by *Amyelois transitella*?														
Results	P1%	P2.5%	**P5%**	P10%	P16.7%	P25%	P33.3%	**P50%**	P66.7%	P75%	P83.3%	P90%	**P95%**	P97.5%	P99%
Elicited values	0.00%					0.50%		1.0%		2.0%					4.0%
EKE results	0.01%	0.04%	0.08%	0.17%	0.29%	0.46%	0.6%	1.1%	1.6%	1.9%	2.4%	2.8%	3.3%	3.6%	4.0%
Fitted distribution	BetaGeneral (0.94102, 2.5448, 0, 0.048)														

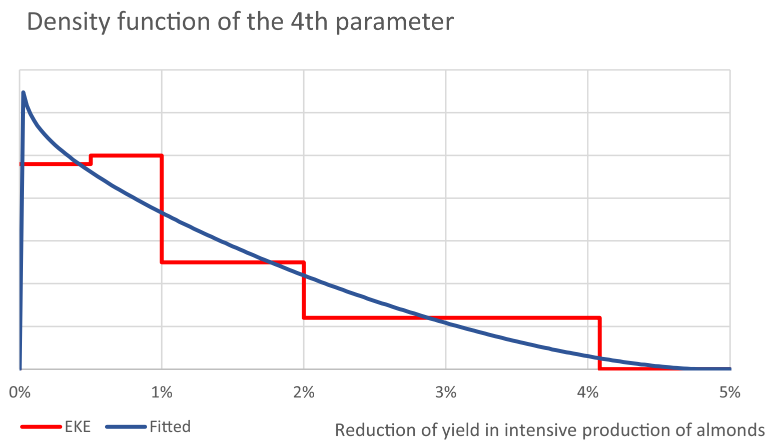


Figure (a): Comparison of elicited and fitted values/density function to describe the remaining uncertainties of the parameter

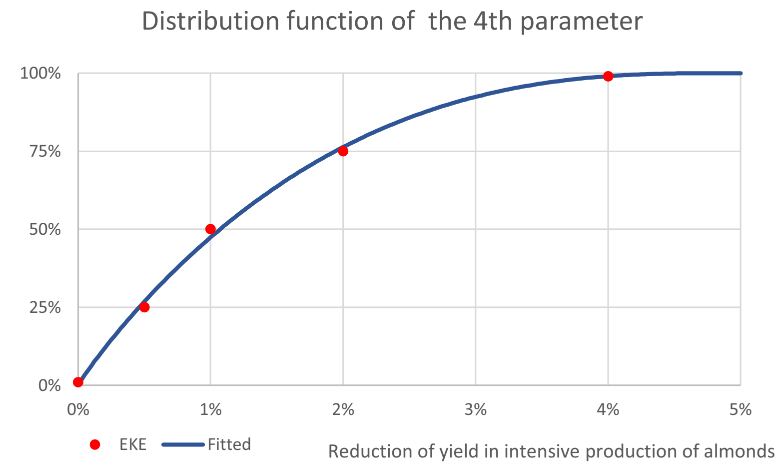


Figure (b): Cumulative distribution function (CDF) of the likelihood of the parameter

Summary of the evidence used for the evaluation	
• The differences between intensive, traditional and organic production of walnuts were discussed. It was concluded, that the influence of production conditions on the yield loss is minor compared to other influential factors. No stratification is needed. • Additional references on yield loss on walnuts were screened, esp. Michelbacher and Davis (1961), Light and Knight (2011), Burks et al. (2021) (project report). • Michelbacher and Davis (1961) report yield loss between 3 and 6%, Burks et al. 2021 between 0 and 7.2% with majority below 4%. • It was concluded that the codling moth is the current key pest in EU for damage and phytosanitary measures. • The possibility of additional yield loss attributed to *Amyelois* was discussed. It was concluded that *Amyelois* is a secondary pest. Nevertheless before harvest exist a short time window, when (after hull split) *Amyelois* could cause primary damage. • In Spanish intensive production sites similar varieties as in California (e.g. Chandler) are used, while in France AOP varieties are dominant. All European varieties have late harvest.	
Main uncertainties	
• The influence of current treatments against other pest on *Amyelois* is unclear. • The differences between California and European (e.g. AOP) varieties are unclear, esp. the vulnerability at late harvest. • The influence of differences between California and European climate on the life cycles of *Amyelois* is unclear. • The influence of differences in sanitation and phytosanitary measures between California and the EU is uncertain. • The influence of more heterogenous European production areas (e.g. smaller plot size, more alternative hosts) is uncertain.	
Reasoning for a scenario which would lead to a reasonable high proportion	The judgement on the upper limit considers that • European climate allows 3–4 generations of *Amyelois* until harvest • Sanitation and non-targeted phytosanitary measures are less effective in EU • Current measures against the codling moth are not effective against *Amyelois* • Smaller EU plots lead to uncontrolled pest development in the surrounding, e.g. non-managed hosts • EU harvest practice of ripened nuts allows primary infestations by *Amyelois*
Reasoning for a scenario which would lead to a reasonable low proportion	The judgement on the lower limit considers that • *Amyelois* is only a secondary pest using infested nuts by the codling moths (no additional damage) • The vulnerability of European varieties is not different from California, esp. Chandler • Small plot size leads to lower population levels of *Amyelois*
Fair estimate as judgement on the weighted evidence	The judgement on the median considers that • primary damage of *Amyelois* is less likely (and attribution in the studies was questionable)
Precision of the judgement as description of remaining uncertainties	The judgement on the interquartile range considers that • Maximum uncertainty is judged below the median with preference for lower values (L-shaped distribution) • Medium uncertainty is judged above the median, the upper bound is less likely

