APPROVED: 17 May 2019
Doi: 10.5281/zenodo.2785520

Anastrepha ludens
Pest Report to support ranking of EU candidate priority pests

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Requestor: European Commission
Question number: EFSA-Q-2018-00378
Output number: EN-1635
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Acknowledgements: EFSA wishes to acknowledge the contribution of Elma Bali, Josep Anton Jaques Miret, Nikolaos Papadopoulos, Stella Papanastassiou to the EKE and the review conducted by Dirkjan van der Gaag.

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1. Introduction to the report

This document is one of the 28 Pest Reports produced by the EFSA Working Group on EU Priority Pests under task 3 of the mandate M-2017-0136. It supports the corresponding Pest Datasheet published together on Zenodo[1] and applies the methodology described in the Methodology Report published on the EFSA Journal (EFSA, 2019).

This Pest Report has five sections. In addition to this introduction, a conclusion and references, there are two key sections, sections 2 and 3.

Section 2 first summarises the relevant information on the pest related to its biology and taxonomy. The second part of Section 2 provides a review of the host range and the hosts present in the EU in order to select the hosts that will be evaluated in the expert elicitations on yield and quality losses. The third part of Section 2 identifies the area of potential distribution in the EU based on the pest's current distribution and assessments of the area where hosts are present, the climate is suitable for establishment and transient populations may be present. The fourth part of Section 2 assesses the extent to which the presence of the pest in the EU is likely to result in increased treatments of plant protection products. The fifth part of section 2 reviews additional potential effects due to increases in mycotoxin contamination or the transmission of pathogens.

In Section 3, the expert elicitations that assess potential yield losses, quality losses, the spread rate and the time to detection are described in detail. For each elicitation, the general and specific assumptions are outlined, the parameters to be estimated are selected, the question is defined, the evidence is reviewed and uncertainties are identified. The elicited values for the five quantiles are then given and compared to a fitted distribution both in a table and with graphs to show more clearly, for example, the magnitude and distribution of uncertainty. A short conclusion is then provided.

The report has two appendices. Appendix A contains a host list created by amalgamating the host lists in the EPPO Global Database (EPPO, online) and the CABI Crop Protection Compendium (CABI, 2018). Appendix B provides a summary of the evidence used in the expert elicitations.

It should be noted that this report is based on information available up to the last day of the meeting[2] that the Priority Pests WG dedicated to the assessment of this specific pest. Therefore, more recent information has not been taken into account.

For *Anastrepha ludens*, the following documents were used as key references: Sequeira et al. (2001), USDA environmental assessments on the cooperative eradication program for Zapata County (Stewart, 2016a) and for Lower Rio Grande Valley (Stewart, 2016b).

[1] Open-access repository developed under the European OpenAIRE program and operated by CERN, https://about.zenodo.org/

[2] The minutes of the Working Group on EU Priority Pests are available at http://www.efsa.europa.eu/sites/default/files/wgs/plant-health/wg-plh-EU_Priority_pests.pdf

2. The biology, ecology and distribution of the pest

2.1. Summary of the biology and taxonomy

Anastrepha ludens, the Mexican fruit fly, is a single taxonomic entity. Species of the genus *Anastrepha* are endemic to tropical and subtropical areas of the new world (America) and hence, with few exceptions (i.e. *Anastrepha fraterculus* indigenous of South America), they pose great threat to fruit growing zones in such areas. *A. ludens* is considered among the most important pests of fruits in Mexico and central America, infesting mainly species of the family Rutaceae and *Mangifera indica* (mango). Like other fruit flies, *A. ludens* lays eggs in fruit mesocarp and larvae destroy the flesh of the fruit. Oviposition stings and larvae activity facilitate secondary fungi and bacteria infections that drive fruits to collapse. Adults are extremely long lived and considered to express great mobility. It is considered as a main invasive species that may threat fruit production in many tropical and subtropical areas of the globe.

2.2. Host plants

2.2.1. List of hosts

In its native range (northeastern Mexico), *A. ludens* is associated to *Casimiroa greggi*, a wild host belonging to Rutaceae, that may also be located on the banks of rivers near to citrus areas damaged by heavy infestations of *A. ludens* (Vanoye-Eligio et al., 2017). In Mexico, the worst impact is observed on citrus but also on mango and guava, while a total of about 60 different plant species are potential hosts in natural conditions, and many others in laboratory studies (Steck, 2003).

Appendix A provides the full list of hosts. In addition to that list, USDA APHIS provides Cooperative Fruit fly hosts lists that are used for state and federal regulatory decision making (USDA, 2016).

2.2.2. Selection of hosts for the evaluation

In the EU, sweet orange (*C. sinensis*), grapefruit (*C. paradisi*), *C. reticulata, C. aurantium, C. aurantifolia* and mango (*M. indica*) are of main concern as they are among the main hosts of this pest and represent important crops for the EU. For citrus species, Mangan et al. (2011 and 2012) assessed in laboratory conditions host preference among citrus species based on oviposition and immature performance

In addition, laboratory studies on the susceptibility of several apple varieties have been conducted by Aluja et al. (2014), revealing that some important cultivars (Golden Delicious, Gala, Milwa, Topaz and Elstar) are as suitable as grapefruit for *A. ludens* larvae and eggs development. However, there is no confirmation of those observations in natural conditions. Myrtaceae (e.g. *Psidium guajava* - guavas) and Rosaceae (e.g. *Prunus persica* - peaches) are only occasional hosts (EPPO, online; CABI, 2018).

2.2.3. Conclusions on the hosts selected for the evaluation

The complete list of hosts is produced by merging

- The list of host plants defined by EPPO (EPPO, online)
- The list of host species reported by CABI (CABI, 2018)
- The list of species reported by USDA Aphis (USDA, 2016).

The host on which the impact is assessed are

- *Citrus* spp. as they are known to be host of *A. ludens, Citrus* spp. are considered together with peach, since experts judge that the yield loss for both Citrus spp. and peach would be comparable.

- Under the host group of exotic fruit, yield loss is assessed for *Mangifera indica* (mango) as the major host for *A. ludens*. In addition, secondary hosts *Psidium guajava* (guava), *Annona cherimola* (cherimoya) and *Punica granatum* (pomegranate) are also included in the assessment with the assumption of an impact comparable to the one for *Mangifera indica*.
- Quality loss is not assessed.

2.3. Area of potential distribution

2.3.1. Area of current distribution

Figure 1 provides an overview of the current area of distribution of the pest. In the EU no outbreaks have yet been reported.

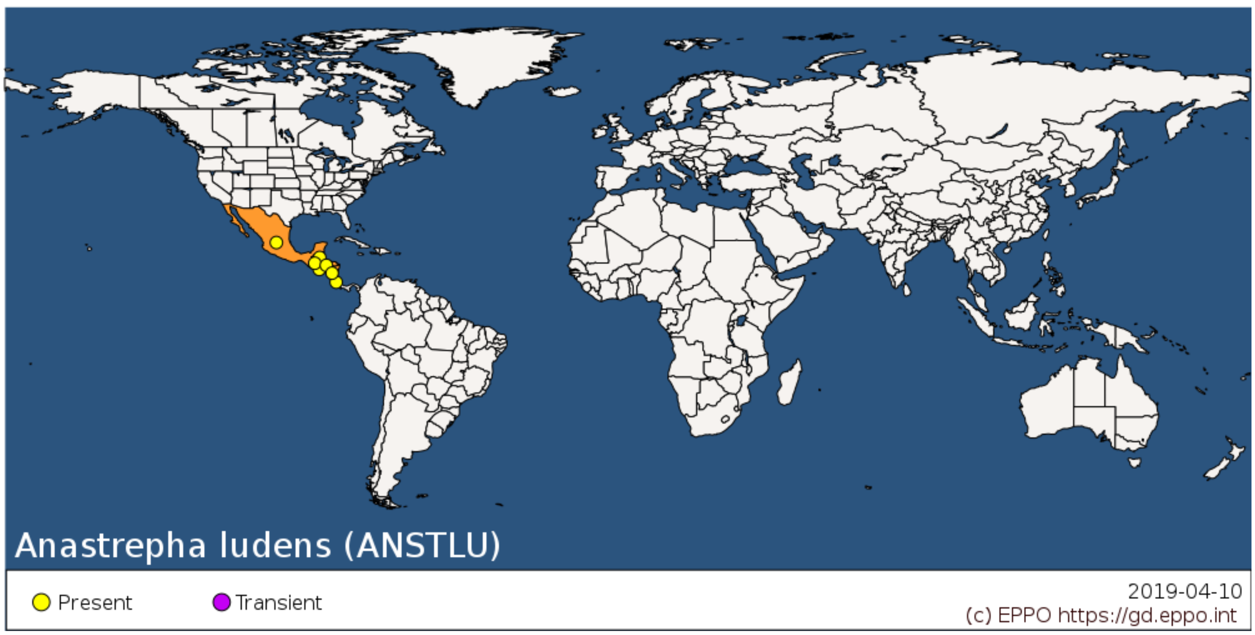

Figure 1 Distribution map of *Anastrepha ludens* from the EPPO Global Database accessed 10/04/2019 (EPPO, online).