Experts	Vicente DALMAU, Charles S. BURKS, Stefano LA MALFA, Frank ZALOM, Agnès VERHAEGHE, Alexander MASTIN
Facilitator/Reporter	Olaf MOSBACH-SCHULZ/Sara TRAMONTINI
Date and place of the EKE	The EKE (with behavioural aggregation protocol) was done on the 22nd March 2022 in a virtual meeting

Appendix I – Probit-9

Governments and NPPOs provide guidance on use of quarantine treatments such as sulfuryl fluoride for quarantine and pre-shipment purposes (e.g. Department of Agriculture and Water Resources, 2018; Ganesh, 2018). Such postharvest quarantine treatments are often required to provide probit-9 mortality.

A probit-9 treatment will result in 32 survivors from 1,000,000 individuals treated where mortality is the desired response (equivalent to 99.9968% mortality). However, with fluctuations in distribution and population levels, the 95% confidence limit for surviving individuals based on normal probit 9 conditions may range from 29 to 136 individuals per 1,000,000 organisms treated (99.9971–99.9864% mortality) (Paull and Armstrong, 1994).

Since first recommended as an appropriate level of quarantine protection by Baker (1939), probit-9 level treatments became the benchmark for quarantine security for the USA and many other countries (Schortemeyer et al., 2011; Griffen, 2012). Probit-9 level mortality treatments are appropriate in cases where (i) the treatment does not adversely affect the host commodity (i.e. treatment has no phytotoxicity), (ii) the pest infestation rate could be relatively high, (recall perhaps 1% walnuts could be infected at harvest), (iii) the pest is internal or difficult to detect (Griffen, 2012).

From the statistical point of view, probit analysis is a statistical method used to calculate a dose–response relationship and is commonly used in plant health and quarantine to derive the appropriate dose for a specific degree of mortality. In the context of Probit-9, the response (mortality) is modelled as a cumulative normal distribution with zero as lower limit of response and one as upper limit, while probit 5 represents 50% response, i.e. 50% mortality. The independent variable is often dose or concentration of a pesticide product (or pathogen) or the logarithm of the dose. Probit-6 is the response at a dose or log dose of one standard deviation more (on the independent variable scale) than the dose giving 50% response while probit-7 is the response at two standard deviations above the dose or log dose giving 50% response. Probit-9 is the response at four standard deviations above the dose or log dose giving 50% response. Dose–response curves are fitted to data for specific pest-product relationships under specific conditions.

Probit	Survival (out of 1,000,000)
0	999999.7
1	999,968
2	998,650
3	977,250
4	841,345
5	500,000
6	158,655
7	22,750
8	1,350
9	32
10	0.3

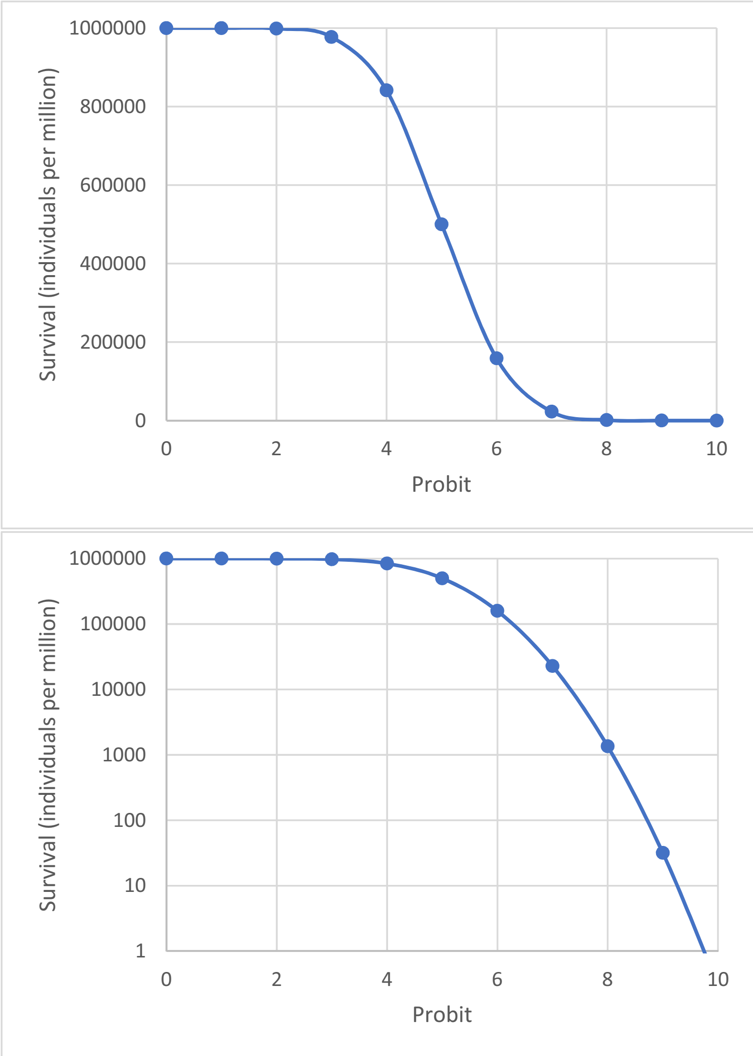


Illustration of dose–response where dose is expressed in probits, and response in individuals out of 1,000,000.