The map from Sequeira et al. (2001, fig. 4 pag. 41) shows the distribution in North America: *A. ludens* appears as widespread in Mexico and annually detected in specific areas of south Texas. In California eradication actions are conducted in case of detections California (Papadopoulos et al., 2013; Carey et al., 2017a and b; Shelly et al., 2017) and) for further discussion. Few detections in Florida have been eradicated. The fly is widely dispersed in Central America as well and it is detected as south as Honduras. Detections are reported in Panama as well where the fly is considered as invasive. Reports of the fly in south America in countries such as Argentina and Colombia are now considered as erroneous (EPPO, online).

2.3.2. Area of potential establishment

Data on cold tolerance and the overwintering potential of this species are limited but it is not known to have any adaptations for overwintering survival, such as diapause. In addition, its response to cold temperatures cannot be inferred from its distribution because it is confined to areas with consistently warm climates. The northerly limits where the fly has been detected (and eradication is officially declared) is southern and western USA (southern Texas, California and Florida) with the southerly limits lying in Honduras and Panama. This makes it very difficult to apply and interpret the results of species distribution models, such as CLIMEX, to determine its establishment potential in Europe. Geng et al. (2008) used CLIMEX to map the potential distribution of the Mexican fruit fly in China showing that the southern and eastern parts of the country are highly suitable. If CLIMEX is rerun with the parameters used by Geng et al. (2008) and the outputs projected for Europe the model estimates a predominantly southern Mediterranean distribution for this pest that includes the most southern parts of Spain, Italy, Greece, the whole of Cyprus and Malta, parts of Central, South Portugal, Azores, Madeira and the Canary islands. The potential distribution also extends northwards along the Atlantic coast to northern France and even a few locations in southern England. However, despite the relatively mild winters along the Atlantic seaboard, it seems very unlikely that, even if freezing temperatures rarely occur, such a warmth-loving species could survive the long damp cool winters in this area.

Since species distribution models for this species are so difficult to interpret due to their inability to estimate overwintering potential, we have used a degree day model to map potential *A. ludens* distribution in Europe. This approach was adopted by Sequeira et al. (2001) who combined temperature requirements, generation potential and host availability to show that for *Anastrepha* species as a whole (including the Mexican fruit fly) most southern USA states, California and Arizona are highly suitable for the establishment of these species.

Meats (1989) provided an upper temperature development threshold of 39°C and a lower threshold of 10°C. No data on other developmental stages are available in Meats (1989) paper. The lower developmental threshold was estimated at 9.4°C and upper limit of 31°C following studies and interpolations of Leyva-Vazquez (1988). Additional development data can be found in Flitters and Messenger (1965). One generation required 766°D to be completed (Thomas, 1997).

Figure 2a shows that *Anastrepha ludens* (based on 10°C as the lower developmental threshold and 766 DD for completion of one generation) may complete a maximum of 4 generations in most coastal Mediterranean areas of Europe as well as in continental parts of central southern Spain, Greece, Italy and central south Portugal. This area has been selected as the area of potential distribution in Europe because it not only represents locations where temperatures are most favourable for multiple generations but also where winters, as shown in a map of minimum temperatures in the coldest month (January) (see Figure 2b) are least severe.

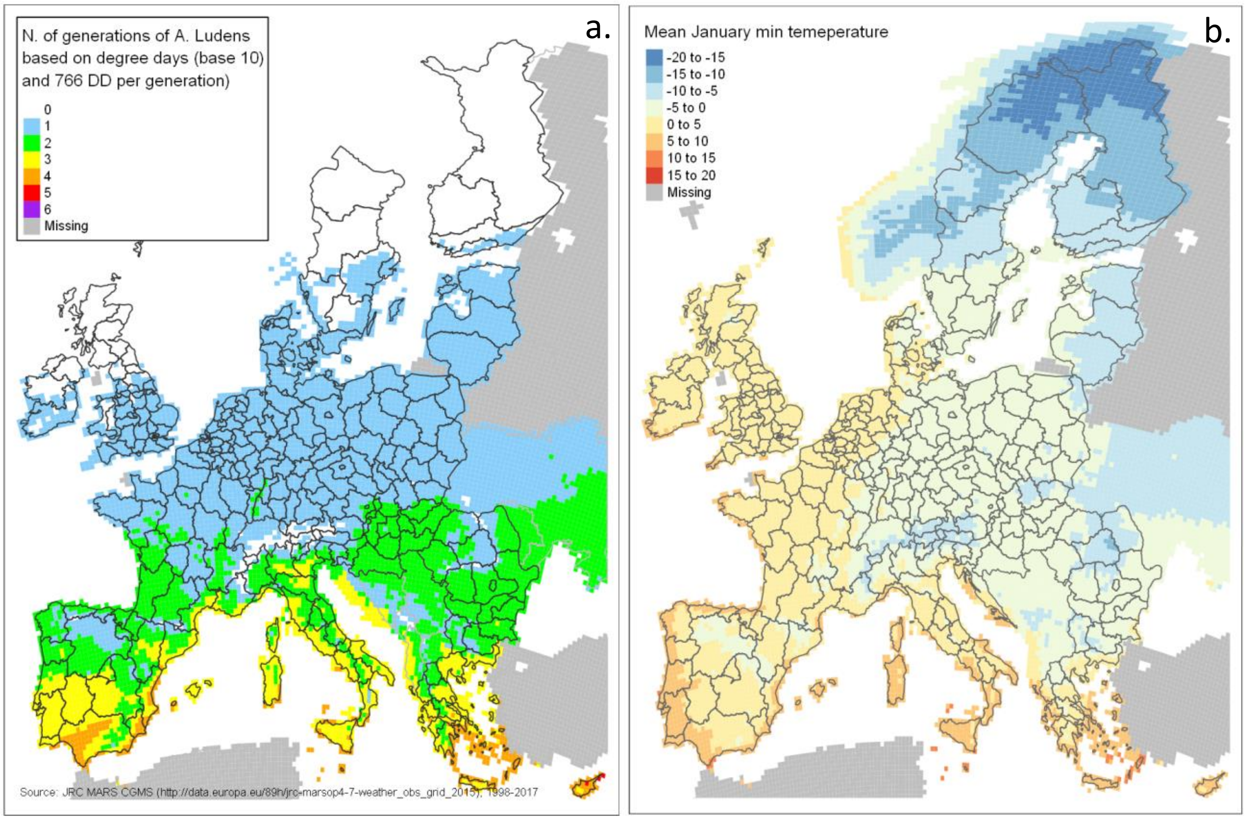

Figure 2 a) The number of generations estimated for *Anastrepha ludens* in Europe based on a degree day model with 10°C as the lower developmental threshold and 766 degree days for completion of each generation using 1997-2017 climatic data from the European Joint Research Centre interpolated to 25 km x 25 km resolution. b) The mean minimum temperatures in °C based on 1997-2017 climatic data from the European Joint Research Centre interpolated to 25 km x 25 km resolution.

2.3.3. Transient populations

Anastrepha ludens is not expected to form transient populations in the EU (for "transient" see the definition in EFSA, 2019).

2.3.4. Conclusions on the area of potential distribution

The area of potential distribution of the pest is a proportion of the area of the main hosts in the assessment area. Part of the area where the main hosts are distributed (e.g., peach) is not suitable for the pest due to climate or other ecological factors preventing the establishment. The area of potential distribution is limited to central and southern Spain, central and southern Portugal, Madeira, the Azores, southern Italy, Malta, southern Greece and Cyprus (see Fig. 2 and 3). For this species, transient populations are not considered, and the assessment is limited to the area of potential establishment.