Appendix J – Effect of cold treatment on survival of *A. transitella*

An estimated 30% of shipments across the Atlantic is done in chilled reefers. Here, we estimate the survival of larvae and eggs during cold transport. We take into account the duration of transport and the mortality-time relationship, depending on the temperature in the shipment.

Transport to the EU (almonds)

The EFSA PLH Panel assumes the vast majority of almonds will be transported by rail or road from California to ports on the east coast of USA for export to the EU. To preserve quality, transport is assumed to take 5 or 6 days whilst crossing the Atlantic on a container ship may take 8–14 days (cross reference to walnuts). Allowing for some dwell time in port, onward distribution and storage within the EU, total transport time whilst chilled could be approximately 15–30 days or longer. There is no information on transport time in the walnut dossier.

cargohandbook.com recommends transporting nuts at −3° to 0°C. This leads us to assess survival under cold transport at the lowest temperature tested, which is 0°C (Johnson et al., 2007).

Survival

Tebbets et al. (1978) reported on mortality of immature stages of the navel orangeworm at 3.5°C. They reported their data as LT50 and LT95, i.e. the time to 50 and 95% mortality. Data were analysed using probit analysis. From the reported data, the panel reconstructed the mortality-time relationships and plotted these relationship along with the reported LT50, LT95 and extrapolated time till probit-9 mortality, i.e. 32 survivors out of a million exposed individuals.

Age and stage	Days from oviposition	LT50 (days) (95% confidence interval)	LT95 (days) (95% confidence interval)	Probit-9 (32 surviving out of one million)
Days and stage	Days	Days	Days	Days
0–1 Eggs	0–1	1.05 (1.03–1.07)	5.09 (5.06–5.12)	10.9
3–4 Eggs	3–4	4.10 (4.09–4.11)	8.77 (8.75–8.79)	15.5
3–4 Larvae	7–8	4.54 (4.53–4.55)	7.14 (7.10–7.19)	10.9
9–10 Larvae	13–14	4.84 (4.83–4.85)	8.87 (8.85–8.89)	14.6
19–20 Larvae	23–24	5.24 (5.23–5.25)	13.00 (12.97–13.03)	24.1
1–3 Pupae	26–28	10.89 (10.74–11.04)	21.38 (20.61–22.18)	36.3
5–7 Pupae	30–32	8.13 (8.08–8.17)	17.34 (17.19–17.49)	30.5

Johnson (2007) reported on survival of eggs, larvae and pupae of Navel orangeworm at 0, 5 and 10°C. Below is a table with the most important reported parameters.

Survival duration of eggs at three temperatures

Temperature	Age	Intercept	Slope	LD50	LCL	UCL	LD95	LCL	UCL	Probit-9
°C	h	–	/d	d	d	d	d	d	d	d
0	15	−0.86 ± 0.042	2.24 ± 0.064	0.4	0.07	0.7	1.1	0.6	20	2.2
	39	−1.03 ± 0.037	0.92 ± 0.023	1.1	0.9	1.3	2.9	2.6	3.3	5.5
	63	−0.99 ± 0.030	1.20 ± 0.018	0.8	0.1	1.5	2.2	1.5	3.5	4.2
5	15	−0.42 ± 0.028	0.46 ± 0.012	0.9	0.5	1.3	4.5	3.9	5.3	9.6
	39	−0.92 ± 0.029	0.46 ± 0.010	2.0	1.8	2.2	5.6	5.2	6.0	10.7
	63	−1.39 ± 0.031	0.46 ± 0.031	3.0	2.8	3.3	6.6	6.3	7.1	11.7
10	15	−1.53 ± 0.079	0.42 ± 0.014	3.6	3.3	3.9	7.5	7.2	7.9	13.1
	39	−1.86 ± 0.084	0.36 ± 0.084	5.1	4.4	5.7	9.7	8.9	10.7	16.2
	63	−1.67 ± 0.079	0.36 ± 0.012	4.6	3.9	5.3	9.2	8.4	10.2	15.8

LCL = lower 95% confidence limit.
UCL = upper 95% confidence limit.

Survival duration of **larvae** at three temperatures

Temperature	Intercept	Slope	LD50	LCL	UCL	LD95	LCL	UCL	Probit9
°C	–	/d	d	d	d	d	d	d	d
0	−1.07 ± 0.104	0.64 ± 0.037	1.7	−0.3	3.5	4.3	2.7	9.8	7.9
5	−1.33 ± 0.105	0.27 ± 0.016	4.8	3.9	5.7	10.9	9.6	12.7	14.5
10	−1.09 ± 0.066	0.03 ± 0.001	39.7	34.2	44.3	23.3	20.6	27.2	169

Survival duration of **pupae** at three temperatures

Temperature	Intercept	Slope	LD50	LCL	UCL	LD95	LCL	UCL	Probit9
°C	–	/d	d	d	d	d	d	d	d
0	−1.08 ± 0.090	0.35 ± 0.017	3.1	2.3	3.7	7.7	6.9	8.9	14.5
5	−0.96 ± 0.074	0.14 ± 0.007	6.8	5.4	8.1	18.4	16.3	21.4	19.7
10	−0.93 ± 0.088	0.11 ± 0.006	8.4	6.0	10.4	23.3	20.6	27.2	44.8

For shelled nuts (almonds, walnuts) we assumed that only larvae or pupae would be present.