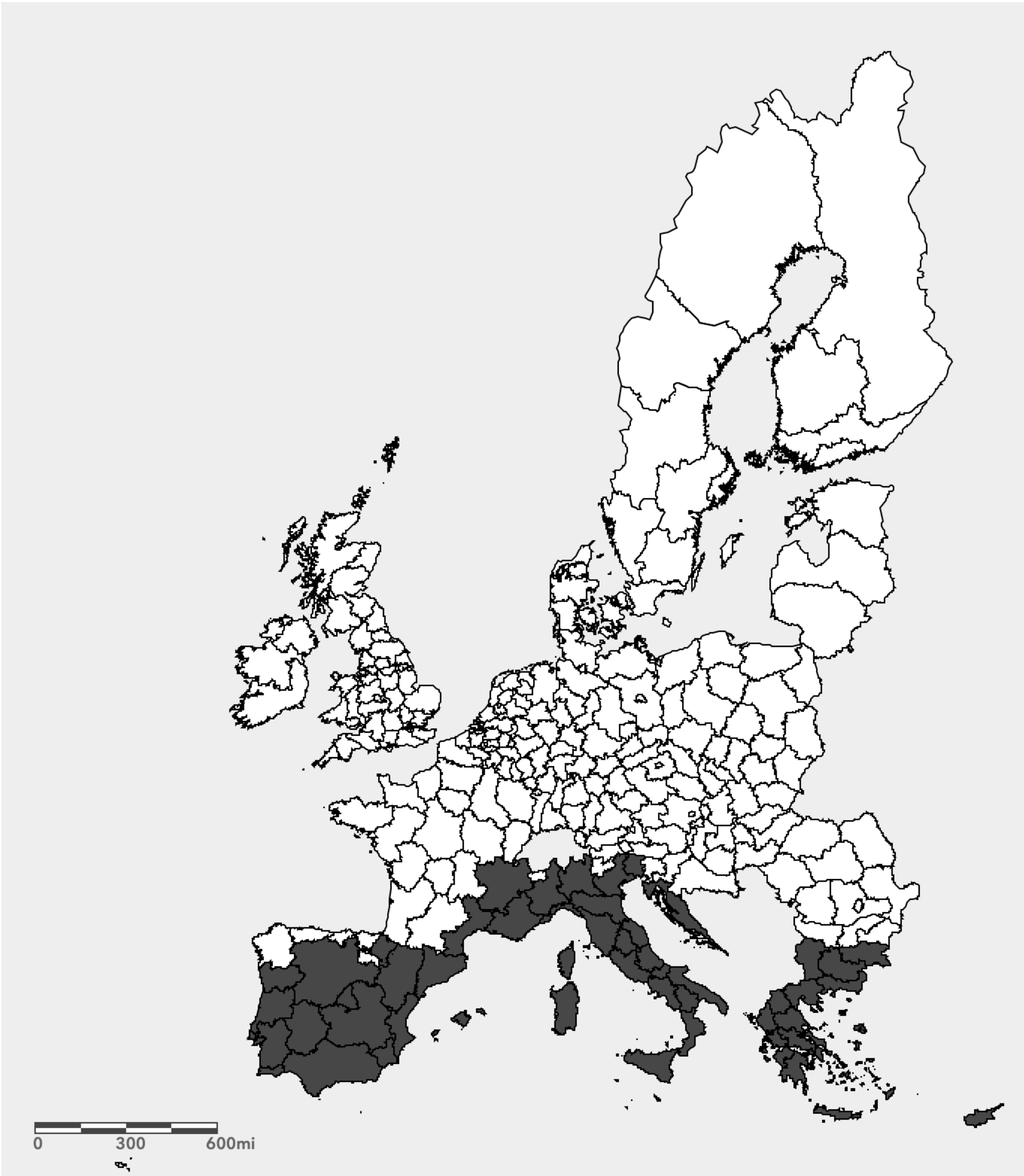

Figure 3 The potential distribution of the pest in the EU NUTS2 regions based on the scenarios established for assessing the impacts of the pest by the EFSA Working Group on EU Priority Pests (EFSA, 2019). This link provides an online interactive version of the map that can be used to explore the data further: https://arcg.is/1mHSae

2.4. Expected change in the use of plant protection products

Spinosad combined with food attractants and formulated as GF-120 is extensively used for the control of the Mexican fruit fly following bait spray applications (Flores et al., 2017). Lure and kill devices have been also extensively tested with positive results in Mexico (Flores et al., 2011 and2017; Lasa et al., 2013), where they seem to be effective in both the dry and the rainy season (Díaz-Fleischer et al., 2017).

Bait stations were found to be as effective as ground spray to control *A. ludens* in Mexico in mango orchards especially during the rainy season (Flores et al., 2017). It is likely that specific lure and kill devices will be developed for the European conditions if the fly becomes established and therefore the presence of *A. ludens* would require an increase in the use of plant protection products.

In addition to the use of plant protection products, the Sterile Insect Release Technique has been extensively used to control and eradicate this pest in Mexico and the USA. In many cases this technique is coupled with a preliminary inundative augmentations of parasitoids, such as *Diachasmimorpha longicaudata* (Montoya et al., 2000; Isiordia-Aquino et al., 2017). Entomopathogenic fungi, such as *Beuveria bassiana* and *Metarhizium anisopliae* can infect both adult and larvae of *A. ludens*, and, in the past, entomopathogenicity to wild populations was induced using sterile males (Toledo 2007; Toledo-Hernandez et al., 2016 and 2017). The efficacy of essential oil formulations with *Thymus vulgaris*, *Ocimum basilicum*, *Eugenia caryophyllus* have also been tested in ingestion assays, resulting *E. caryophyllus* the most toxic (Buentello-Wong et al., 2016).

Due to the fact that effective treatments with plant protection products (PPPs) are currently available but an increase in their use would be expected in presence of this pest, the most suitable PPP indicator is Case "C" and the category is "1" based on Table 1.

Table 1: Expected changes in the use of Plant Protection Products (PPPs) following *Anastrepha ludens* establishment in the EU in relation to four cases (A-D) and three level score (0-2) for the expected change in the use of PPPs.

Expected change in the use of PPPs	**Case**	**PPPs indicator**
PPPs effective against the pest are not available/feasible in the EU	A	0
PPPs applied against other pests in the risk assessment area are also effective against the pest, without increasing the amount/number of treatments	B	0
PPPs applied against other pests in the risk assessment area are also effective against the pest but only if the amount/number of treatments is increased	**C**	**1**
A significant increase in the use of PPPs is not sufficient to control the pest: only new integrated strategies combining different tactics are likely to be effective	D	2

2.5. Additional potential effects

2.5.1. Mycotoxins

The species is not known to be related to problems caused by mycotoxins.

2.5.2. Capacity to transmit pathogens

The species is not known to vector any plant pathogens.

3. Expert Knowledge Elicitation report

3.1. Yield and quality losses

3.1.1. Structured expert judgement

3.1.1.1. Generic scenario assumptions

All the generic scenario assumptions common to the assessments of all the priority pests are listed in the section 2.4.1.1 of the Methodology Report (EFSA, 2019).

3.1.1.2. Specific scenario assumptions

- Part of the Mediterranean area, where peach, citrus and exotic fruit are grown, is potentially suitable to the pest establishment
- 1 single egg is considered sufficient to cause the full loss of a fruit
- Yield loss is assessed for two groups of hosts: (I) citrus/peach and (II) exotic fruit. The selection and grouping of hosts for the assessment of yield loss was carried out considering the major hosts listed in the EPPO Global Database (EPPO, online), the availability of production data in Eurostat and the supporting literature about quantitative records of yield losses.
    - (I) citrus/peach
      The assessment considers all the citrus species (*Citrus* spp.) that are grown in the area of potential establishment (most of the citrus production in Europe, including the major citrus hosts for *A. ludens*: *C. sinensis*, *C. paradisi*, *C. reticulata*, *C. aurantium* and *C. aurantifolia*).
      There is a lack of quantitative evidence of yield losses for peach. Experts' judgement considers yield loss for both Citrus spp. and peach as comparable, therefore the two were grouped together. The yield losses for *Prunus persica* (peach, nectarine) is assessed in the area of potential establishment.

    - (II) exotic fruit
      The host group of exotic fruit considers all host species for *A. ludens* that have production data in Eurostat grouped together under category "F2900- Other fruits from subtropical and tropical climate zones n.e.c."
      Under the host group of exotic fruit yield loss is assessed for *Mangifera indica* (mango) as the major host for *A. ludens*. In addition, secondary host *Psidium guajava* (guava), *Annona cherimola* (cherimoya) and *Punica granatum* (pomegranate) are also included in the assessment. Without detailed information concerning the impacts on each exotic fruit crop, the experts decided to assess yield loss for all these fruit together.

3.1.1.3. Selection of the parameter(s) estimated

In case of early infestations, the fruit can drop or suffer for cosmetic damage due to deformation during growth and/or secondary infections (which make the fruit inedible); in case of late infestation the fruit doesn't drop, neither is deformed but is affected by cosmetic damage and/or secondary infections. Undeveloped eggs will not result in yield loss because fruit with oviposition stings are still marketable.

Therefore:

- Yield loss in this case corresponds to the proportion of fruits lost due to premature dropping and to unmarketable fruits due to cosmetic damage, larval infestations and secondary infections.
- Quality losses have not been included in the assessment because considered cosmetic damage is considered as full loss and included under the assessment of yield losses.

3.1.1.4. Defined question(s)

What is the percentage yield loss in citrus/peach production under the scenario assumptions in the area of the EU under assessment for *Anastrepha ludens*, as defined in the Pest Report?

What is the percentage yield loss in exotic fruit production under the scenario assumptions in the area of the EU under assessment for *Anastrepha ludens*, as defined in the Pest Report?

3.1.1.5. Evidence selected

The experts reviewed the evidence obtained from the literature (see Table B.1 in Appendix B) selecting the data and references used as the key evidence for the EKE on impact. A few general points were made:

- The life span of *A. ludens* is longer than *R. pomonella* (around 100 days)
- Is one of the strongest fruit flies which easily moves among orchards
- End of summer the pest affects mango, later during the beginning of winter season goes to orange
- Release of sterile insect works better than the control with chemical sprays.
- Growing conditions in California are warmer than in Malaga
- **Citrus**
    - Available evidence comes from tropical areas (Guatemala). No quantitative data are available; calculations (% of yield loss) were made from evidence on the number of larvae per fruit and the number of pupae per kilo of fruit (Table B.1 in Appendix B).
    - Control measures in place for *Ceratitis capitata* will have an effect on the *A. ludens*. Both pests have similar development cycles.
    - Mandarins and sweet oranges are harvested at the same time.
    - All citrus will be estimated together, average estimation for yield loss for grapefruit, mandarins, oranges.

- Not each oviposition will cause yield loss.

- **Peach**
  - like citrus
- **Exotic fruit**
  - At the end of the summer, the pest population has a high density and is still growing; in that moment, from a productive point of view, exotic fruit have a short time window for ripening
  - Evidence for mango from Mangan et al., 1997.
  - *Ceratitis* treatment for mango production will have an effect on *A. ludens* populations too

3.1.1.6. Uncertainties identified

- How much control measures targeted to other pests of *A. ludens* hosts are effective also against the Mexican fruit fly.
- The proportion of yield loss in the Guatemala citrus crop (Eskafi, 1988) due to attack by *A. ludens* and not by other fruit flies.

3.1.2. Elicited values for yield loss on citrus/peach

What is the percentage yield loss in citrus/peach production under the scenario assumptions in the area of the EU under assessment for *A. ludens*, as defined in the Pest Report?

The five elicited values on yield loss on citrus/peach on which the group agreed are reported in the table below.

Table 2: The 5 elicited values on yield loss (%) on citrus/peach orchards

Percentile	**1%**	**25%**	**50%**	**75%**	**99%**
Expert elicitation	0.5%	3%	5%	8%	25%

3.1.2.1. Justification for the elicited values for yield loss on citrus/peach

Reasoning for a scenario which would lead to high yield loss (99th percentile / upper limit)

In this scenario the following elements are considered: favourable climatic conditions in autumn, mild conditions during winter, control measures for *Ceratitis* are less effective on *A. ludens*, although it is assumed that the control measures will still keep the populations low.

The pest has the capacity to develop on alternative host.

Reasoning for a scenario which would lead to low yield loss (1st percentile / lower limit)

Med fly control will be effective for *A. ludens*. Unfavourable climatic conditions keep the population level low. Low fruit, host availability. Grapefruit is small part of citrus production although. Citrus production in Europe is timed towards winter when low temperatures are unfavourable for *A. ludens*.

Reasoning for a central scenario equally likely to over- or underestimate the yield loss (50th percentile / median)

Most of the area of potential establishment in the EU has sub-optimal climatic conditions for a tropical pest, this would limit yield losses. The generally applied control against *Ceratitis* is expected to impact *A. ludens* populations too. High mobility of *A. ludens* would favour higher yield losses.

Reasoning for the precision of the judgement describing the remaining uncertainties (1st and 3rd quartile / interquartile range)

High uncertainty for the lower values. More confidence towards the lower values on the upper side of the median.

3.1.2.2. *Estimation of the uncertainty distribution for yield loss on citrus/peach*

The comparison between the fitted values of the uncertainty distribution and the values agreed by the group of experts is reported in the table below.

Table 3: Fitted values of the uncertainty distribution on the yield loss (%) on citrus/peach

Percentile	1%	2.5%	5%	10%	17%	25%	33%	50%	67%	75%	83%	90%	95%	97.5%	99%
Expert elicitation	0.5%					3%		5%		8%					25%
Fitted distribution	0.9%	1.2%	1.5%	1.9%	2.4%	3.0%	3.6%	4.9%	6.8%	8.1%	10.0%	12.5%	16.3%	20.5%	26.8%

Fitted distribution: Lognorm(0.064344,0.053645), @RISK7.5

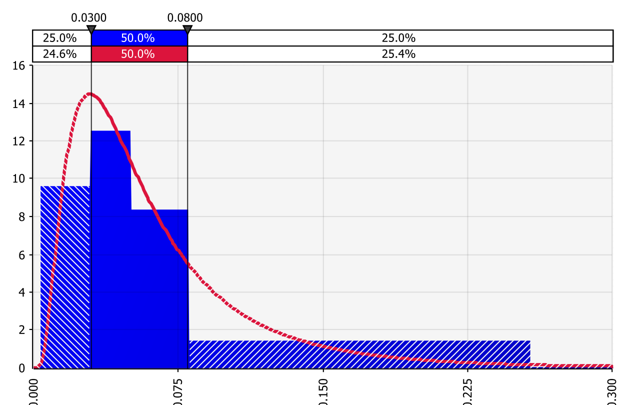

Figure 4 Comparison of judged values (histogram in blue) and fitted distribution (red line) for yield loss on citrus/peach.

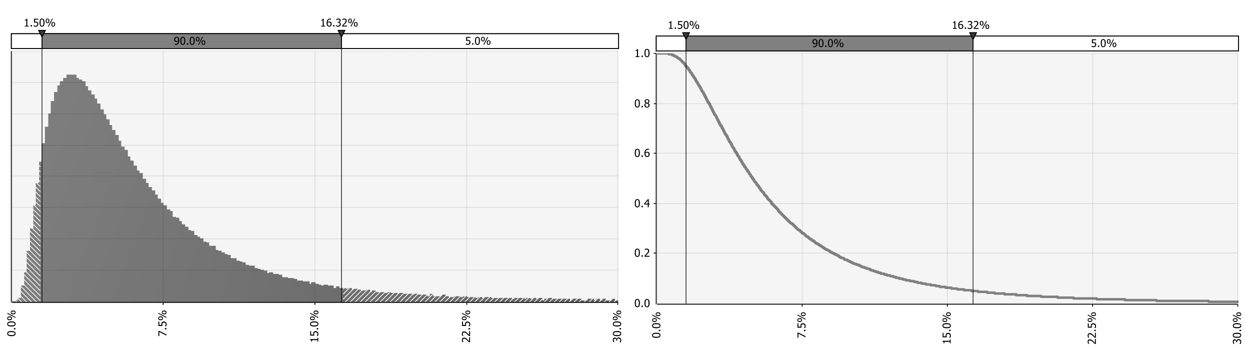

Figure 5 Fitted density function to describe the uncertainties with 90% uncertainty interval (left) and fitted descending distribution function showing the likelihood (y-axis) that a given proportion (x-axis) maybe exceeded (right) for yield loss on citrus/peach.