For unshelled nuts (almonds, walnuts) we assumed that also eggs would be present. We assumed equal numbers of eggs and larvae.

2022-06-13 The data from Johnson (2007) indicate that survival will be well below the probit-9 level of survival if the temperature is 0°C. For eggs, time to probit-9 is 2.2, 5.5 or 4.2 days at 0°C. The actual time in cold storage during transport varies from 15 to 30 days or longer. We do not know the temperature from data, but the industry standard is between −3 and 0°C (CargoHandbook.com, 2022 https://www.cargohandbook.com/Nuts_and_Kernels (Accessed 6th Feb 2022); TIS, 2022. Transport information services. Walnut https://www.tis-gdv.de/tis_e/ware/nuesse/walnuss/walnuss-htm/ (Accessed 6th Feb 2022)).

Assess the survival of eggs in nuts if transported in cooled reefers during cross-Atlantic transport.

	1%	25%	50%	75%	99%
Consensus	**0/million**	**0.5**	**1**	**1.5**	**2/million**

For larvae it is 7.9 days at 0°C to probit-9 mortality. The actual time in cold storage during transport varies from 15 to 30 days or longer.

Assess the survival of larvae in nuts if transported in cooled reefers during cross-Atlantic transport.

	1%	25%	50%	75%	99%
Consensus	**2/million**	**4/million**	**6/million**	**8/million**	**10/million**

2022-06-13 For larvae it is 7.9 days, for pupae it is 14.5 days at 0°C. The actual time in cold storage during transport varies from 15 to 30 days or longer. Thus, we conclude that with transport at 0°C, probit-9 level survival or lower is obtained. At 5°C, you get 9.6, 10.7 or 11.7 days until probit-9 survival for eggs and 14.5 days till probit-9 survival for larvae and 19.7 days for probit-9 survival of pupae.

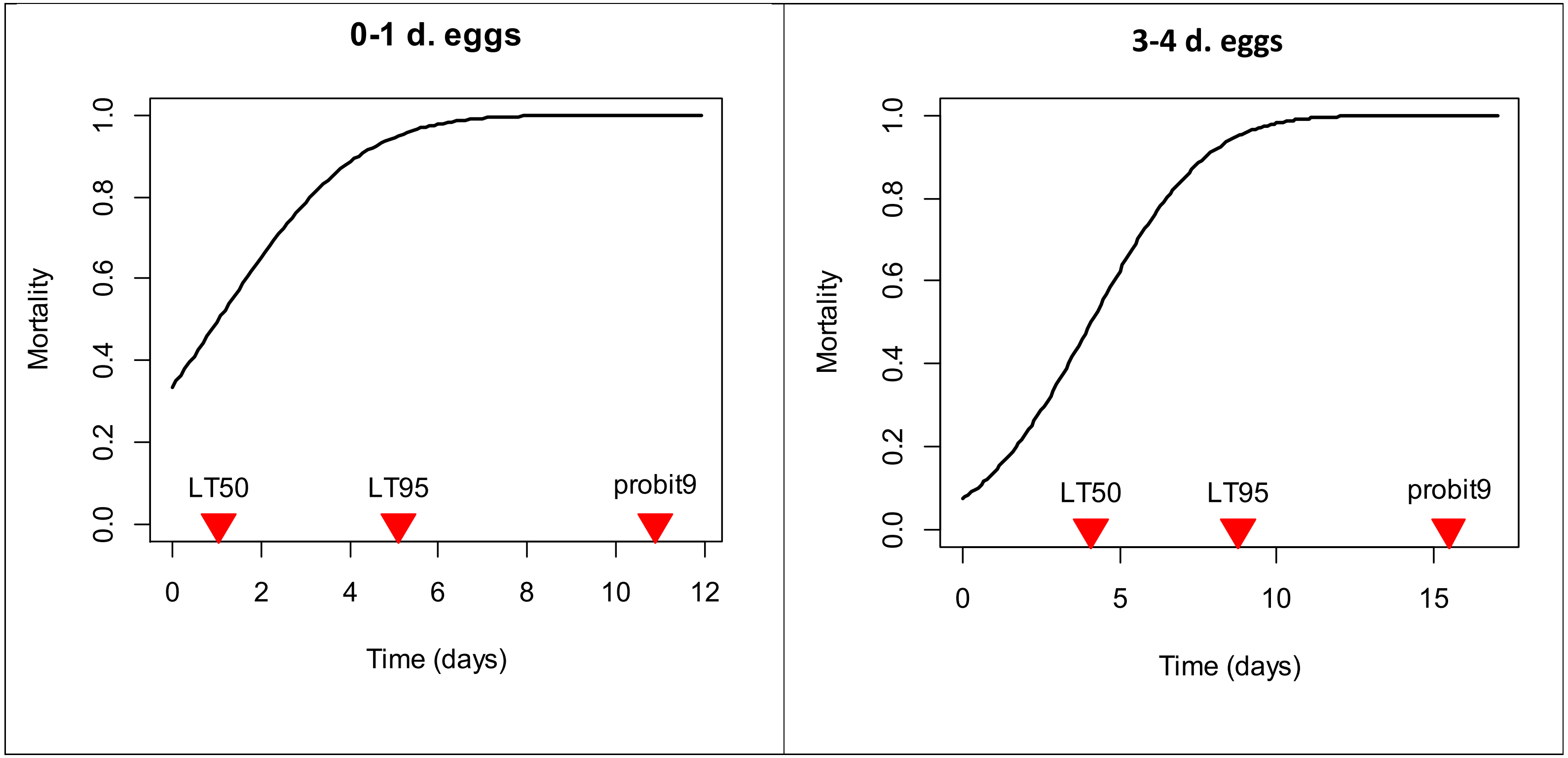
Insects on nuts in shell are assumed to consist of 50% larvae and 50% eggs.