3.1.3. Elicited values for yield loss on exotic fruit

What is the percentage yield loss in exotic fruit production under the scenario assumptions in the area of the EU under assessment for *A. ludens*, as defined in the Pest Report?

The five elicited values on yield loss on exotic fruit on which the group agreed are reported in the table below.

Table 4: The 5 elicited values on yield loss (%) on exotic fruit orchards

Percentile	**1%**	**25%**	**50%**	**75%**	**99%**
Expert elicitation	2%	5%	8%	12%	30%

3.1.3.1. Justification for the elicited values for yield loss on exotic fruit

Reasoning for a scenario which would lead to high yield loss (99th percentile / upper limit)

Mango and other exotic fruits are grown in the warmest areas of Europe. Control treatments of *Ceratitis* would prevent the populations from getting too high.

Reasoning for a scenario which would lead to low yield loss (1st percentile / lower limit)

Control measures currently in use are effective and have a strong effect in controlling the pest populations.

Reasoning for a central scenario equally likely to over- or underestimate the yield loss (50th percentile / median)

Mangoes are high value crop and farmers are cautious and well aware of pests. The same is for the other exotic fruits assessed. The assessment of the median value considers the situation in Malaga, where the almost the totality of the EU commercial production is located.

Reasoning for the precision of the judgement describing the remaining uncertainties (1st and 3rd quartile / interquartile range)

High uncertainty for lower values, more confidence towards the lower values on the upper side of the median.

3.1.3.2. Estimation of the uncertainty distribution for yield loss on exotic fruit

The comparison between the fitted values of the uncertainty distribution and the values agreed by the group of experts is reported in the table below.

Table 5: Fitted values of the uncertainty distribution on the yield loss (%) on exotic fruit

Percentile	1%	2.5%	5%	10%	17%	25%	33%	50%	67%	75%	83%	90%	95%	97.5%	99%
Expert elicitation	2%					5%		8%		12%					30%
Fitted distribution	2.0%	2.3%	2.7%	3.4%	4.1%	5.0%	5.9%	7.9%	10.4%	12.1%	14.3%	17.1%	20.7%	24.2%	28.7%

Fitted distribution: Gamma(1.7976,0.043463,RiskShift(0.015)), @RISK7.5

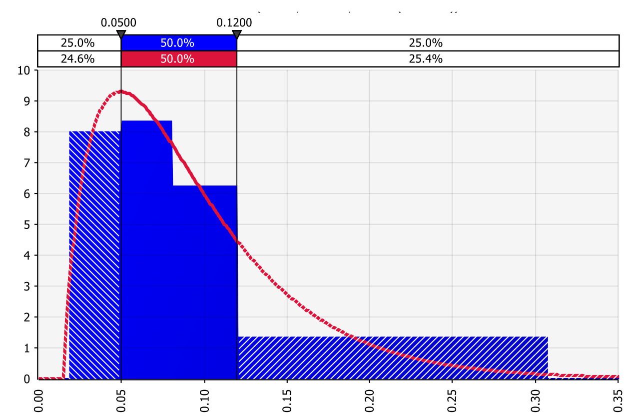

Figure 6 Comparison of judged values (histogram in blue) and fitted distribution (red line) for yield loss on exotic fruit.

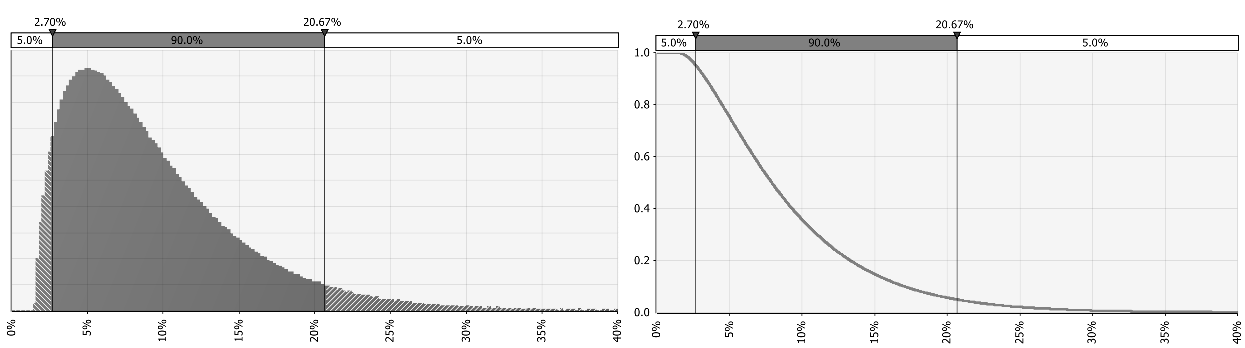

Figure 7 Fitted density function to describe the uncertainties with 90% uncertainty interval (left) and fitted descending distribution function showing the likelihood (y-axis) that a given proportion (x-axis) maybe exceeded (right) for yield loss on exotic fruit.

3.1.4. Conclusions on yield and quality losses

Based on the general and specific scenario considered in this assessment, the proportion (in %) of yield losses (here with the meaning of proportion of fruits lost due to premature dropping and to unmarketable fruits due to larval infestation at harvest) is estimated to be

- 4.9% (with a 95% uncertainty range of 1.2-20.5%) on citrus and peach (including both peaches and nectarines)
- 7.9% (with a 95% uncertainty range of 2.3-24.2%) on exotic fruit (in particular avocado, mango, guava and papaya)

Quality losses have not been included in the assessment because they are considered as full losses and included under the assessment of yield losses.

3.2. Spread rate

3.2.1. Structured expert judgement

3.2.1.1. Generic scenario assumptions

All the generic scenario assumptions common to the assessments of all the priority pests are listed in the section 2.4.2.1 of the Methodology Report (EFSA, 2019).

3.2.1.2. Specific scenario assumptions

- The initial population consists of a very small number of adults emerging from pupal phase
- Local human assisted movement due to agricultural activity in and among the orchards is taken into account (e.g. pupae dispersed with soil on machineries), but the movement of harvested fruit is excluded
- The maximum spread rate is assessed after one year, during that time span the pest will be able to develop two generations
- Potential host fruits are available during the whole year

3.2.1.3. Selection of the parameter(s) estimated

The spread rate has been assessed in terms of number of kilometres per year and refers to the movement of the population and not of the individuals.

3.2.1.4. Defined question(s)

What is the spread rate in 1 year for an isolated focus within this scenario based on average European conditions? (units: km/year)

3.2.1.5. Evidence selected

The experts reviewed the evidence obtained from the literature (see Table B.2 in Appendix B) selecting the data and references used as the key evidence for the EKE on spread rate. One general point was made: no evidence of oriented migration.

3.2.1.6. Uncertainties identified

Comparability of Southern California conditions (for climate and host availability and distribution) with conditions in the area of potential distribution.

3.2.2. Elicited values for the spread rate

What is the spread rate in 1 year for an isolated focus within this scenario based on average European conditions? (units: km/year)

The five elicited values on spread rate on which the group agreed are reported in the table below.

Table 6: The 5 elicited values on spread rate (km/y)

Percentile	**1%**	**25%**	**50%**	**75%**	**99%**
Expert elicitation	1	6	10	13	30

3.2.2.1. Justification for the elicited values of the spread rate

Reasoning for a scenario which would lead to wide spread (99th percentile / upper limit)

The upper value takes into account the fact that more than 1 generation (up to 3?) compose the spread rate in one year. The fly is not expected always to move in a single direction. There are supporting winds. The spread is increased due to the presence of some strong fliers in the population. A patchy host distribution is likely to increase dispersal activity.

Reasoning for a scenario, which would lead to limited spread (1st percentile / lower limit)

The lower value of spread rate is justified by the fact that there are no real drivers for the pest to fly over long distances (no specific host preference). The spread rate is assessed for an area that does not have very suitable temperatures for pest development, which limits the reproduction to 1 generation. Also the flying capacity is limited by the climate, since the adults are not very active in sub-optimal temperature conditions.

Reasoning for a central scenario, equally likely to over- or underestimate the spread (50th percentile / median)

The median value is considering average Mediterranean conditions in southern EU where the pest can survive and overwinter, with hosts present throughout the year. The observations from Shaw et al. (1967) are taken into account for the estimation of the median value.

Reasoning for the precision of the judgement describing the remaining uncertainties (1st and 3rd quartile / interquartile range)

The uncertainty is on the lower bound. The likelihood of highest value is not very high.