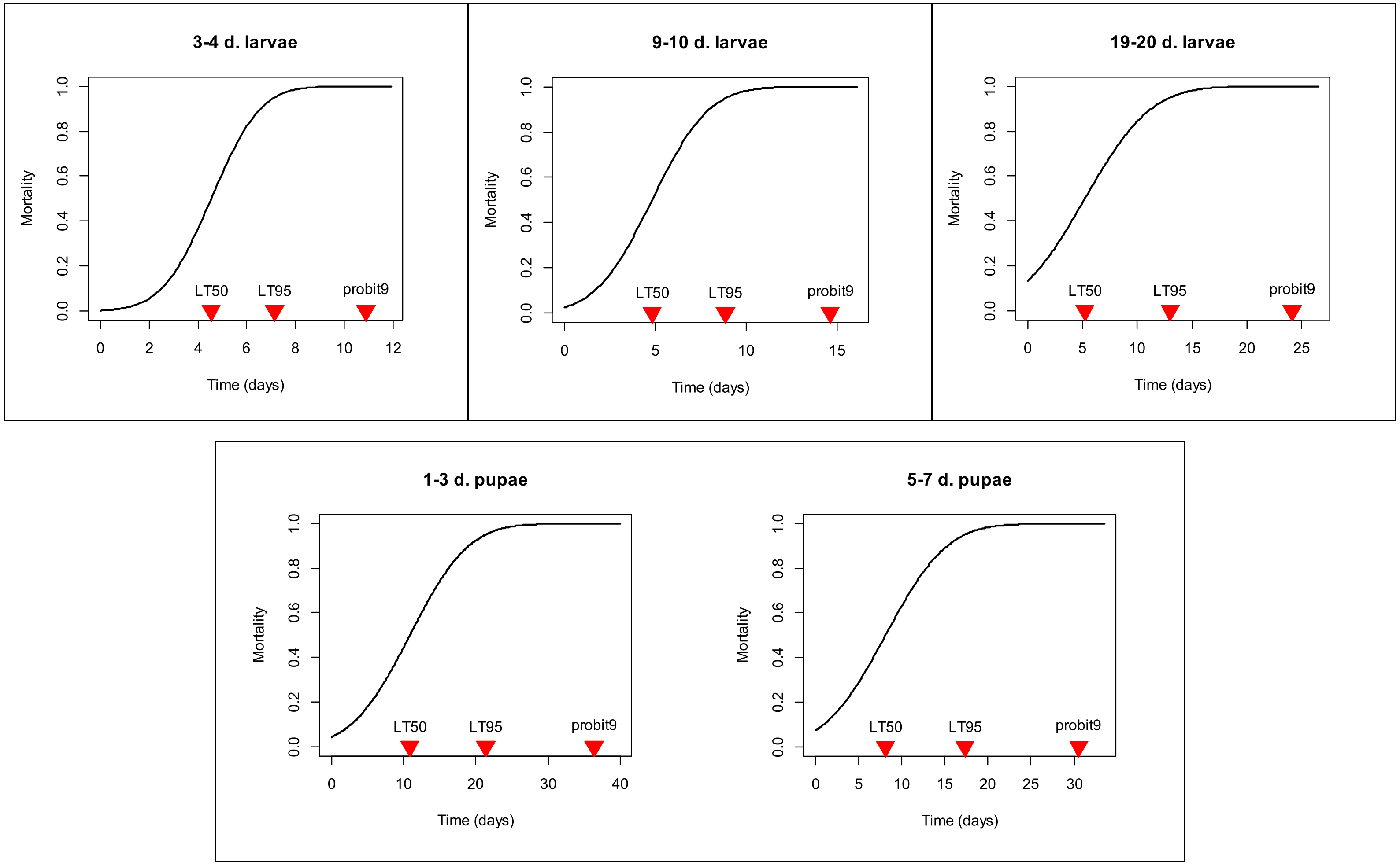
Insects on shelled nuts are assumed to consist of 100% larvae (because eggs cannot be laid inside the shell).

So, the elicitation results for larvae is applicable to pathways of shelled nuts.

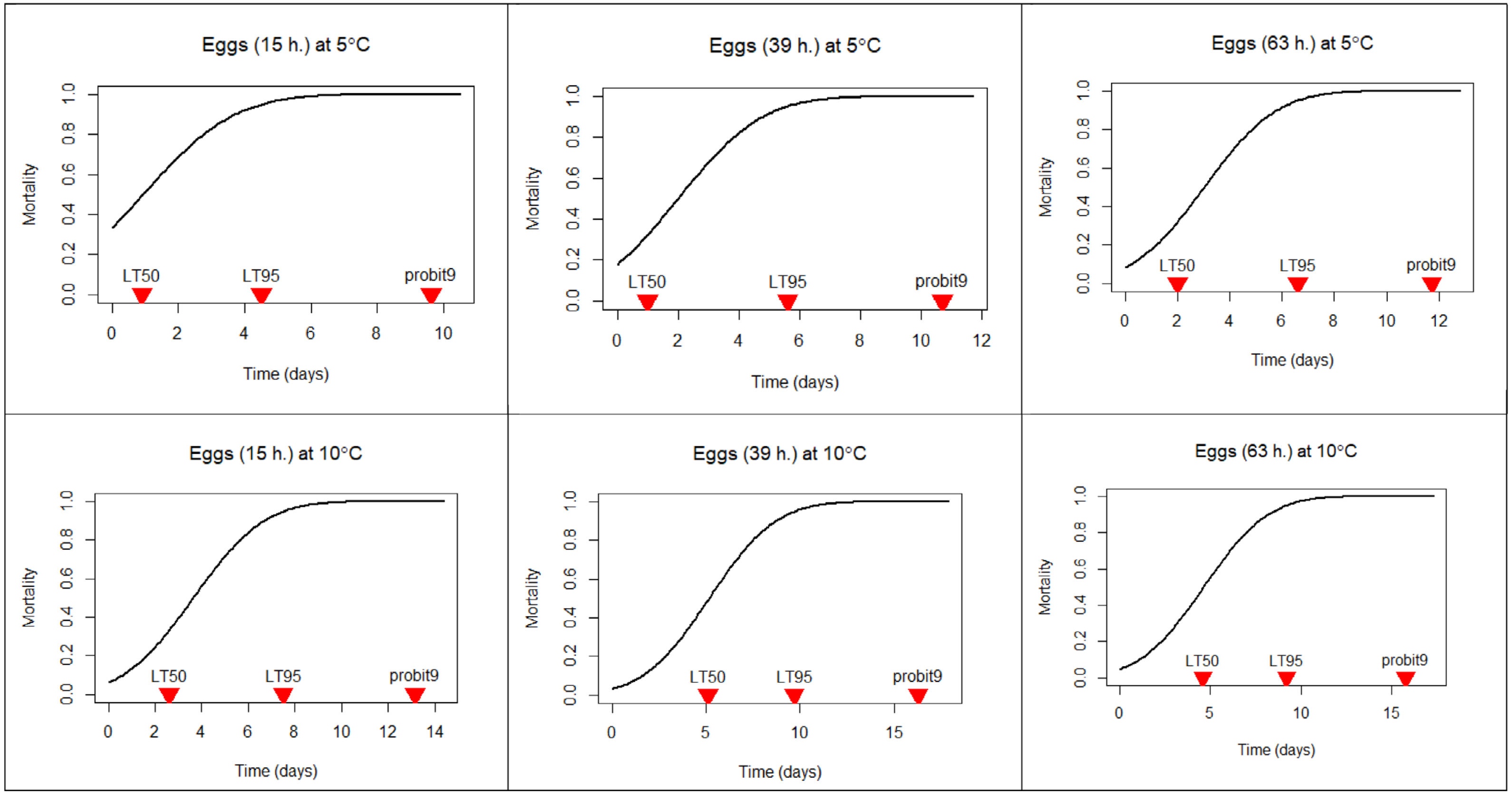
And the 'average' distribution for eggs and larvae (50/50 average) would be applicable for the insects on nuts with shell.

Figures for Tebbets et al. (1978)

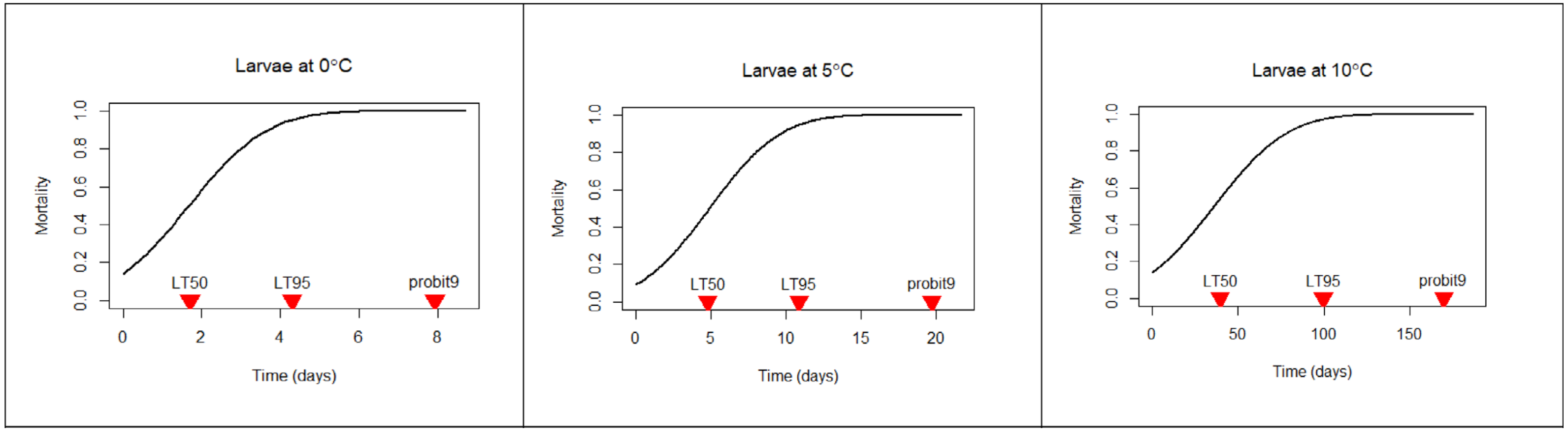



3-4 d. larvae
9-10 d. larvae
19-20 d. larvae
1-3 d. pupae
5-7 d. pupae
Mortality
Time (days)
LT50
LT95
probit9