3.2.2.2. *Estimation of the uncertainty distribution for the spread rate*

The comparison between the fitted values of the uncertainty distribution and the values agreed by the group of experts is reported in the table below.

Table 7: Fitted values of the uncertainty distribution on the spread rate (km/y)

Percentile	1%	2.5%	5%	10%	17%	25%	33%	50%	67%	75%	83%	90%	95%	97.5%	99%
Expert elicitation	1					6		10		13					30
Fitted distribution	1.7	2.4	3.1	4.1	5.1	6.2	7.3	9.4	12.0	13.6	15.8	18.3	21.5	24.6	28.4

Fitted distribution: Gamma(3.2705,3.2098), @RISK7.5

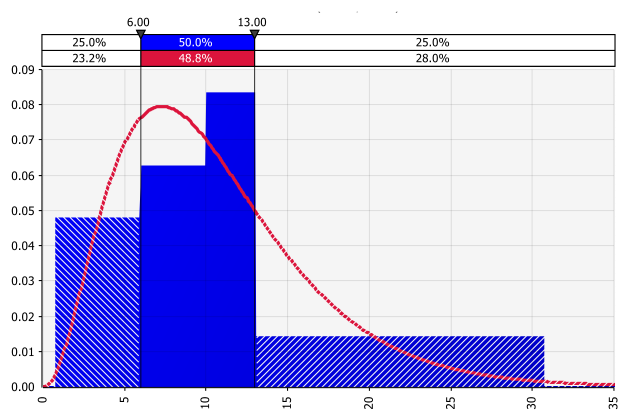

Figure 8 Comparison of judged values (histogram in blue) and fitted distribution (red line) for spread rate.

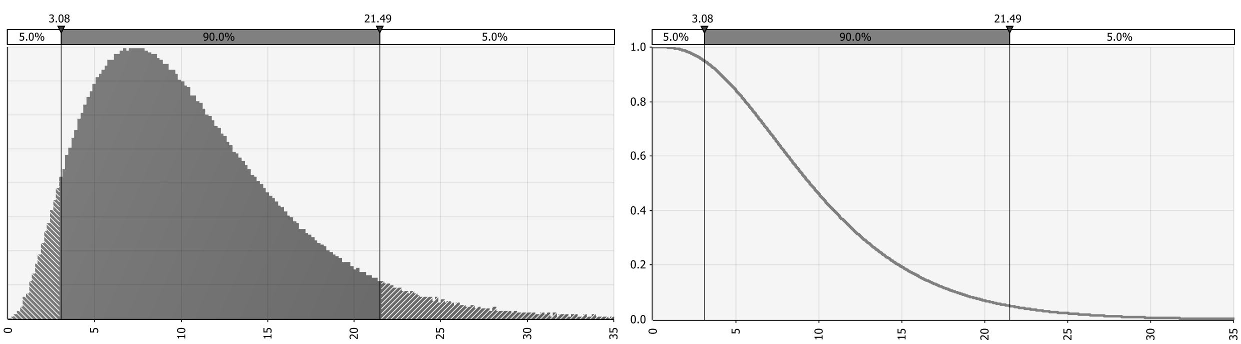

Figure 9 Fitted density function to describe the uncertainties with 90% uncertainty interval (left) and fitted descending distribution function showing the likelihood (y-axis) that a given proportion (x-axis) maybe exceeded (right) for spread rate.

3.2.3. Conclusions on the spread rate

Based on the general and specific scenarios considered in this assessment, the maximum distance expected to be covered in one year by *A. ludens* is 9.4 km (with a 95% uncertainty interval ranging from 2.4 km to 24.6 km).

3.3. Time to detection

3.3.1. Structured expert judgement

3.3.1.1. Generic scenario assumptions

All the generic scenario assumptions common to the assessments of all the priority pests are listed in the section 2.4.2.1 of the Methodology Report (EFSA, 2019).

3.3.1.2. Specific scenario assumptions

- The maximum spread rate is assessed after one year, during that time span the pest will be able to develop two generations
- Potential host fruits are available during the whole year
- The population size has to increase a bit before the pest is detectable (more than 1 generation is needed), then the pest could be detected in a Medfly trap network.

3.3.1.3. Selection of the parameter(s) estimated

The time for detection has been assessed as the number of months between the first event of pest transfer to a suitable host and its detection.

3.3.1.4. Defined question(s)

What is the time between the event of pest transfer to a suitable host and its first detection within this scenario based on average European conditions? (unit: months)

3.3.1.5. Evidence selected

- *A. ludens*' size is larger than *Bactrocera* and *Rhagoletis*
- It could be detected in citrus orchards where *Ceratitis capitata* is controlled
- Multivoltine (maximum four generations per year)
- No specific attractant compared with *Bactrocera*
- All relevant hosts of *A. ludens* are also hosts of Med fly, therefore control and monitoring for fruit flies are already performed

3.3.1.6. Uncertainties identified

- How much the monitoring activity and used traps targeted to other fruit flies are suitable for *A. ludens*

3.3.2. Elicited values for the time to detection

What is the time between the event of pest transfer to a suitable host and its first detection within this scenario based on average European conditions? (unit: months)

The five elicited values on time to detection on which the group agreed are reported in the table below.

Table 8: The 5 elicited values on time to detection (months)

Percentile	**1%**	**25%**	**50%**	**75%**	**99%**
Expert elicitation	8	16	24	30	60

3.3.2.1. Justification for the elicited values of the time to detection

Reasoning for a scenario which would lead to a long time for detection (99th percentile / upper limit)

The upper value is due to a scenario of a lower life cycle, due to sub-optimal climatic conditions (slowing the reproductive cycle) and to the effect of current control practices against other fruit flies.

Coexistence with Med flies in commercial orchards would keep the density of the population quite low. Low probability to detect the pest within the same season due to low capacity to increase the population in the same season. The Med fly traps are not targeted to *A. ludens*. The first generation could take 2 months.

Reasoning for a scenario which would lead to a short time for detection (1st percentile / lower limit)

People in citrus producing areas has trap network to detect Med flies. In these circumstances producers and professionals are used to the morphology of Med flies and would be therefore able to spot a different and so larger species.

If the outbreak starts early in the summer, this would allow the pest to build a sufficiently high population after 2 generations (6 months).

R. pomonella has only 1 generation and is less distinctive, that's why the lower limit for *R. pomonella* is 12 months.

Reasoning for a central scenario, equally likely to over- or underestimate the time for detection (50th percentile / median)

The median value of 2 years is related to the fact that the Mediterranean climate is not the most suitable climate to this pest and that it will mainly survive and reproduce in orchards where also Med fly is present and also surveyed and controlled.

Reasoning for the precision of the judgement describing the remaining uncertainties (1st and 3rd quartile / interquartile range)

The uncertainty is on the lower part and it is unlikely to reach the 5 years due to presence of survey activity (although targeted to other species).

3.3.2.2. Estimation of the uncertainty distribution for the time to detection

The comparison between the fitted values of the uncertainty distribution and the values agreed by the group of experts is reported in the table below.

Table 9: Fitted values of the uncertainty distribution on the time to detection (months)

Percentile	**1%**	**2.5%**	**5%**	**10%**	**17%**	**25%**	**33%**	**50%**	**67%**	**75%**	**83%**	**90%**	**95%**	**97.5%**	**99%**
Expert elicitation	8					16		24		30					60
Fitted distribution	8.3	9.3	10.5	12.3	14.3	16.5	18.7	23.0	28.0	31.0	34.9	39.4	44.8	49.7	55.7

Fitted distribution: Weibull(1.7001,19.825,RiskShift(7)), @RISK7.5

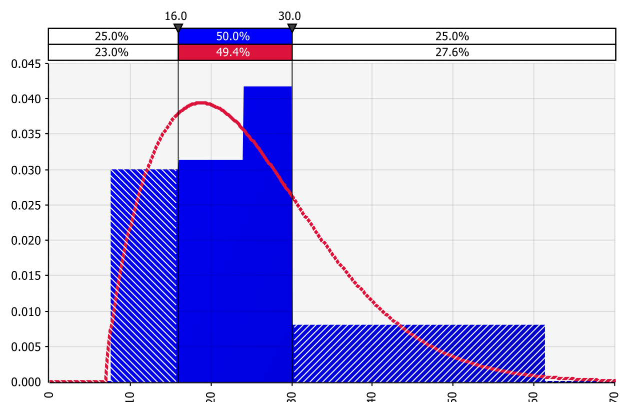

Figure 10 Comparison of judged values (histogram in blue) and fitted distribution (red line) for time to detection.