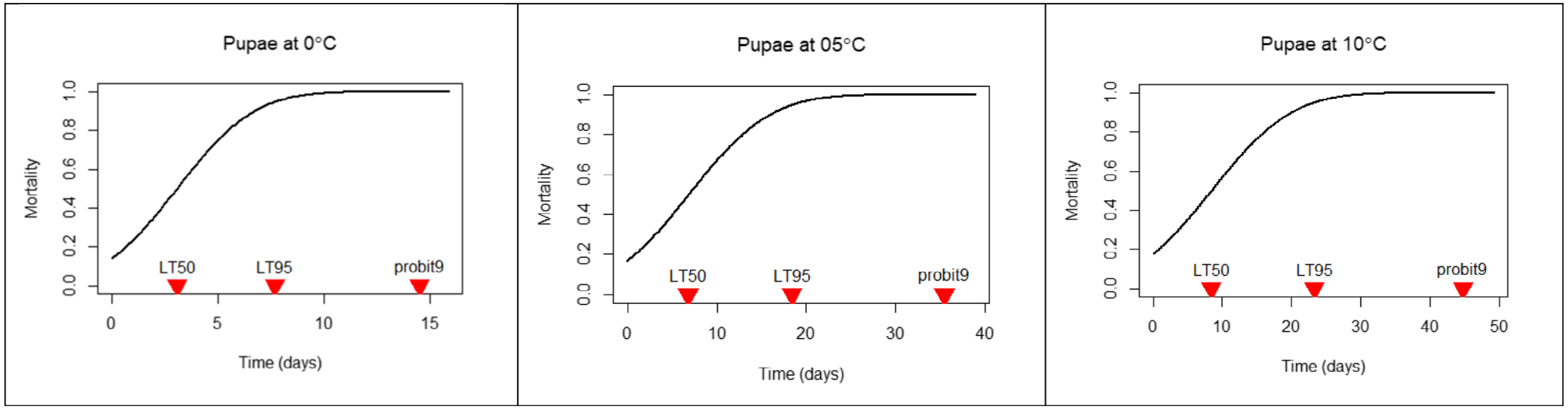
Figures for Johnson (2007) Eggs



Figures for Johnson (2007) Larvae



Figures for Johnson (2007) Pupae



Methods

The probit curve is given mathematically by the relationship:

$$\text{Probit}(\text{mortality}) = \text{intercept} + \text{slope} * \text{time}$$

The probit is here defined as the quantile of the normal distribution (here: exposure time) at a cumulative probability equal to the mortality. For instance, if exposure time is zero, the probit of mortality is equal to the intercept. This means that the mortality is equal to the cumulative probability of the normal distribution at the value of intercept. For instance, if the intercept is –2, then the mortality is equal to the cumulative normal probability at $x = -2$, which is 0.023 (in R: pnorm(–2, mean = 0, sd = 1)). At LT50, the cumulative probability is 0.5, and this occurs if the standard normal quantile is zero. This is the case if exposure time = –intercept/slope. The LT95 occurs if the cumulative probability is 0.95, which happens when the normal quantile is 1.64 (in R: qnorm(0.95, mean = 0, sd = 1)). probit9 happens when the standard normal quantile is 4, i.e. 4 sigma to the right of the mean. The following equality holds:

$$\text{probit9} = \text{LT50} + 4 * \text{sigma}$$

with

$$\text{sigma} = \frac{\text{LT95} - \text{LT50}}{\text{qnorm}(0.95) - \text{qnorm}(0.50)} = \frac{\text{LT95} - \text{LT50}}{1.64}$$

Where qnorm denotes the inverse of the cumulative normal density function. Thus:

$$\text{Probit9} = \text{LT50} + \frac{4}{1.64} * (\text{LT95} - \text{LT50})$$

$$= \text{LT50} + 2.43 * (\text{LT95} - \text{LT50})$$

$$= \text{LT95} + 1.43 * (\text{LT95} - \text{LT50})$$

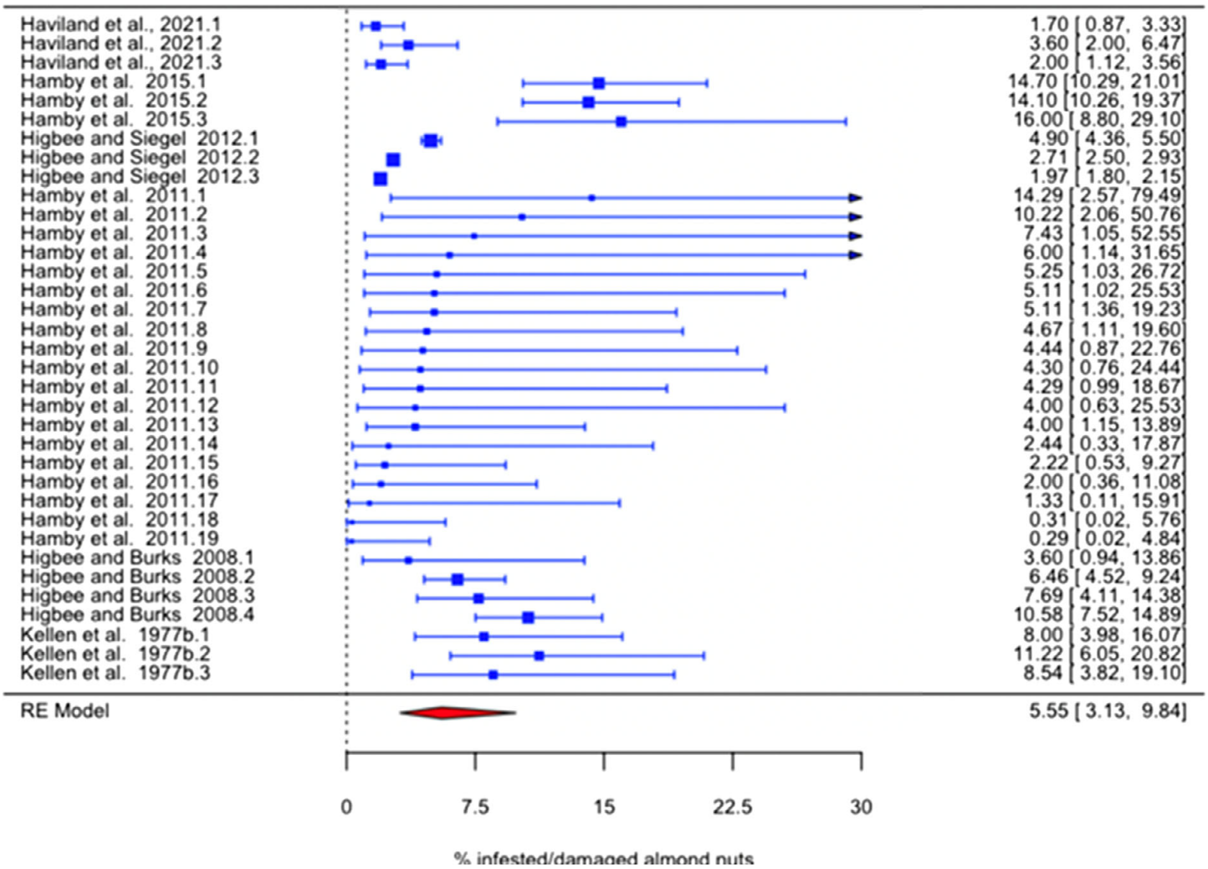
Note that in the equations used in the document, we define probit as the inverse of the standard normal distribution. In some of the older literature (e.g. Finney, 1971) and in the term probit-9, a shift of 5 units is applied on the probit scale to work with only positive numbers, but this definition is not used in these analyses or in the papers of Tebbets et al. (1978) and Johnson (2007).

Appendix K – Proportion of infested almonds; a meta-analysis

A literature review was carried out in preparation of the EKE on impact. This allowed the recovery of a large amount of quantitative data on the proportion of infested almonds. Thanks to this, it was possible to perform a meta-analysis on almonds, in support of the EKE activity. This was not possible for pistachios, walnuts and other hosts, for which the number of quantitative observations was limited.

Several papers on almonds were excluded, either due to the absence of standard errors or to the unclear definition of the variable 'damage'. Here, the proportion damage means either the proportion of infested nuts (sometimes named 'damaged' nuts in the papers) and sometimes this proportion is weighted by the nut weights. In this case, the proportion damage is the proportion of infested nut harvest measured in kg. Both estimates and their standard errors were extracted from the selected papers and organised by author, almond cultivar, location and year. Both types of data (proportion infested nuts and proportion of infested nut mass) were included in the analysis.

A meta-analysis was performed on this data set. Individual data of infestation proportions were log-transformed and weighted by their standard errors. The mean proportion of infested nuts (and its 95% confidence interval) was then estimated using a random-effects (RE) model. Estimates were back-transformed to their original scale for ease of interpretation. The information is presented as a 'forest plot'. The forest plot is a standard graphic used in meta-analysis. It summarises the available estimates and their uncertainty of the percentage of infested (damaged) almonds.



The obtained forest plot should be interpreted as follows:

- Labels on the left: reference of the paper and observation labels.
- Blue squares: individual percentages of infested almonds. The square areas are proportional to the individual data weights (inverse of their variances, i.e. squared SEs). Thus, the most accurate data get the largest squares.
- Blue horizontal bars: individual 95% confidence intervals (the four arrows indicate that the upper bounds exceed the max value covered by the x axis, for the four percentages concerned).
- Black numbers on the right: numerical values of the percentages and of the associated confidence intervals

- Red diamond ('RE Model'): estimated overall mean percentage infested nuts and its 95% confidence interval. This estimated value is equal to a weighted average of the individual values (taking both the individual standard errors and the between-study variability into account, as commonly done in standard meta-analysis).