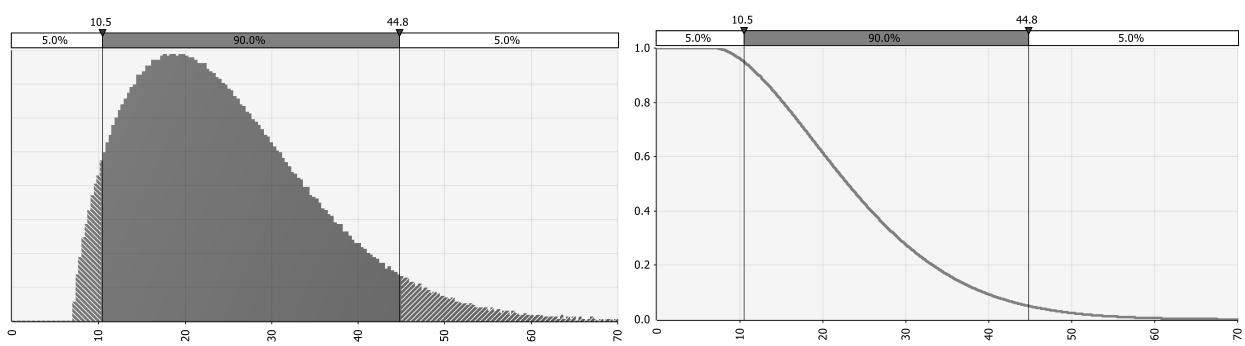

Figure 11 Fitted density function to describe the uncertainties with 90% uncertainty interval (left) and fitted descending distribution function showing the likelihood (y-axis) that a given proportion (x-axis) maybe exceeded (right) for time to detection.

3.3.3. Conclusions on the time to detection

Based on the general and specific scenarios considered in this assessment, the time between the event of pest transfer to a suitable host and its detection is estimated to be almost 2 years (with a 95% uncertainty range of 9 – 50 months).

4. Conclusions

Hosts selection

The host on which the impact is assessed are

- Citrus spp. as they are known to be host of *A. ludens*, *Citrus* spp. are considered together with peach, since experts judge that the yield loss for both Citrus spp. and peach would be comparable.
- Under the host group of exotic fruit yield loss is assessed for *Mangifera indica* (mango) as the major host for *A. ludens*. In addition, secondary hosts *Psidium guajava* (guava), *Annona cherimola* (cherimoya) and *Punica granatum* (pomegranate) are also included in the assessment with the assumption of an impact comparable to the one for *Mangifera indica*.
- Quality loss is not assessed.

Area of potential distribution

The area of potential distribution is limited to central and southern Spain, central and southern Portugal, Madeira, the Azores, southern Italy, Malta, southern Greece and Cyprus. For this species, transient population are not considered and the assessment is limited to the area of potential establishment.

Expected change in the use of plant protection products

Due to the fact that effective treatments with plant protection products (PPPs) are currently available but an increase in their use would be expected in presence of this pest, the most suitable PPP indicator is Case “C” and category “1”.

Yield and quality losses

Based on the general and specific scenario considered in this assessment, the proportion (in %) of yield losses (here with the meaning of proportion of fruits lost due to premature dropping and to unmarketable fruits due to larval infestation at harvest) is estimated to be

- 4.9% (with a 95% uncertainty range of 1.2-20.5%) on citrus and peach (including both peaches and nectarines)
- 7.9% (with a 95% uncertainty range of 2.3-24.2%) on exotic fruit (in particular avocado, mango, guava and papaya)

Quality losses have not been included in the assessment because they are considered as full losses and included under the assessment of yield losses.

Spread rate

Based on the general and specific scenarios considered in this assessment, the maximum distance expected to be covered in one year by *A. ludens* is 9.4 km (with a 95% uncertainty range of 2.4 – 24.6 km).

Time for detection after entry

Based on the general and specific scenarios considered in this assessment, the time between the event of pest transfer to a suitable host and its detection is estimated to be almost 2 years (with a 95% uncertainty range of 9 – 50 months).

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Appendix A – CABI/EPPO host list

The following list, defined in the Methodology Report (EFSA, 2019) as the full list of host plants, is compiled merging the information from the most recent PRAs, the CABI Crop Protection Compendium and the EPPO Global Database. Hosts from the CABI list classified as 'Unknown', as well as hosts from the EPPO list classified as 'Alternate', 'Artificial', or 'Incidental' have been excluded from the list.

Genus	**Species epithet**
Anacardium	*occidentale*
Annona	
Annona	*cherimola*
Annona	*liebmanniana*
Annona	*muricata*
Annona	*reticulata*
Annona	*squamosa*
Carica	*papaya*
Casimiroa	*edulis*
Casimiroa	*pubescens*
Citrus	
Citrus	*aurantiifolia*
Citrus	*aurantium*
Citrus	*limetta*
Citrus	*maxima*
Citrus	*medica*
Citrus	*paradisi*
Citrus	*reticulata*
Citrus	*sinensis*
Coffea	*arabica*
Diospyros	*kaki*
Fruit	*trees*
Fruits	
Inga	
Malus	*domestica*
Mammea	*americana*
Mangifera	*indica*
Passiflora	*edulis*
Persea	*americana*
Prunus	*persica*
Psidium	*cattleianum*
Psidium	*guajava*
Punica	*granatum*
Pyrus	*communis*
Sargentia	*greggii*
Spondias	*purpurea*
Syzygium	*jambos*
Talisia	*olivaeformis*

Appendix B – Evidence tables

B.1 Summary on the evidence supporting the elicitation of yield and quality losses

Susceptibility	**Infestation**	**Symptoms**	**Impact**	**Additional information**	**Reference**	**Uncertainties**
	Incidence	***Severity***	***Losses***			
Grapefruit	0.05-16.04 pupae per kilo		Losses calculation: 3 fruit/kg 0.2-53.5% infested fruit	Guatemala	Eskafi, 1988	*Anastrepha ludens* (Loew) comprised more than 99% of this genus recovered from the citrus fruits, the remaining 1% comprising *A. obliqua* (Macquart), *A. fraterculus* (Wiedemann), and some unidentified species comprising the remainder. *C. capitata* made up only 1% of total flies recovered. *Anastrepha spp.* attacked grapefruits in significantly higher numbers than oranges, tangerines, tangelos, or lemons. About 90% of *C. capitata* were found in Cleopatra tangerine
Orange	0.02-2.99 pupae per kilo		Losses calculation: 5 fruit/kg 0.04-6% infested fruit	Guatemala	Eskafi, 1988	The same as above
Tangerine	0.14-4.90 pupae per kilo			Guatemala	Eskafi, 1988	
Tangelo	0.05-3.64 pupae per kilo			Guatemala	Eskafi, 1988	
Lemons	0.02-2.03 pupae per kilo		Losses calculation: 7 fruit/kg 0.1-5.8% infested fruit	Guatemala	Eskafi, 1988	

Citrus			About 37% of fruit injuries provoked by infestations of *A. ludens* can occur in Mexico (*Citrus*) although higher damages have been observed in Tamaulipas, especially in grapefruit	Mexico	Lopéz-Arroyo and Loera-Gallardo, 2009	
Citrus		Proportion of infested fruit ranged from <1 % to up to 85%	The average number of pupae per infested (excluding the biased ground samples from Llera) fruit varied from 1.33 to 8.57 pupae per infested fruit	Mexico. Much greater proportions of native hosts were infested than the commercial hosts.	Mangan et al., 1997	Mango was treated
Orange		Proportion of infested fruit 0.039	The average number of pupae per infested fruit 3.45	Mexico Samples from the ground, untreated	Mangan et al., 1997	
Grapefruit		Proportion of infested fruit 0.008-0.065 (fruits from trees) 0.05-085 (fruits from ground)	The average number of pupae per infested fruit 3.70-6.38 (fruits from trees) 0.09-5.69 (fruits from ground)	Mexico, untreated	Mangan et al., 1997	
Tangrine		Proportion of infested fruit 0.01-0.06	The average number of pupae per infested fruit 1.5-1.67	Mexico Samples from the ground, untreated	Mangan et al., 1997	
Yellow chapote and white zapote		0.10 – 0.77 infested fruit	1.4 to 12.81 pupae per infested fruit	Mexico	Mangan et al., 1997	For comparison, with above
'Hass' Avocados	(20%)		Infestation levels were very low.	Mexico	Aluja et al., 2004	laboratory
Papaya/ mangoes (control)			None of the papaya fruit Maradol were infested by *A. ludens* under field conditions. No larvae were recovered from papaya fruits independent of the ripeness-stage, the orchards, or the season. the fruits at the commercial degree of ripeness were infested after 72 h postharvest. However, the	Mexico	Arredondo et al., 2014	these fruits must be considered non-natural, conditional host because they became infested in the laboratory

			mangoes exhibited high rates of infestation and adult emergence			
‘Persian’ lime (*Citrus latifolia*) and ‘Ataulfo’ mangoes (*Mangifera indica*) (control)			No fruit showed any signs of infestation despite fly presence. The number of flies per trap per day (FTD) varied significantly between the two orchards/No ‘Persian’ lime fruits at all were infested *by A. ludens* flies, regardless of the orchard or the season. However, the mangoes were infested in the two orchards and in the two seasons and fly immatures developed quite well, reaching adult stages in high percentages	A total of 2,596 kg of lime fruit was harvested (approximately 17,005 fruits) in the “St. Teresa” orchard and 1,276 kg (approximately 8,220) in the “La Vega” orchard. / A total of 2,000 limes were exposed to flies during the study.	Arredondo et al., 2015	
Psidium guajava cv ‘Criollo de Veracruz’		Infestation levels were very low	Not a natural host but a conditional one	Mexico	Birke et al., 2015	
Citrus aurantium (13.4 kg)	1.6 Larvae per kilo of fruit	7.2 Larvae per fruit	Losses calculation: 7 fruit/kg 3.2% infested fruit	The Mexican state of Quintana Roo.	Sosa-Armenta et al., 2015	
Citrus meyeri (1.4 kg)	0.2 Larvae per kilo of fruit	2.7 Larvae per fruit		The Mexican state of Quintana Roo.	Sosa-Armenta et al., 2015	
Citrus reticulate (1.8 kg)	0.1 Larvae per kilo of fruit	2.2 Larvae per fruit	Losses calculation: 10 fruit/kg 0.5% infested fruit	The Mexican state of Quintana Roo.	Sosa-Armenta et al., 2015	
Citrus sinensis (32.0 kg)	2.4 Larvae per kilo of fruit	10.7 Larvae per fruit	Losses calculation: 5 fruit/kg 4.5% infested fruit	The Mexican state of Quintana Roo.	Sosa-Armenta et al., 2015	
Chile peppers (*Capsicum pubescens*)			The majority of the live larvae that were recovered from the intercepted manzano peppers (42 of 50) Successfully pupariated. From these 42 puparia only 11 adults successfully developed and eclosed, about 25%	Shipment, interception USA	Thomas, 2004	

Talisia olivaeformis			yielded 168 pupae, of which 81 were *Anastrepha fraterculus* (Wiedemann) (47 females and 34 males), 6 were *Anastrepha ludens* (Loew) (3 females and 3 males), and 5 were *Doryctobracon areolatus*	Mexico	García-Ramírez et al., 2010	
Annona liebmanniana			5 *A. ludens* individuals emerged (9.1% of the total recovered)	Mexico	Ruiz-Montiel et al., 2013	
Annona reticulata			(48 adults, 87.3% of the total)	Mexico	Ruiz-Montiel et al., 2013	
Annona cherimola x A. reticulata			(2 adults, 3.6% of the total)	Mexico	Ruiz-Montiel et al., 2013	

B.2 Summary on the evidence supporting the elicitation of the spread rate

Spread	**Additional information**	**Reference**	**Uncertainty**
	E.g. country where the experiment was conducted		Any observation concerning the provided evidence
A. ludens are able to move over considerable distances (> 30 km)	Because *A. ludens* is multivoltine and polyphagous, it is likely that adults had to retain the ability to move over considerable distances to find alternate hosts throughout the year	Aluja et al., 2009	
~135 km 36 km	From breeding sites in Mexico to citrus groves in southern Texas. trapped up to 36 km from a release site.	Sequeira et al., 2001	This information was taken from McAllister and Clore, 1941 and Shaw et al., 1967 respectively. Values provided by these authors are higher than those reported in other papers
Max 11 miles (Central Mexico) Max 23 miles (Baja California) males 7- 12 miles in San Diego	Mark-release-recapture technique 1.8-2.4% recovery Reasons for the long-distance flights could be both migratory instinct and yearly sequence of hosts	Shaw et al., 1967	

	Anastrepha ludens, in release – recapture studies using sterile flies, was shorter than that of *C. capitata* (<50m)	Baker et al., 1986	Release recapture studies might not provide the best tool for estimates. This is because the behaviour of reared, usually sterilised, realised flies may substantial differ from that of the wild flies that are adopted to their habit.
110m on average 240m max	Dispersal of wild and mass reared sterilized flies in field experiments in Mexico revealed no difference between flies categories	Hernández, et al., 2007	
	Presumably as a result of long range fligh t, each fall and winter *A. ludens* in vade citrus groves in south Texas, approximately 80 airline miles from the nearest known breeding area in Mexico. Occasionally individuals have been trapped as far north as Falfurias and Dimmit, Texas, approximately 160 and 175 mi. respectively, from the nearest breeding area (data from studies made by N. O. Berry and associates, Plant Pest Control Division, U. S. Department of Agriculture)	Christenson and Foote, 1960	

B.3 Summary on the evidence supporting the elicitation of the time to detection

Category of factors	**case**	**Evidence**	**Additional information**	**Reference**
Detection methods	Visual symptoms	Oviposition stings are visible on fruits, like in many other fruit flies		
Detection methods		Trapping activity in Campania during the first Italia outbreak		Nugnes et al., 2018
Biology of the pest	Pest life cycle	A combined egg and larval development time of 14 days at 26˚C		Baker et al., 1944
Biology of the pest	Pest life cycle	Mean, median, mode, and maximum life span of 49.1, 51, 55, and 96 days, respectively has been estimated Lifetime egg production is estimated to 1400 eggs/female, and maximum age specific egg laying of 60 eggs/per female/per day	Laboratory studies in Mexico	Carey et al., 2005
Biology of the pest	Pest life cycle	Number of generations per year in Mexico Monitoring and control activity		Gallardo, 2010
Biology of the pest	Pest life cycle	This is a multivoltine species that can infest wild and cultivated plants. Similar to other fruit flies, females lay a group of eggs in fruit mesocarp and larvae		Weems et al., 2015

		drill holes destroying the fruit. Fungi and bacteria, facilitated by *A. ludens* oviposition and larvae activity, inhabit fruit contributing further to fruit damage		
Biology of the pest	Pest life cycle	The eggs are laid below the skin of the host fruit in clutches of 1-23 eggs. Egg development required approximately three days and larval development 8-13 days		CABI, 2018; Celedonio-Hurtado et al., 1988
Biology of the pest	Pest life cycle	Pupariation is in the soil under the host plant and the adults emerge after 13-17 days (longer in cool conditions); the adults occur throughout the year		CABI, 2018; Celedonio-Hurtado et al., 1988
Biology of the pest	Pest reproduction	highly fecund, laying 1,500 eggs or more		Weems et al., 2015
Biology of the pest	Feeding and flying behaviour	*A. ludens* may be found in fruit-growing areas with suitable hosts and in natural forests.	”Adults “like” to feed on juices oozing from fruit, especially oranges and guavas. In orchards, flies “like” to rest on the underside of leaves.	CABI, 2018; Aluja et al., 2001
Biology of the pest	Lifespan	Adults may survive for many months, occasionally almost a full year, and males appear to be able to survive much longer than females, even as much as 16 months.		Weems et al., 2015
Biology of the pest	Infestation progress	The newly hatched larvae eat and burrow into the pulp of the fruit, taking on the colour of their food so that when small they are overlooked easily. Many maggots may be found in a single fruit. When fully grown, the larvae emerge through conspicuous exit holes, usually after the fruit has fallen to the ground, and pupate in the soil.		Weems et al., 2015
Host conditions during the period of potential detection	Host size	The adult female typically oviposits in citrus and other fruit at the time when the fruit begins to ripe (colour break).		Weems et al., 2015